HUMAN PERFORMANCE, EMOTIONS AND THE COGNITIVE VIEWPOINT

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Abstract

Although it is generally acknowledged that emotional processes, in particular stress, influence human performance, this is only rarely included in theories and models for human performance in man-machine systems. To the extent that psychological factors are included in such theories and models these are predominantly of a cognitive nature and leave aside the influence from emotion and motivation. The purpose of the present paper is to make an analysis of the concept of emotion in psychology and to try to incorporate the influence of emotion – or affective processes – in a model for performance in a man-machine system.

The development of theories of emotion within psychology is briefly presented with special emphasis on the so-called cognitive theories of emotion, which were developed in the 1960s. According to this theoretical view the labelling of an experience as being a particular emotion is the result of a complex psychological process, which takes into account the experience of the person, the information present in the situation, the expectations to the situation, etc. The labelling of a situation as being of a particular type is thus viewed as the interpretation which is sufficiently consistent for the person. This view of emotions is analogous to the cognitive viewpoint according to which the interpretation of the information, which reaches the person, is a complex process, which is mediated by the person s model of the world. Emotions are therefore not something, which exist *sui generis* but should rather be treated on par with the other phenomena subsumed under the cognitive viewpoint.

The problem of the influence of emotions on performance could therefore be changed to the problem of the influence of affective processes, in particular stress, on cognition. This was discussed in terms of performance as activity controlled by a hierarchy of plans, and the influence of stress was considered with respect to four major aspects:

1. the formation of plans,
2. the execution of plans,
3. the gathering of information, and

4. the processing of information

The general conclusion of this discussion was that the influence of stress on cognition and performance could be described satisfactorily by the way in which interruptions of the execution of a plan could degrade performance. This description was formulated as a model for a homeostatic performance system, which also took account of the way in which stress could occur, could increase, and could be neutralised. The presentation of this model was followed by a discussion of how the labelling of a situation as being, e.g., a particular emotion could influence the performance by changing the criteria, which were used by the person in selecting plans. The conclusions reached here reinforced the cognitive viewpoint and its emphasis of the functional significance of the operator's model of the world.

1. INTRODUCTION

One crucial test for any psychological theory is whether or not it can be used in a real-life environment, i.e., whether it can be used to give a consistent description and explanation of human performance, either in general or in a particular task. (It is common to add a third requirement namely that a theory also should be able to yield predictions of future events. Scriven (1959) has, however, argued that explanation and prediction may be considered as separate aspects of a theory in certain cases – among which psychology seem to be one.) Most psychological theories are well suited to a specific laboratory setting but fail miserably when applied outside the laboratory. There are, of course, a certain number of theories which claim to have a general applicability, as, e.g., psychoanalytic theories, theories of cognitive consistency, social-learning theories, and – last but not least – human information processing theories or cognitive theories. In this paper we will restrict ourselves to look only at the latter; it should be mentioned in passing, however, that theories, which claim to be general often, are so only because they mainly contain a set of common sense tautological statements cf. Smedslund (1978).

Theories of human information processing have been very successful in accounting for a lot of special phenomena as well as for establishing a general theoretical framework within which most phenomena of a cognitive or intellectual nature may be placed. There have notably been some positive results in associating theories of perception, of learning, of memory, of problem solving, of language, and several others within this general framework. In fact, one may reasonably talk about a general cognitive viewpoint or paradigm that can be applied to a host of different phenomena (e.g., De Mey, 1977; Hollnagel 1978a; Neisser, 1976). In spite of this the real-life applicability of cognitive theories – and of the cognitive viewpoint – is less than one could wish. Although it has been claimed that a general theory of problem solving has been produced (namely the Newell & Simon (1972) theory), this theory will on closer inspection turn out to be general just because it is vague. Applied to any particular phenomenon the theory breaks down – not because it cannot be used to describe the phenomenon in question post hoc, but because this description does not in itself serve as an explanation of how the problem was solved, except in common-sense terms. It is thus of little value as a practical tool in solving practical problems – precisely the area where good theories are needed.

The reason for this failure is evident – human behaviour and human performance in real-life is complex, but cognitive theories do only include a part of this complexity in their domain, namely that part which can adequately be described in theories of information processing as it is presently used. To put it briefly human information processing theories deal mainly with that part of the (hypothetical) psychological processes or functions which either directly enters consciousness or which directly influence the contents of consciousness. An example of the first kind would be the conscious, goal-directed thinking, and an example of the other would be the hypothetical organising processes in long-term memory, which reveal themselves in, e.g., the phenomenon of clustering in recall.

There are two obvious solutions to this problem. One is to use a combination of psychological theories which together account for all the aspects of human performance, and another is to develop a particular theory, e.g., the cognitive viewpoint, to account for a sufficient large number of aspects. The first solution does seem inviting at first hand, since it is relatively easy to find an adequate theory for practically any aspect of human behaviour one may think of. One aspect, which is lacking in the cognitive theories, is the role of emotions (or affective processes) and motivation in shaping human performance. There are a number of theories, which deal with this very aspect, from the more general psychodynamic ones to the more specific theories of motivation and learning, e.g., the theories of arousal. If one tries to merge such theories with, e.g., cognitive theories it will soon be discovered that this is by no means an easy task, and they may in fact be considered almost incompatible. The reason for this incompatibility is that the various theories have developed from different historical and meta-theoretical backgrounds, which means that they are widely different not only in the way they describe human behaviour but also in their implicit assumptions concerning the principles governing human behaviour. Thus even theories of a particular phenomenon as, e.g., motivation may be very hard to reconcile into an integrated theory. And this difficulty is, of course, not smaller when one tries to integrate theories for different aspects of human behaviour, e.g., the cognitive aspect and the motivational aspect. Therefore the first solution to the problem stated above is not really as workable as it seemed by first sight.

The second solution was to try to develop a particular theory to cover a larger number of aspects, with the aim of providing a sufficient coverage for working with the complexity of real-life phenomena. This solution may, of course, be attempted with a large number of theories, and it is quite possible that it would succeed in most cases, at least if the challenge is taken seriously. In this paper and in the present context we will try to take the cognitive paradigm as a starting point. One reason for this is that the problem domain (the design of process control interfaces) is one where information processing already plays a large role, and where the task of the operator contains a large aspect of intellectual activities (cf. Rasmussen, 1978a). Another reason is that the cognitive viewpoint has proved to be applicable within a number of various disciplines, as described in, e.g., De Mey et al., (1977). A separate reason is the author's belief in the utility of the general systems theoretical viewpoint (or a cybernetic viewpoint), which is inherent in the cognitive viewpoint. Up to now General Systems Theory has shown itself to be useful as a general theoretical tool, also on a meta-theoretical level.

2. THE COGNITIVE VIEWPOINT

The cognitive viewpoint or paradigm, which the present paper attempts to expand, has been introduced in the following way:

> "The tradition of modern cognitive psychology has been marked by two characteristics that set it apart from its predecessors. First, it has adopted the theoretically neutral but systematically useful device of the flowchart. By considering the various subsystems within the mental organisation as essentially independent entities connected by theoretically specifiable relationships, it has opened up theoretical psychology to a pluralism that is in sharp contrast to the monolithic theories of the 1930s and 1940s. This approach, together with general advantages of control system theories, has made it possible for psychologists as has been the case in other sciences for many years, to work on minitheories instead of on the megalotheories of earlier years."
> (Mandler, 1975, p. 12).

Although this work on minitheories has achieved a very high degree of success it is also part of the reason why cognitive psychology in its present state of development is inadequate as the only theoretical tool for dealing with real-life situations. One reason why the minitheories have failed is perhaps that they have relied too much on the analogy between the digital computing machine as a general information processing device and the human cognitive functions. This analogy, which initially proved very useful, has been stated programmatically as follows:

> "A theory of man that takes account of his characteristics as an information processing system is just beginning to emerge. Already, the theory suggests a system exhibiting a degree of complexity with which the sciences – and certainly the behavioural sciences – have not hitherto dealt. Modern electronic computers have been, and continue to be, an important influence, by way of analogy, on the emergence of this theory. If the argument advanced here is correct, these same computing devices may provide us with the materials for a methodology powerful enough to cope with the complexity of the theory as it emerges."
> (Simon & Newell, 1956, p. 83).

There were several reasons why this analogy failed to meet the initial expectations as expressed, e.g., by Simon and Newell. One reason was that the concept of information was quite difficult to define in an unequivocal way – as, e.g., in information theory – when dealing with psychological phenomena. Information was not something which existed in the environment and which could be measured in an independent and objective way. Another reason was that information processing turned out to be an equally vague concept – and not only because of the vagueness of information. For example, everyone agreed that, e.g., perception – whether visual or auditory – could be explained as information processing, but there was little agreement on the exact nature of this information processing and on the number and nature of the elements of which the information processing system was made up. Another well-known example is the controversy over the nature of the "chunk". It had been known for more than a century that the human span of attention (or the cognitive capacity) was limited, and there was general agreement concerning the size of this limitation. In 1956 George A. Miller suggested that this limitation could be explained by using the information processing analogy, but also demonstrated that the limited capacity could not be measured in bits in a meaningful way. Instead he suggested that the limitation should be measured in chunks, since the number of chunks then would be constant for a variety of situations, but he did not define what a chunk was. Since then there has been a large number of papers and opinions on the nature of the chunk and the reason for the limited cognitive capacity, introducing all types of short-term, processing, rehearsal, and other types of memory – yet without producing any generally accepted explanation.

In recent years there has been a clear trend to use the information processing analogy in other ways and to use it less literally. This has also been influenced by the failure within Artificial Intelligence to solve the problems, e.g., in language processing, by straightforward information processing methods. It was realised that any information processing system (or any computer) which should be able to solve even a moderately complex problem, or which should be able to behave reasonably in even a very simplified environment, had to have a substantial amount of knowledge given a priori, if not in the philosophical then at least in the technical sense. In consequence of this the information processing analogy has been replaced by a less stringent concept called the cognitive viewpoint:

> “The central point of the cognitive view is that any processing of information, whether perceptual or symbolic, is mediated by a system of categories or concepts which, for the information processing device, are a model of his world.”
> (De Mey, 1977, p. xvi-xvii).

The important concepts here are model and world (or environment). Information processing – and that includes perception comprehension, problem-solving, deciding, acting, etc. – is based on a set of previous knowledge of the situation and may as a result modify that set of knowledge. The way in which such a model is used has been analysed in a number of different situations, including the work of a process control operator (cf. Rasmussen, 1974; for other references see, e.g., Belkin, 1977; Hollnagel, 1978b; Oddy, 1977).

Another way of describing this development is by supplementing the concept of information processing with the concept of information pickup. Information processing is essentially passive or reactive, i.e., the system or organism responds to information entered through the sensory system and processes it according to certain rules and procedures. Information pickup is different from that because it implies that the system is actively seeking information in the environment. This has been described in relation to visual perception in the following way.

> “The cognitive structures crucial for vision are the anticipatory schemata that prepare the perceiver to accept certain kinds of information rather than others and thus control the activity of looking. At each moment the perceiver is constructing anticipations of certain kinds of information, that enable him to accept it as it becomes available. Often he must actively explore the optic array to make it available, by moving his eyes or his head or his body. These explorations are directed by the anticipatory schemata, which are plans for perceptual action as well as readiness for particular kinds of optical structure. The outcome of the

> explorations – the information picked up – modifies the original schema. Thus modified, it directs further exploration and becomes ready for more information ... Because schemata are anticipations, they are the medium by which the past affects the future; information already acquired determines what will be picked up next."
>
> (Neisser, 1976, p. 20-21).

The perceptual cycle described above may conveniently be visualised as in Figure 1. The concept of a schema must, of course, not be taken too literally. What this theory tries to describe is the simple, well-known fact that we only perceive what we are prepared to perceive. Thus any two persons may either perceive different aspects of the same situation, or may even perceive the same aspect in a different way. The concept of a schema does not in itself explain anything but is merely a convenient way of describing a common, psychological phenomenon.

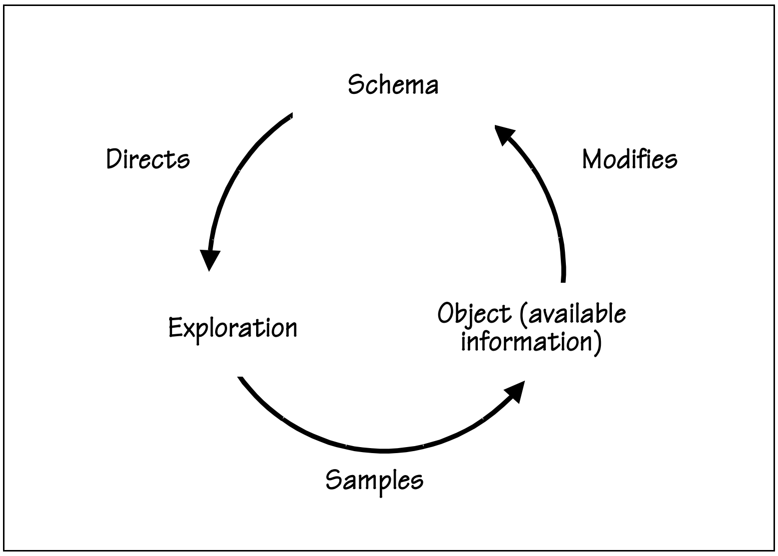

Figure 1: The perceptual cycle

This description of information pickup versus information processing is, of course, not limited to only visual perception. It is a characteristic feature of all cognitive functions and of all information processing, that it is an interactive process where the interaction is between the person's anticipations or model of the environment and the actual environment. A parallel description for concept formation may be found in Bruner (1973), and a more general analysis of the cognitive paradigm has been provided by Hollnagel (1978a).

It is this cognitive viewpoint, which will be used in the rest of this paper as a basis for the analysis of emotions and performance. It must be emphasised that the cognitive viewpoint is a conceptual framework, the value of which must be proved through its application. The main danger is that if the formulations are kept as vague and general as above, the cognitive viewpoint may become a kind of megalotheory, which can claim a large degree of generality, but which may be useless just as it has happened to similar attempts in the past. It is, however, in the opinion of the author possible to make the cognitive viewpoint more precise and to widen its scope without turning it into a megalotheory. At the end of this paper the reader may judge whether the attempt was successful or not.

3. THE CONCEPT OF CAUSAL EXPLANATION

Human behaviour is complex. It is, however, not complex because it is random (in whole or in part) but because the conceptual framework by which it is described is inadequate. The assumption is that if we had adequate means of recording and describing human behaviour then it would no longer seem to be complex. “The central task of natural science is to make the wonderful commonplace: to show that complexity, correctly viewed, is only a mask for simplicity; to find pattern hidden in apparent chaos” (Simon, 1970, p. 1).

In behavioural sciences and in psychology in particular this assumption often takes the form of a concept of causality, i.e., that everything we do is caused by something – be it an event, a stimulus, or a motive, and that this is true whether we realise it or not. This is, for example, the basic assumption in all psychodynamic theories, in traditional learning theories, in theories of motivation, in traditional theories of perception, etc. It is also the case in cognitive theories although it is something, which is more implicit than explicit. Some theories try only to describe a certain phenomenon in an orderly way, e.g., the theories of short-term memory, and some do not use causes but rather anticipated goals, e.g., problem-solving theories. This, however, does not evade the assumption of causality but only removes it to a less conspicuous place.

A strong formulation of the concept of causality in behaviour is the following: A person is a (complex) system the behaviour of which is a function of its present state and its present input – sometimes formalised as $R = f(S, O)$. In this way a person is regarded as a black box, which may be turned into a white box given enough information. Random or unexplainable behaviour is not random or unexplainable per se, but rather because we have not found “the pattern hidden in apparent chaos”.

A weak formulation of the concept of causality in behaviour is the following: A consistent description of the behaviour of a person may be produced if it is assumed that there is a causal relation between the various parts of the behaviour. The weak formulation thus states that the concept of causality is a sufficient condition for producing a consistent description, but does not state that it is also a necessary condition.

The purpose of contrasting these two formulations is, of course, not to throw suspicion on the concept of causality, but only to warn against too uncritical a use of it. It is entirely reasonable to assume that human behaviour is caused by something, and that it is not entirely spontaneous or random. It is in fact precisely the purpose of the present endeavour to provide such a causal explanation by developing and enlarging the cognitive viewpoint. The danger lies in reifying the concept of causality until one believes that causality is something, which exists “out there in the world” as a sort of power or natural force and completely forgets that causality is a product of the descriptions and explanations we produce. This is something, which must be remembered whenever the concept of causality is used, in this context as well as in others (cf. Macklin, 1969).

4. THE TRADITIONAL THEORIES OF EMOTION

Human performance is in the cognitive viewpoint considered as a performance *ceteris paribus*, i.e., performance as it would be if everything else were unchanging and constant. Everything else means all that which is not included in the cognitive viewpoint or in the particular cognitive theory under consideration. Thus theories of problem solving, for example the GPS-theory, only consider those psychological functions which are relevant for problem solving, and assumes that everything else is either unchanging or of no significance. Included in this “everything else” are affective processes, and it is generally true that the model of man implicit in the cognitive viewpoint is a person who is in an emotional equilibrium.

It is obvious, however, that everything else is not equal and that man is not in an emotional equilibrium in the sense that affective processes do not influence behaviour. Human performance is a joint function or product of the present environment, of cognitive and affective processes, and of the person’s experience. The cognitive viewpoint was a great improvement from the traditional information processing theories because it took the function of the internal model and the interactive nature of information processing into consideration. Before it can be regarded as a realistic psychological theory for human performance it must, however, also include a description of how the processing of information takes place and how processes other than those directly aimed at obtaining the current goal may influence it.

The traditional view of emotions has been that they were of a separate quality, something that existed in themselves and different from other parts of human mental life such as consciousness and thought.[1] One of the earliest partitions of psychological functions was into affection, cognition, and conation corresponding to emotions, thinking, and motivation. Although this tripartition is now considered obsolete it has been very influential during the development of scientific psychology, e.g., in the discussion of whether or not emotion and motivation were qualitatively different phenomena and may, in fact, still be discovered in the traditional tripartition of attitudes into emotional, cognitive and behavioural components.

Concerning the emotions or affective processes (the latter term will be preferred here) it has been recognised at least since Descartes that one may distinguish three different aspects, namely (1) the behavioural aspect, (2) the physiological aspect, and (3) the subjective aspect (also called the introspective or phenomenological aspect. The behavioural aspect is the way in which a person reacts or behaves when he is in a particular emotional state, e.g., when he is angry: he may “have the strength of a demon” but be “blind with passion”. The physiological aspect concerns the physiological changes in an emotional state, e.g., rapid heartbeat and breathing, flushed face, etc. And the third aspect deals with the introspective reports a person may give of an emotion, e.g., how it feels to him or is experienced by him. Examples of this are perhaps easiest to find in the traditional description of emotional behaviour such as may be found in the literature.

The various psychological theories of emotion have either tried to describe how the aspects of emotion were related, or how and why one aspect was more important than the others. Thus the early psychological investigations put their focus on the introspective aspect and how the experience of an emotion could be analysed into parts. At the other extreme were the behaviourist theories, which equated emotion with overt behaviour. Leaving such attempts aside there are two of the psychological theories of emotion which have been of great influence and which were in strong opposition to each other. The first of these was the James-Lange theory, named after the American psychologist William James and the Danish physiologist Carl Lange. This theory, which was presented around 1884, stated that emotional feelings were a result of bodily response, and not the other way around; the latter was, of course, the common belief based on everyday experience. In a well-known quotation James said that:

> “Our natural way of thinking about emotions is that the mental perception of some fact excites the mental affection called the emotion, and that this latter state of mind gives rise to the bodily expression. My thesis on the contrary is that the bodily changes follow directly the PERCEPTION of the exciting fact, and that our feeling of the same changes as they occur IS the emotion ... The hypothesis here to be defended says that ... we feel sorry because we cry, angry because we strike, afraid because we tremble, and not that we cry, strike, or tremble, because we are sorry, angry, or fearful, as the case may be. Without the bodily states following on the perception, the latter would be purely cognitive in form, pale, colourless, destitute of emotional warmth”.
> (James, 1884, p. 189-190).

The sequence of events in the James-Lange theory of emotion is thus as follows:

1. we perceive something,
2. we react physically/physiologically to it,
3. we perceive these reactions, and
4. we react emotionally according to the physical reactions, cf. also Figure 2.

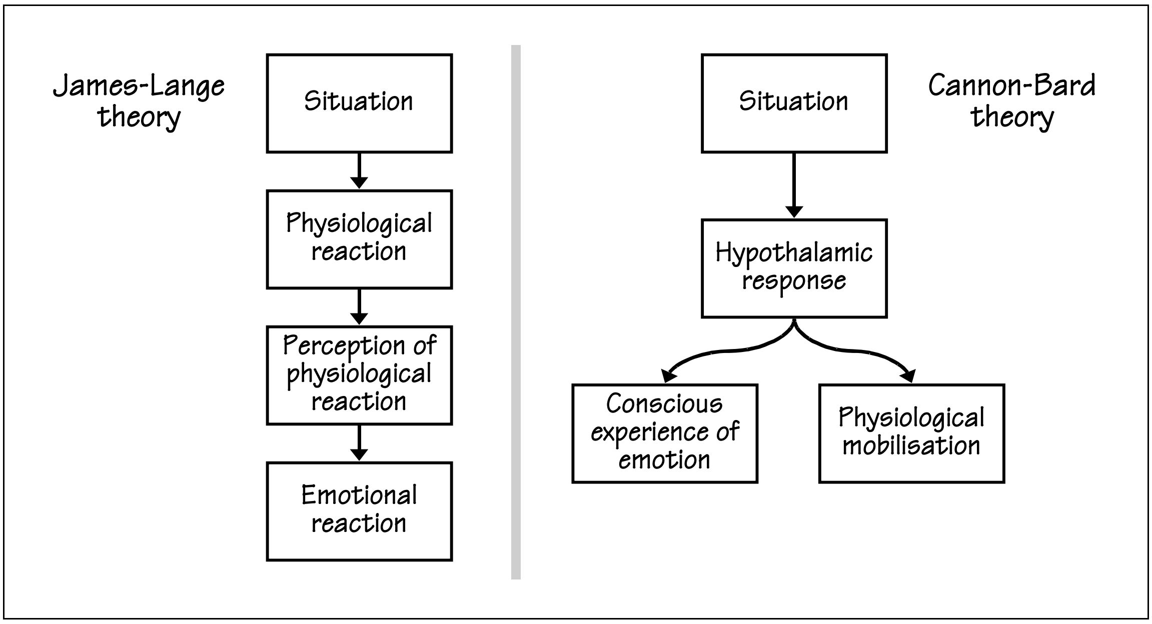

Figure 2: Theories of emotion

Feelings were thus produced by something rather than given a priori. There were, of course, many more details in the James-Lange theory and also many hypotheses and speculations since the state-of-the-art of physiology in the 1880s was far from what it is today. The essential point in the theory is, however, not the way it may be explained physiologically, but rather the assumption of the mediated nature of emotions, something that is found also in the present cognitive theories of emotion.

One particular strong critique of the James-Lange theory came from the physiologist Walter B Cannon (1927), who otherwise is known for his work on the sympathetic and parasympathetic nervous systems. Cannon pointed out that among other things the visceral changes are not sufficiently differentiated to account for the various emotions, and that furthermore the visceral changes are too slow (in the order of 1 to 2 seconds) to explain the experience of emotion, which usually is much faster. Cannon was correct in pointing to some of the weaknesses in the James-Lange theory, but unfortunately he followed it up by presenting a neurophysiological theory of emotion of his own which, psychologically at least, is inadequate as a substitute for the other theory. The central theme in the Cannon-Bard theory is the crucial role of the hypothalamus in emotion. The theory said in brief that the conscious experience ensued upon an upward discharge from the hypothalamus to the cerebral cortex, rather than upon return impulses from the muscles and viscera, cf. also Figure 2.

Although the Cannon-Bard theory is more correct than the James-Lange theory on a purely neurophysiological level, it is difficult to compare them on the psychological level, mainly because the Cannon-Bard theory does not concern itself with the experience of emotion in any detail. This, of course, makes it of limited value as a psychological theory and thus not much of a substitute for the James-Lange theory. That may account for the fact that the James-Lange theory in spite of its obvious shortcomings had a greater impact than the Cannon-Bard theory, and probably also than any of the other theories of emotion which have been suggested (cf. Woodworth & Schlosberg, 1965 or Mandler, 1975 for examples). This was approximately the state of affairs of the theories of emotion until the 1950s, when some alternate theories began to appear.

5. THE COGNITIVE THEORIES OF EMOTION

The trouble with the theories attempting to integrate visceral changes and emotions, whether they considered the first as the cause of the second or vice versa, was that the same visceral changes occurred in different emotional states as well as in non-emotional states. G. Marañon performed one of the early experiments, which proved this, as early as 1924. He simply injected adrenaline into his subjects, and asked them to introspect, i.e., to describe what they experienced. (Adrenaline is a sympathomimetic agent i.e., that it induces the same visceral changes as do the sympathetic nervous system – tenseness of the muscles, rising heart-rate, constriction of blood vessels and a rise in blood pressure.) More than seventy percent of them simply reported the physical symptoms with no emotional overtones; this finding was quite contrary to the predictions of the James-Lange theory. The rest of the subjects responded in an apparent emotional fashion. The great majority used a description of their feelings, which has been termed "cold" or "as if" emotions. They would, e.g., say that they felt as if they were afraid or as it they were awaiting a great happiness. They described their experience of the altered physiological state as that emotion which they thought corresponded to it but which they did not really experience. They experienced certain physiological changes, and they knew that such changes occurred in particular emotional states, so accordingly they described their experience as if they had that emotion.

This was, of course, a very important observation that Marañon made, although the time was not ripe for integrating it into a psychological theory. The discovery was, however, not forgotten but was replicated from time to time in other places, cf. Schachter & Singer, 1962 – almost as if it was waiting for a change in the scientific paradigm. This change occurred in the late 1950s when cognitive psychology appeared and began to gain ground. According to this new view an emotional state was not radically different from any other situation, i.e., emotions were not something, which was qualitatively different from the other phenomena, which cognitive psychology occupied itself with.

When a person is in a situation, which normally leads to an emotional state, he is physiologically aroused. The arousal may be produced by natural causes or be introduced artificially as in the experiment mentioned above. In any event the person will try to identify or categorise the aroused state, just as he will try to identify or categorise any other information, which he is confronted with, e.g., through the sense organs. The identification of an aroused state is made (1) partly on the basis of the nature of the state, (2) partly on his knowledge of what caused it, (3) partly on his expectations to the situation, and (4) partly on his experience with similar situations. Normally we have an explanation immediately ready for the aroused states that occur, which is why the exceptions demonstrated in the experiments are so puzzling. (One might this compare with visual perception, where we normally are able to identify what we see in a smooth and automatic way. This means that we are usually not aware of how it is done, and this is why, e.g., visual illusions are so startling.) This view of emotions was formalised by Schachter and Singer into the following propositions:

1. Given a state of physiological arousal for which an individual has no immediate explanation, he will “label” this state and describe his feelings in terms of the cognitions available to him. To the extent that cognitive factors are potent determiners of emotional states it could be anticipated that precisely the same state of physiological arousal could be labelled “joy” or “fury” or “jealousy” or any of a great diversity of emotional labels depending on the cognitive aspects of the situation.

2. Given a state of physiological arousal for which an individual has a completely appropriate explanation, no evaluative need will arise and the individual is unlikely to label his feelings in terms of the alternative cognitions available.

3. Given the same cognitive circumstances, the individual will react emotionally or describe his feelings as emotions only to the extent that he experiences a state of physiological arousal. (Schachter & Singer, 1962, p. 381-382).

Schachter and Singer then performed an ingenious psychological experiment, which tried to verify the three propositions. The experiment may briefly be summarised in the following way (cf. also Figure 3):

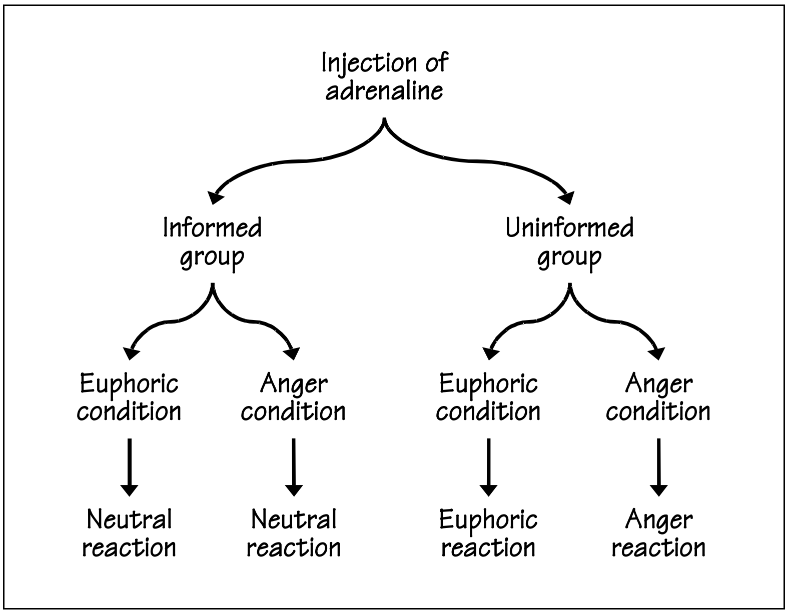

Figure 3: Schacter & Singer experiment

All subjects were injected with adrenaline but were told that it was only a vitamin compound called Suproxin. They all agreed to this, since they were made to believe that the purpose of the experiment was to test the effects of this vitamin compound on their vision

The subjects were then divided into two groups, called the informed group and the uninformed group. In the informed group the subjects were told, that the vitamin injection might have slight side effects such as flushed face, trembling hand, and an increase heartbeat; these are, of course, the effects of injection adrenaline into the body. The uninformed group was told that there would be no side effects.

Each subject (the experiment was made on individual subjects rather than on groups) was then shown into a room to wait for the vitamin injection to take effect. Already in the room was a stooge, i.e., a person instructed to behave in a certain way, yet pretending to be a subject just as the real one. For half of each group (informed/uninformed) the stooge was instructed to behave in an euphoric way, i.e., laughing, dancing, playing around with things in the room, etc. For the other half of each group the stooge was instructed to behave in an angry way: both subjects were asked to answer a deliberately insulting questionnaire, and the stooge showed increasing signs of anger and tried to get to subject to take part in this.

The results in these four conditions were roughly as follows. In the informed-euphoric condition the subjects interpreted the physical sensations as side effects of the drug and did not follow the example of the stooge. In the informed-angry condition the results were the same: the subject remained calm because he interpreted the physical sensations as coming from the injection. In the uninformed-euphoric condition the subject interpreted the physical sensations as emotional arousal and joined in the euphoric behaviour of the stooges. And in the uninformed-angry condition the results were similar, i.e., the subject interpreted the physical sensations as emotional arousal and became angry as well. (Introducing a group receiving a placebo tested the third proposition, but for reasons of clarity this will not be discussed here. Interested readers may enjoy the detailed description in the original paper.)

All in all the experiment verified the propositions and thus substantiated the view, that the experience of emotions involve cognitive processes and is explainable in terms of cognitive psychology just as most other phenomena are. More particularly it was demonstrated, that the experience was a joint function of the physiological state and the persons knowledge of and expectations to the situation. Emotions are thus not qualitatively different from other phenomena of which we can become aware, but seem rather to be subject to the same general principles – as formulated, e.g., in the cognitive viewpoint.

Since then a number of other experiments have been performed and a number of other hypothesis have been investigated. Thus in addition to investigating the effect of sympathomimetic drugs, the effect of sympatholytic drugs has been explored; sympatholytic drugs have the opposite effect of sympathomimetic drugs, and the results were as expected, i.e. the normal emotional reactions were suppressed or reduced. Other investigations have dealt with the problem of distinguishing the effects of pseudo-feedback from mimic-feedback. Pseudo-feedback is the fake or false feedback to a person, which indicates he is in an emotional state although that is not the case; an example of that would be the sound of an increased heart rate (which, of course, must block the normal auditory feedback from heart rate). It was shown that when a person is given pseudo-feedback, he may experience the corresponding emotional state, which convincingly demonstrates that visceral changes not are necessary as an initial condition for the experience of an emotion. Mimic-feedback is that genuine physiological feedback which arises from being in an emotional state, i.e., the fact that a person knows that he is in emotional state (frightened, happy, excited, etc.) will amplify the physiological response. Thus it has been demonstrated that if you give a person pseudo-feedback of, e.g., increased heart rate, then his actual heart rate will increase. The problem is then whether the experience of emotion comes from the pseudo-feedback and the mimic feedback comes from the experience of the emotion, or if rather the mimic feedback comes from the pseudo-feedback and the experience of emotion comes after the mimic-feedback (cf. Bell, 1972 for a more detailed discussion of that.)

Even though there obviously are a number of problems concerning the details of the cognitive theory of emotion, the general outline seems quite clear and acceptable. According to this the experience of an emotion is the result of a cognitive process, which involves the physiological feedback, the general state of knowledge and experience of the person, and his specific expectations to the current situation. Normally one is unaware of this complex relationship, because the various factors are consistent and the emotional response thus adequate, in the same way as with most other cognitive processes.

6. AFFECTIVE PROCESSES AND COGNITIVE PROCESSES

The cognitive theories of emotion have demonstrated that some part of the affective processes, namely the identification or labelling of the affective state, may be described in a way, which is similar to the cognitive viewpoint. Thus a general description of the identification of an emotion may be as shown in Figure 4.

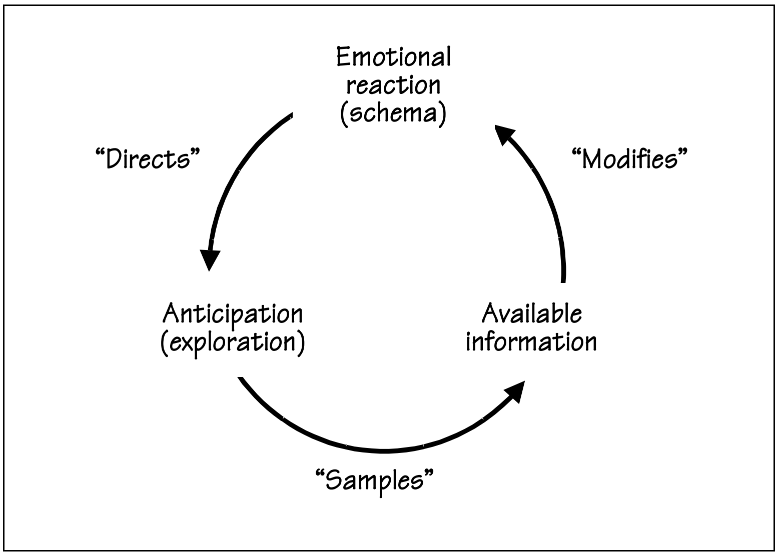

Figure 4: The "emotional" cycle

The available information is in this case information concerning the physiological state (visceral input), information concerning the situation as perceived (i.e., the kind of input which is normally treated in cognitive theories), and information from the person's experience. All this information is processed and results in the proper identification of the situation as such, whether it be as an emotional state or not (cf. the propositions by Schachter & Singer). In case of an emotional state this will lead to an emotional reaction, which may again produce both a mimic feedback, i.e., a biochemical and neutral activation, and a psychological activation in the form of an anticipation or expectation concerning what is going to happen next. This double effect of the emotional state may, of course, amplify the available information so that the emotional reaction becomes stronger, and so the cycle may be repeated. A person may for example expect that he is going to meet something frightening, either as an object or a situation. This may cause him to feel a little frightened or afraid (e.g., before facing an examination board) and lead both to a mimic feedback as well as to the psychological “understanding” or rationalisation that since he is feeling afraid, there is in fact something to be afraid of. It is easy to see how this cycle may amplify itself in each state, until it leads to a state of panic or hypervigilance. This development is, however, not inevitable, since we normally are capable of controlling our emotions such that not every situation ends in, e.g., a panic-like state. The word is in fact very appropriate since what happens is that a negative feedback loop is added to the emotional cycle. This may be in the form of a critical evaluation of the information or of the anticipations, e.g., by using the “cold” cognitive processes to evaluate the anticipations in relation to the available information.

One way of introducing this is shown in Figure 5, which has been borrowed from Lindsay & Norman, 1977. The “emotional” cycle may be discovered in the sequence: Environment – Perceptual analysis – (Cognitive comparator) – chemical & neural activation, which is also labelled the data driven analysis. This terms means that the analysis is basically an analysis of information coming to the person from outside, although that does also include interoceptive and proprioceptive information. The data driven analysis is thus based on the data, which are available in the situational context. (Note that this data driven analysis corresponds to the traditional information-processing paradigm mentioned earlier. As a result of applying the cognitive viewpoint it would be more correct to describe the perceptual analysis as both data driven and conceptually driven. This has, however, not been done here for reasons of simplicity.)

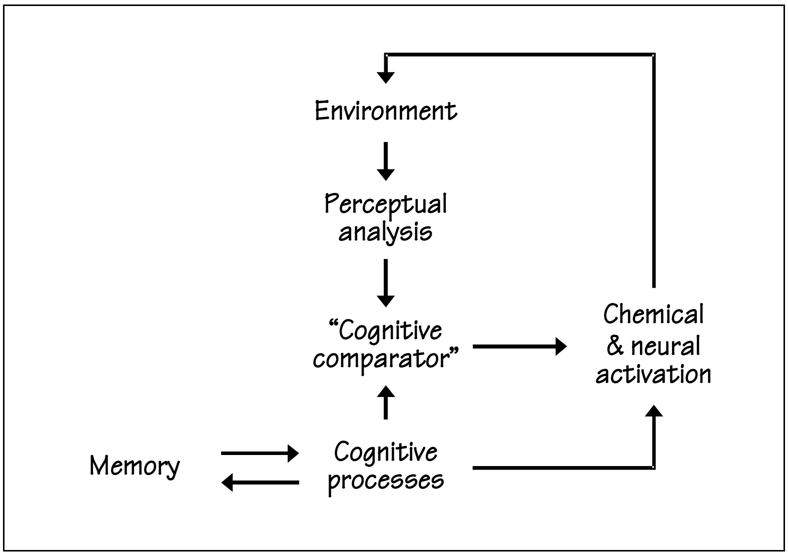

Figure 5: An information processing theory of emotion

In addition to this data driven “emotional” cycle, there is another source of information, which is called the conceptually driven analysis. This is basically the person’s cognitive process, i.e., the expectations generated with the aid of the person’s memory and knowledge.

These expectations are compared with reality (or the person's perception of reality) in a so-called cognitive comparator, and it is the result of this comparison, which determines whether or not an emotional state will result. If there is a sufficiently large discrepancy between expectations and reality, the cognitive comparator triggers the release of appropriate chemicals, which may produce the mimic feedback. When there is little or no discrepancy there will be no emotional reaction, and there may in fact be a reduction in the current emotional state.

All in all this type of description can show us how the cognitive processes and the affective processes may work in parallel and how they may influence each other. A highly schematic way of doing this is shown in Figure 6, where the two cycles, the emotional and the cognitive, are simply shown as orthogonal to each other. Although a representation such as this is highly schematic it does point to two problems of importance. The first of these is how the interaction between the cognitive and affective processes takes place, whether one is in control of the other or whether they are independent. The second problem is whether it is reasonable to speak of affective and cognitive processes as if they were qualitatively different. This dichotomy is, of course, the result of a very long tradition of speculations about human nature but in view of the development of the cognitive theories of emotion one may seriously consider whether this bisection should be upheld or not. The description shown in Figure 5 may be seen as an attempt to avoid it, although that was not the primary purpose in this case. (And to reassure anyone who may feel upset but such an endeavour, the relinquishing of affective processes does not mean that the existence of emotional experiences as such is denied.) It is those two problems, which will be the subject matter for the rest of this paper.

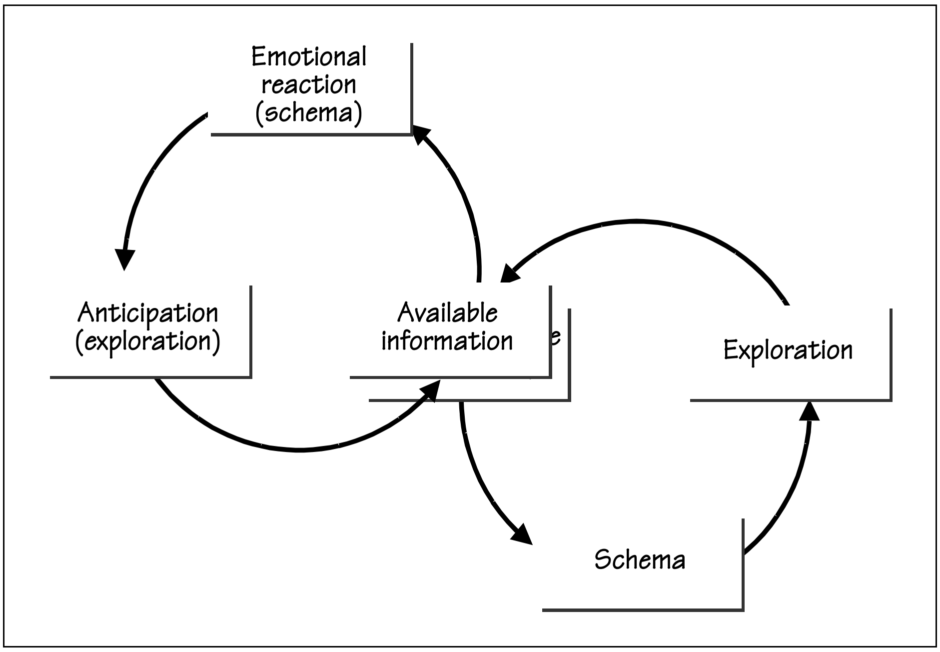

Figure 6: The perceptual and emotional cycles

7. EMOTION AS A QUALITATIVELY INDEPENDENT PHENOMENON

Of the two problems mentioned above we will take the last one first, since in a way it is the most fundamental of the two and since the answer to that may have implications for how the first problem should be formulated.

The position taken here will be that emotions, as something connected with the interpretation of affective processes which is qualitatively different from cognitive processes, should not be considered as a separate phenomenon in an explanation of human performance. That does not mean that emotions should be considered to be cognitive epiphenomena, since cognitive processes in themselves are something, which we deduct from observations of behaviour, and thus not something, which have an existence of their own in the physical or materialistic sense of the word. For example, when we observe that person X performs action Y we may deduct that he therefore is in the state z (or that process Z therefore has occurred). In other words x is (regarded as being) in state Z because x did Y. This is a pure deduction and is the only admissible way to use “cognitive processes” (z), since they are used as the theoretical foundation for a consistent explanation. Contrasting to this we could also say that X does Y because he is in the state z. That would be a causal, physicalistic explanation, which is completely unwarranted. It is an example of a category-mistake since the hypothetical cognitive processes (z) are assumed to be the cause of behaviour (cf. Bateson, 1972 for a further discussion of this). Consequently neither cognitive processes nor affective processes (nor motivational processes or any other kind of processes) should be used in a causal explanation of human performance, although they may be used to produce a consistent description of performance. What we shall try here is to show how human performance may be described adequately without invoking several qualitatively different types of processes.

If we consider the ways in which human performance can be influenced or shaped it is obvious that a distinction must be made between two types of influence. One is the influence, which is unconscious; the other is the one, which is conscious. That an influence is unconscious does not mean that it involves unconscious psychological processes a modus psychoanalysts, but rather that the influence is more on the physiological side. It is an undeniable fact that the psychological processes take place in a physiological environment (the brain and the body). This is not the same as arguing for a materialistic or physicalistic reductionism, but simply an acknowledgement of the fact that the brain and the body necessarily must exist for psychological processes to occur. A consequence of this is that physiological processes can influence the psychological processes; one need only point to situations of stress and fatigue to demonstrate that this is the case. In such situations the influence of physiological processes (or the resulting physiological states) is evident: we know when we are tired and we know when we are stressed – we feel unfit for mental work, unable to concentrate or to keep our thoughts in order. There are, however, many situations where the influence from physiological processes is too weak to enter our awareness, yet strong enough to influence the psychological processes. Such situations can, of course, only be recognised afterwards, when we can see that we did Y (or rather: could not do Y) because we were in state Z. We could not keep our concentration on the task because we were tired, or we did not detect a signal, because we were distracted, or because we forgot to look after it. Both logical reasoning and experience tells us, that this is so.

In general our attention is concentrated on the visual and auditory information, which is available to us, probably because that has the largest survival value. This means that information from other modalities (smell, touch, taste, balance, proprioceptors, etc.) only enters awareness when it is sufficiently strong or when we direct our attention to it. We may sit and work for hours without becoming aware of the various impressions of touch on our body; or we may walk for miles without paying attention to the tactile information from our feet: or we may breathe a thousand times without smelling the air. It is possible to rank order the various senses with respect to how easy it is to become aware of them (or technically, how large a change in stimulation must be for the person to detect it, cf. Woodworth & Schlosberg, 1965). In this respect the physiological changes which come from the activation of the sympathetic nervous system (increased heart rate, circulation, breathing, muscular tonus, etc.) are those, which are most difficult to detect, so that we normally are unaware of small changes. The small changes do nevertheless have an influence on the psychological processes, not because they change the psychological processes in themselves but because they change the conditions under which these processes take place. This is something, which will be discussed more thoroughly in the following.

Concerning the conscious influence on human performance this is something, which is evident from the fact that we are able to control our performance. We do what we intend to do and we are thus free to choose any behaviour which seems appropriate. The choice may, however, be influenced by a number of factors such as preferences, attitudes, values, etc. All of these factors need not be conscious for us, but they may be made conscious if that is necessary. We may take them into consideration when we make a choice or make a decision, and we may afterwards explain what we did by referring to those factors. To put it very simply: the conscious influences are those, which contribute to the rationality of human performance, and the unconscious influences are those, which contribute to the lack of rationality. But lack of rationality here means that we are unable to perform as planned, and not that we are irrational in the traditional meanings of that word.[2]

7.1 Affective processes and consciousness

One factor, which may have contributed to the traditional belief in emotions as a qualitatively separate phenomenon, is that it is much more difficult to describe and talk about emotions than it is to describe and talk about cognitive or intellectual phenomena. Although we may be aware of our emotions – or rather of our present physiological state – and although this experience may be just as intense or real as the experience of seeing something or of thinking of something, it is nevertheless far more difficult to express this experience.

According to the view presented here it is quite important to make a distinction between the affective processes (the physiological processes) and the labelling or recognition of them as being, e.g., a particular emotion. The affective processes are something, which are experienced as signs rather than as symbols. This means essentially that we experience them directly as sensations and not mediated through some symbolic description. In contrast to that the cognitive phenomena (or the products of the cognitive processes) are normally expressed in symbols and thus also experienced in a more indirect way. When we perceive an object visually, we do usually not experience the visual impression but do rather see a thing, i.e., that we classify what we perceive into some well-defined category, by using a description in our language. This can be demonstrated in many ways, e.g., by the fact that we only remember that part of the visual information which we have been able to “code” symbolically in one way or the other (cf. Bransford & McCarrell, 1972; From, 1965; Sperling, 1967). The ability to remember details of a visual presentation is quite rare among adults (the so-called eidetics) although it is more common among young children.

To illustrate the difference just try to imagine how it feels to sit on a chair. If one is sitting on a chair and directs the attention to the impression from ones body, it is quite possible to experience this in detail, i.e., one can get a very intense and exhaustive sensation of how it is to sit on a chair. Compare that to the attempts to either maintain that experience or reconstruct it when one is not sitting on a chair, and it is easily seen that this kind of information is not coded in symbols and thus not available when the situation no longer exists. Sitting on a chair is, of course, not an affective process, but the physiological changes in affective processes are probably more vague and difficult to describe than the impression of sitting on a chair. This means that there is a large part of the information available to us which it is difficult to store/remember and communicate, simply because it is difficult to express it in the symbols of our language. We may very well be aware of our affective processes but it is very difficult to express and communicate to others about this awareness. It might in fact be more consequent to say that we are only aware of them and not conscious about them, since the meaning of consciousness in a cybernetic sense is that one is able to communicate (to oneself or to others) about that which is conscious (cf. Pask, 1969).

It may precisely be this discrepancy between awareness and consciousness, which has contributed to the general belief that emotions were something special and unique. In sharp contrast to this, emotions do not exist per se in the cognitive viewpoint. What exists are the affective processes on the one side and the conscious recognition of them on the other. This conscious recognition is, however, not unique for a particular affective state but may, as Schachter & Singer demonstrated, vary with the circumstances. It is accordingly not necessary – and probably only confusing – to speak of affective processes as something which exist in parallel to cognitive processes and on the same level. The term affective processes should therefore be restricted to mean only those physiological changes, which accompany the activation of the sympathetic nervous system, whether this activation can be traced to physical or psychological factors. This does in no way deny or exclude that affective processes may (and indeed do) influence cognitive processes (i.e., human performance) both unconsciously and consciously as, e.g., when they are consciously recognised and labelled as emotions.

8. STRESS AND COGNITION

It is precisely toward this possible influence that we now will turn, i.e., to the first of the two questions mentioned earlier. In order to avoid unnecessary complications we will restrict ourselves to discuss only those affective processes, which are known as stress. First of all because this is the kind of affective processes which have been very intensely studied, and secondly because stress probably is that type of affective process which is most important in relation to work in control rooms. It should, however, been borne in mind that stress is used first and foremost as an example of affective processes and that any conclusions and generalisations made with respect to the influence of stress on cognition might just as well have been made taking some other affective process as an example.

Stress is that affective process which arise "whenever there is a departure from optimum conditions which the organism is unable, or not easily able, to correct" (Welford, 1974, p. 1). A more comprehensive definition intended to be valid for systems at all levels, is the following:

> "There is a range of stability for each of numerous variables in all living systems. It is that range within which the rate of correction of deviations is minimal or zero, and beyond which correction occurs. All input or output of either matter energy or information which, by lack or excess of some characteristic, forces the variables beyond the range of stability, constitutes stress and produces a strain (or strains) within the system.. Stress may be anticipated. Information that a stress is imminent constitutes a threat to the system. A threat can create a strain. Recognition of the meaning of the information of such a threat must be based on previously stored (usually learned) information about such situations."
> (Miller, 1978, p. 34).

The effect of stress is thus to produce a change (a strain) in the person. This change is often described by the term arousal, a physiological state that is roughly characterised by: the activation of the sympathetic nervous system as described earlier. It is, however, quite common not to maintain the distinction between stress and strain, but instead simply to talk of stress as the aroused state, or (in our terminology) the affective process. It should also be acknowledged that a person could be stressed without being conscious of it. We may assume that stress can occur in different strengths, from the mildest stress where the person is unaware of it even though it may influence his performance, through intermediate levels where the person is aware of it, to the most extreme situations where the person is fully conscious of it. The difference between being aware of stress and being conscious of it is important, since the conscious realisation of stress in itself makes a demand to the cognitive system and thus increases the total load on the system. It is also through the conscious realisation of stress that various forms of mimic (physiological) feedback may be activated, leading to a possible aggravation of the stressful situation. That a person's performance can be influenced by stress even though he is not aware of it is also quite obvious, since there is a lower threshold (an absolute threshold) for stress as well as for any other kind of information, which comes to the person. Thus one may easily imagine a situation where the demands to the performance build up gradually and where the person is so concentrated on what he is doing, that he is not aware that his performance is changed as a result of the stress.

An important detail in the definitions of stress is the specification of what constitutes optimum conditions or conditions within the tolerable range. The optimum condition for any person is naturally something, which to a large extent depends on that person and also on the circumstances, but one may nevertheless point to three principles, which are characteristic of the "optimum".

> "First, we tend to avoid extremes of stimulation and to seek moderate levels. For

> example, high levels of noise and complete sensory deprivation both tend to be distressing. Second, we prefer our stimulation to have a moderate level of patterning, or perhaps more precisely predictability, in both space and time. We enjoy a certain amount of surprise, but find continual unpredictable change exhausting, and unvarying routine dull. Third, we prefer a moderate degree of conflict, either of cognitive data or of potential action … specification of "optimum" in these ways emphasises the fact that demand and human capacity are to be conceived not only in terms of muscular strength or heat-regulation of oxygen supply, but also in terms of information processing. In most everyday situations performance is limited much more by the time taken to resolve uncertainty when making decisions, or by the amount of data that can be handled at any one instant, than by purely physical factors. Some of the most severe demands thus arise from the speed with which a task has to be done or the number of sources of data that have to be monitored, or the complexity of the decisions required."
> (Welford, 1974, p. 3).

The relation between performance and the optimum condition is, of course, the well-known Inverted-U Curve which expresses that performance decreases when conditions fall below or rise above the optimum; this will be described more detailed in a following section.

Having defined what we understand by "stress" we should perhaps also define what is understood by "cognition". It is quite normal to use the term "cognition" as a synonym to "information processing" and by that include all the possible (and hypothetical) ways in which a person can be described as processing information – from the environment or from himself. Such a usage should, however, be avoided since it fails to make a distinction between the qualitatively different ways in which information processing may take place. There is, for example, a significant difference between the way in which information is processed on the neural level in the Retina or the Lateral Geniculate Nucleus, and the way in which it is processed when a person tries to calculate how fast he must drive to reach his destination in time. Although both examples may be said to belong to cognitive psychology, a more proper usage of the term cognition would include only the latter example and not the former.

Cognition will thus in this context be taken to mean the conscious processing of information which in whole or in part is the basis for human performance. Cognition is quite literally the way in which the person cognises (and recognises) in the situation – although that does not imply that all performance is based on cognition in this sense of the word. There are two reasons for defining cognition in this way. The first is that it is this part of the person's psychological processes, which is important to us in the study of man-machine communication. The second is that this is sufficient to explain the influence from affective processes on human performance. It is precisely the way in which stress influences cognition, which is important for performance, and it will be demonstrated that this type of influence is sufficiently detailed and varied to account for any observed phenomena. In addition to that one could hypothesise that there was a parallel influence on the more subconscious processes, e.g., the way in which associations were produced, such that the person might get other associations in a stressed situation. Since such types of influence, however, are quite superfluous in the theoretical framework used here they will not be discussed or taken into account – in good accordance with the principle of parsimony.

9. STRESS AND COGNITIVE CAPACITY

Describing the influence of stress on cognition and performance is, however, no simple task. One reason for this is that the concept of cognitive capacity is rather ill defined. In relation to performance, cognitive capacity may be taken to mean the capacity of the person to perform as intended (or expected). If his performance is insufficient it may be because his cognitive capacity was insufficient – since for the moment we may leave other possible causes (misunderstanding, lack of motivation, etc.) aside. Regarded in this way cognitive capacity is a factor, which is necessary for a satisfactory performance, although not sufficient to guarantee it. And since our aim is to describe the influence of stress on cognition, we may safely restrict ourselves to regarding only the question of cognitive capacity.

There are, however, many ways in which a person can be unable to perform in a satisfactory way – whether the criterion is set subjectively or objectively. In general one may say, that in order to give a satisfactory performance, the following conditions must be met:

1) The person must have a plan, i.e., he must have identified the situation, have established a goal and have discovered or constructed a set of actions, which will bring him (nearer) to the goal.

2) The person must be able to carry out the actions in the planned sequence, i.e., he must be able to follow the plan.

3) The person must be able to get all the information that is needed, both information from the environment and information from memory.

4) The person must be able to keep together in his mind that information which is necessary according to the planned sequence.

If any of these conditions is not met, we say that the cognitive capacity was insufficient. Other ways of expressing the same is by using terms as memory load, cognitive pressure, of attention, information overflow, etc. These terms are not completely synonymous with cognitive capacity but describe certain essential aspects of it, some characteristic conditions under which the cognitive capacity may be insufficient. A more detailed description of the relation between stress and cognitive capacity might begin with any of these concepts, or for that matter with a completely different set of concepts such as memory span, level of attention, interruptions, threshold of interruption, level of arousal, etc. Since it would be next to impossible to make an exhaustive list of these factors, a description of cognitive capacity, which departed from that, could easily become confusing. We shall therefore use the alternate method suggested by the four conditions mentioned above, and discuss the relation between stress and cognition / performance as it is relevant for each condition. This may possibly leave some factors untouched, but should nevertheless provide a reasonable, overall description of the relation in all its complexity.

10. THE FORMATION OF PLANS

Human performance is characterised by being conscious, i.e., the person may describe what he is doing, either while he is doing it or afterwards. This description is, however, not simply a description of what he is doing – such as an neutral observer or a robot might give it – but rather a description of what he is trying to accomplish. It is a description of behaviour related to a goal, of something, which has a predicted (or expected) behavioural outcome, rather than a description of behaviour *an sich*, e.g., in the form of muscular movements, etc. This means that it is not so much a description of the behaviour as a description of the plan or action system (Mandler, 1975), which is in control of the performance.

The point I am trying to make here is that all human performance is planned, i.e., we assume the existence of some higher-order description, which controls the performance. The existence of this plan or the realisation that the performance is planned may be something of which the person is unaware at the time of performance, simply because it is something he has done so many times before, that it has become automatic. This may be the case for a musician playing a well-rehearsed sonata, a student solving the quadratic equation for the hundredth time, or an operator carrying out a particular procedure in a process control room. In all cases, however, the automatic performance has once been new and unknown to the person, and thus something, which had to be first planned and then meticulously carried out.

There are thus two ways in which one may talk about the formation of plans. The first situation is that in which the person does not know what to do and thus has to consciously plan and contemplate how he is going to manage. This may appropriately be called the creation of plans. The other situation is the one, which he recognises it in whole or in part, and where his problem is more of retrieving the appropriate plan rather than of creating it anew. These two ways of forming plans are, of course, not mutually exclusive. We shall, however, leave the theoretical intricacies aside and restrict ourselves to look at the possible interaction between stress and the formation of plans.

10.1 The creation of plans

As mentioned above the creation of a plan is never totally separate from the retrieval of a plan, simply because every situation which we experience contains something or some part which is recognised and familiar to us. It is by definition impossible to speak of or conceive a situation, which is totally new and unknown. But situations may vary in their degree of familiarity from those, which are predominantly familiar to those, which are predominantly new and unknown. And this degree of familiarity is furthermore something, which is dependent upon the circumstances, e.g., the level of stress of the person. The person may quite possibly be so stressed that he is unable to recognise the situation immediately, or he may recognise it wrongly; this is something, which will be developed further in a following section.

Precisely how the person creates a plan in a new (i.e., predominantly unfamiliar) situation is something which is inadequately dealt with by most theories. One interesting suggestion has been, that it is done basically on a trial and error basis, i.e., by randomly trying out various possibilities and selecting and retaining those, which were adequate (Campbell, 1963). This point of view is interestingly enough one, which has later been reiterated by the theories of simulated evolution (e.g., Fogel, Owens & Walsh, 1967) and is definitely one which deserves further investigation.

For the present purpose we may, however, rest with the observation, that the creation of plans is something which may be described as being controlled itself by a plan, i.e., that we have available a plan for generating or creating plans. This does not mean that we have available a procedure which is guaranteed to produce an appropriate plan, but rather that the way we go about creating plans is systematic rather than random. The formation of plans in this sense may be described as a form of problem-solving which includes the "traditional" steps of identifying the goal state, identifying the starting state (the present situation), estimating or evaluating the difference between them, and finally trying to find some procedure which can be used to reduce this difference. The most explicit and detailed account of this has been given by Newell & Simon (1972) who also stressed the recursive nature of the process, as it was mentioned above. Other descriptions may deal more extensively with the diagnostic aspect, i.e., the identification of the situation and thereby also of the goal (cf. Rasmussen, 1978b), or may look at the resemblance between conflict resolution and problem solving (e.g., Hollnagel, 1978d; Janis & Mann, 1977). That there are several different ways of describing how new plans are created does only underline the fact that the creation of plans may itself be described as being controlled by a plan.

Concerning the influence of stress on this process this may also be described at several different levels. First of all stress may be regarded as the impetus for creating new plans. Stress normally leads to an interruption of the ongoing performance, and is thus an indication that something is wrong. It means that the present performance is inadequate either because it was in itself inappropriate – perhaps caused by a misconception of the situation – or because the circumstances have changed gradually without the operator becoming aware of it in time. This interruption may thus lead to the formation (creation or retrieval of a new plan to cope with the changed situation.

Stress is, however, not an instantaneous change in the operator, something that comes and disappears rapidly. It is rather something, which lingers on for quite a while, among other things because it produces a physiological arousal, which takes some time to settle again. The stress (via the physiological arousal) will therefore continue to influence the operator and thus cause further interruptions of his performance, e.g., by lowering the threshold for external signals or by reducing the span of attention. This does, however, mean that the creation of plans may itself be influenced by the existence of stress, such that what was supposed to remedy the situation is itself hampered by it. Another deteriorating factor is that the external cause of the stress may still be present. The operator may thus at one and the same time experience that he is stressed, and also that his being stressed prevents him from creating (or retrieving) a plan which can be applied in the situation. This is thus a positive feedback or deviation-amplifying loop (Maruyana, 19631, which could result in a disaster if no other "mechanisms" were playing a role. It is in fact precisely this positive feedback mechanism, which can lead to panic or hypervigilance in certain situations (e.g., Janis & Mann, 1977), i.e., that the creation of plan is deadlocked by the persistent stress.

To recapitulate, the creation of a plan is something, which may itself be described as being controlled by a plan (as indeed all human performance is) It may be described in several different ways, as problem-solving, as diagnosis or as conflict resolution. The success of this plan is among other things dependent upon the possibilities for performing it without disturbance or interruptions. In many situations the creation of a plan is, however, initiated as a result of an interruption of ongoing performance, where this interruption may again be caused by a state of stress in the person. The stress may be reduced if the person is able to form a plan to cope with the situation, but the stress may itself disturb this creation of a plan and through that increase the stress, leading to a veritable vicious circle.

10.2 The retrieval of plans

The retrieval of plans is distinguished from the creation of plans by the person’s awareness of or belief in the existence of an adequate plan. This may be because the situation is familiar to the person so that he recognises it as one he has experienced before, and accordingly as one, which he has been able to handle before. He may either immediately have a plan ready for execution in the situation, or may be confident that he can handle the situation once he has retrieved the plan he has used before, i.e., once he has remembered what he did on the previous occasion. The person is therefore never at a loss concerning what he possibly can do.

This problem of retrieval of plans has traditionally been investigated as a problem of availability of solutions, and there exist a rather extensive literature about it in the field of problem solving (e.g., Maier, 1933; Maier & Burkes, 1966; Raaheim, 1960 & 1964; Saugstad, 1955 & 1958). The concept availability of functions” refers to the observation, that solutions to problems at times are immediately given and obvious for the person, and at other times are difficult to bring about even though the problem objectively may be the very same. Availability thus describes the ease with which a solution is found, but it is a purely descriptive term which does not explain anything, i.e., it does not in any way hint at a reason why solutions are sometimes available and sometimes not. The many problem-solving studies have often been concerned with whether or not the availability of a solution could be manipulated, e.g., by directing the person to think in a certain way, to make him aware of certain “missing parts” of the problem, or by varying the degree of familiarity of the problem. These studies have, however, quite often been traditional investigations of the influence of one parameter against another, and have not produced any substantial improvement in the understanding of what availability really is.

The most precise one may say about availability (or ease of retrieval of plans) is, that it is closely connected to the degree of familiarity of the situation and to the associations which are evoked by the situation. It is in many ways a problem of memory, of ease of access in memory. The degree of familiarity of the situation may tell us, that we know what to do, but 1t may be difficult to remember exactly what should be done. The reason for this may be that we perceive the situation as familiar without being able to identify it completely. this however, bears the risk that familiarity and accessibility each is defined using the other. Such a circular definition must be avoided, of course, and the best way to do this is probably to take the ease with which a plan is retrieved as a starting point, if for nothing else then because this is a measurable parameter.

The ease with which a plan is retrieved may then he seen to depend on (1) the degree of familiarity of the situation, and (2) the actual availability of plans. This latter refers to the fact that most situations may be dealt with in a number of ways, i.e., it is quite rare that there is one and only one possible solution. If therefore the person knows a number of solutions (or has been trained to use a number of solutions instead of just one solution) it seems natural to expect, that the ease of finding a solution will depend on the number of solutions to which he has access, for any given degree of familiarity. This, by the way, seems to be the philosophy behind a number of job analysis and training programs. A quite common procedure is to identify a number of essential functions and train or drill the person to use them, so that he has a (hopefully) sufficient number of plans available to him.

In contrast to this the familiarity of the situations is something which is much more difficult to divide into a number of essential parts which may then be learned. Familiarity is roughly an expression of the experience of the person, since an experienced person obviously is one who knows more than an inexperienced one. The role of experience is, however, not exclusively beneficial since the identification of a situation may be too hasty, leading to inappropriate performance (cf. the “ladder-of-steps” described by Rasmussen, 1974 or the general description of perception and conceptualisation by Bruner, 1973). The implication of this is that the perfect operator should be experienced, but not be lead (or rather: mislead) by his experience into making hasty conclusions.

Concerning the influence of stress on the retrieval of plans it obviously has an influence on the identification of the situation, i.e., on the way in which the situation is recognised and accordingly on the degree of familiarity of it. The identification is easiest to make when the person is free of stress and when he does not feel any constraints of, e.g., time. As the level of stress rises he becomes less efficient in his discrimination and processing of information, and this, of course, influences the result he reaches. We shall later go into more detail concerning the relation between information overload and stress, and may here content ourselves by noting that stress decreases the threshold for information overload. The kind of mistakes that may result from this may be either that the person fails to identify a situation, which he would under normal circumstances he completely familiar with, or that he incorrectly identifies a situation as being familiar even though it is not. In both cases it will be difficult (if not impossible) for him to retrieve an appropriate plan.

Concerning the second factor contributing to the ease of retrieval, the so-called actual availability of plans, this is assumed not to be influenced by the level of stress. One reason for this is purely theoretical, namely that the influence on the identification or recognition of the situation is sufficient to provide an explanation of why the performance deteriorates when the stress increases. Another reason – again mainly theoretical – is that the retrieval of plans is an automatic, hence unconscious process while the recognition of the situation is a predominantly conscious process. If we assumed that stress exerted an influence on unconscious processes as well as on conscious processes, we would be hard pressed to explain why a person under stress may execute a plan correctly (independent of whether the plan is appropriate or not). An influence of stress on the unconscious processes would probably lead to a complete breakdown of all behaviour, since nothing would be as it normally was. This evidently is not the case. Anyone who has observed a person working under stress – or who has himself been working under stress – can testify that the problem lies in managing the situation, i.e., in executing an appropriate plan, rather than in the doing (of something or anything) itself. It is only in the most extreme cases that behaviour is totally disintegrated. Normally the person has access to a number of plans which are generated automatically, so to speak, and the problem lies in selecting or evaluating which plan should be executed, cf. Drwal (1973).

As with the creation of plans we may also in the case of the retrieval of plans consider stress (and the interruption of performance caused by stress as a primary reason for initiating the search. There is thus a considerable resemblance between the two types of formation of plans, which, of course, is not coincidental. It is therefore possible to recapitulate the essential points in the formation of plans as shown in Figure 7. Initially stress is present, caused by some internal or external condition, which has not yet been specified. The immediate influence of stress is to interrupt the ongoing performance; the “+” sign on the arrow from “stress” to “interruption” signifies a directly proportional relationship, i.e., the higher the level of stress, the higher the degree (or rate) of interruption, and vice versa.[3] This interruption leads to a search for new plans, i.e., the person becomes motivated for (or feels the need of) forming a new plan, which can effectively deal with the stressed situation. The relation between the interruption and the formation of plans is again presumably directly proportional, i.e. the more abrupt or frequent the interruption is, the higher is the need to find some way to manage the situation. There is, however, also an influence from stress to the formation of plans as described earlier, in the sense that the formation of plans – whether it be creation or retrieval – is less easy the higher the level of stress is. This is indicated by the arrow from “stress” to “formation of plans”, and the “-” sign indicates that the relation is assumed to be inversely proportional, i.e. the higher the level of stress, the more difficult is the function of plans (the lower is the degree of success)

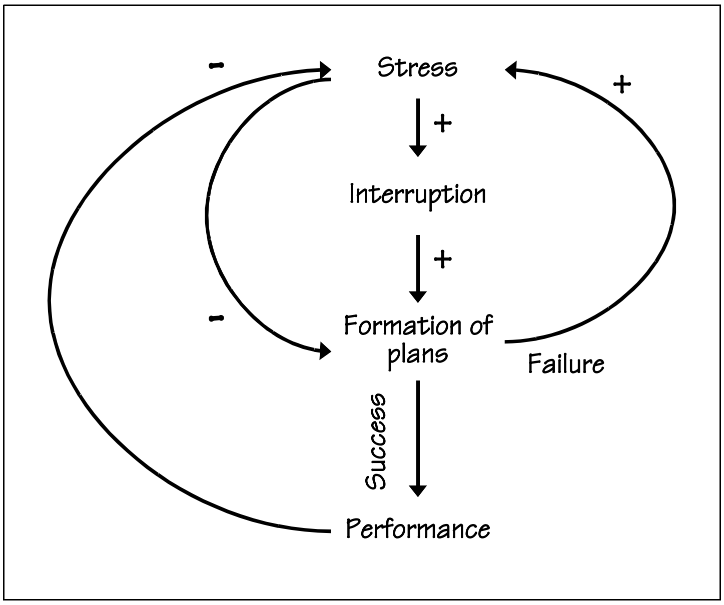

Figure 7: The formation of plans

The formation of plans may somewhat simplified be said to have two possible results. Either the person is able to create or retrieve a plan, i.e., the formation of plans succeed, or he is unable to do so, i.e. the formation of plans fall. In the case of a failure the person will presumably try once more rather than give up completely. There is, however, a negative influence from failure to “stress” indicated by the arrow in Figure 7. This influence is considered to be directly proportional, i.e. the higher the number of failures, the higher the level of stress becomes. It is this negative influence discussed above, which may eventually bring the situation to a deadlock. It is easy to see, that if this is the only influence fed back to “stress”, the whole situation would be described by a positive feedback loop which would amplify any deviation present (because the “-” on the arrow from “stress” to “formation of plans” means that the rate of failure will increase with increasing levels of stress).

The other possible result is, of course, that the person has success, i.e., that he is able to create or retrieve a plan, which can be used in the situation. The presence of such a plan will lead to performance, and one effect of such performance will be that the level of stress is reduced, as indicated by the arrow from “performance” to “stress” in the Figure 7. The “-” sign on the arrow indicates, that the level of stress will be reduced as the level (and access) of performance is increased. The ability to do something in a stressed situation will help the person regain control over the situation and thus reduce the stress. The inclusion of this changes the total description from being controlled by a positive feedback loop to being controlled by a negative feedback loop, and thereby makes possible a state of equilibrium and of counteraction against induced changes. This way of conceptualising the possibilities in the situation thus underlines the importance of performance: if the person is unable to change his performance (i.e., to find a proper plan), he will be unable to control the situation.

One interesting consequence of this is that almost any kind of performance will be helpful, whether it is adequate to the present problem or not. This is in fact something which is often utilised and which has been condensed into, e.g., the rule of count to ten”, cf. James, 1884. The trick in this is simply that the execution out of almost any plan, even that of counting to ten, will bring some measure of control back to the person, and thus reduce the immediate stress, allowing him to gain time and to recover. The major advantage of such a plan is that it is available at all times, since it is totally independent of the situation and the way in which it is recognised. The major drawback is, of course, that a plan like this does not do anything to improve the situation as such. If stress was caused by an external disturbance this will most likely still be there when the person has counted to ten – and it may even have become aggravated. Nevertheless the effect – proverbial and actual – of this method demonstrates the importance of performance in counteracting the influence of stress on cognition

10.3 Goal-completion

Before leaving the question of the formation of plans it is appropriate to mention a different aspect of the execution of plans: the completion of the execution or the goal-controlled stop-rule. As described in the beginning the formation of a plan, whether it be the creation of a new plan or the retrieval of an old one, must to some extent be determined by the goal as it is conceptualised by the person. The goal may be to reduce the level of stress (as in counting to ten), but more often it will be a more specific state of the physical environment in relation to the person, and the reduction of stress will be a beneficial consequence of the performance rather than the goal of it.

Simon (1967) has enumerated four different ways in which a goal can be completed, in the context of human information processing. The first type of completion is called completion by aspiration achievement. This means that the goal of the performance as conceptualised by the person is fully achieved, i.e., the criteria for completion of the performance are fully reached. The goal may, e.g., be to counteract a disturbance or error in a power plant, and this goal will be reached when the operator has brought the process back to a normal state. Goal-completion by aspiration achievement usually requires that the goal itself is well defined and that there is sufficient time and resources to execute the plan as well as to determine that the goal has been reached.

The second type of goal-completion is called satisficing, in analogy with the satisficing principle developed within decision theory (March & Simon, 1958). The difference from the former type is that satisficing employs a less stringent criterion; the performance is stopped when a satisfactory or sufficiently good condition is reached. The goal is thus defined by some minimum criterion rather than by the more comprehensive criteria used in aspiration achievement. Also the determination of whether the criterion has been reached or not, may be less stringent; the performance may be stopped if, e.g., the plant seems to be in a reasonable steady state, or it the disturbance seems to be neutralised.

The third type of goal-completion is by impatience. In this type the goal may have been specified as explicitly as in the first instance, or more vaguely as in the case of satisficing. But the difference between the two first and the third is, that the goal state is never fully reached. The person tries to reach it, but seems to be unable to do so, possibly because of limitations of time. The term “impatience” indicates that the person becomes tired of trying to reach the goal, may be because it is rather more difficult than he expected, or because progress is slower than expected. The person then gives up, and may perhaps instead select as a result that which has been the “best so far”, i.e., he may in reality change his goal-criterion such that an already achieved state becomes the goal state, even though it does not match the initial criteria.

The fourth and final type of goal-completion is by discouragement. This indicates that the goal is not reached at all, but rather that the person gives up the attempt to reach it; at least he gives up using the present plan, but he may, of course, try to formulate a different one for a renewed attempt. Properly speaking this is not a case of goal-completion but rather of stopping of execution. Discouragement indicates a lower threshold for stopping than does impatience, and discouragement may he expected to be frequent when time limitations are severe. Discouragement may he connected to a simple trial-and-error method, i.e., the person tries one possible plan, and if that doesn’t work he immediately shifts to another. This type of stopping may therefore he expected to be predominant in situations where the person has to do something quickly even though he has not fully been able to grasp (recognise or comprehend) the situation.

Concerning the relation between the level of stress and these four types of goal completion it is rather obvious from the descriptions given, that the presence of stress may force the person to shift from the first type of stop-rule towards the other types. The sequence in which they have been mentioned here does in fact constitute a rank ordering in terms of appropriateness; clearly, the use of discouragement is less appropriate than the use of achievement aspiration, no matter what the situation is. The uses of a less appropriate type of goal-completion will furthermore have consequences for the whole situation. Returning to Figure 7, the goal-completion is related to the performance; and it is logical to assume that the quality of the performance is related to the type of stop-rule, which is employed, in the manner suggested above. Therefore, the level of stress is also influenced by how well the person is able to perform, i.e., the extent to which he is able to achieve the goal he has himself established.

11. THE EXECUTION OF PLANS

In the preceding section it was repeatedly pointed out that the execution of a plan was crucial for the maintenance of control in a stressing situation. Nothing was however said about how this performance or execution of a plan in itself could be influenced by stress. There is obviously such an influence, since the execution of a plan is a conscious, cognitive activity, and thus depending upon the possibilities for cognitive activity. In the present section we will take a closer look at some of the essential parameters of cognitive activity, which determine how well a person is able to execute a plan.

In general, the execution of a plan means that the person has access to some overall description of the steps he has to go through in order to reach a specified goal. This description may in whole or in part be either external or internal. External descriptions are also known as operating instructions, as, e.g., the written instructions for the various tasks in a power plan or a cookbook recipe. Internal descriptions are plans which are developed by the person and which he remembers; it may either be plans which he has used before and which therefore are permanently stored in his long-term memory, or it may be plans which have been created for that particular situation. Descriptions, which are partly external and partly internal, are, e.g., written operating instructions, which have been used before by the person and which he has partly memorised. This, of course, involves the risk that he may perform the memorised part of the procedure differently from the way in which it was intended, so that a discrepancy between the internal and the external description may arise.

When a person executes a plan he does it by executing it step by step. The size or span of a step is, however, not something which is objectively defined, but rather something which may vary from situation to situation; typically it is also a function of the proficiency or experience of the person. Perhaps the best way to define a step is to say that it is the unit of activity (including perception, thinking, and bodily movements), which can be performed automatically without demanding attention. (Other names, which have been used for a step, are subroutine, chunk, skill, organised response or schemata.) Thus the size of a step may vary from person to person even though the description may be the same. Take, e.g., the way in which a cooking recipe is executed by a skilled cook and a novice. For a highly skilled person a given description may have only one step, while for a less skilled person the same description may have many steps. The activity, which constitutes a step, may be seen as controlled by a procedure rather than by a goal. Once this procedure is started, it will usually be continued until the step is finished, without any possibilities of stopping or changing it in between. To use the computer analogy, a step is a subroutine which is executed independently of the main processor and which returns a flag when it is finished. Another metaphor which may be used to describe the nature of a step is to say that it is ballistic rather than guided; it is just like firing a mortar, where there is no way of controlling the projectile once it is on its way; in contrast to that a guided missile may change its course in relation to the goal.[4]

The advantage of such steps is obviously that they free the attention of the person, so that he may concentrate on, e.g., gathering further information or organising separate activities towards obtaining the final goal. There is evidently a trade-off between the number of steps (and thereby also the size of the steps) and the degree of control of the execution of the plan in toto. If there are a large number of steps, a correspondingly large amount of attention will be necessary for the control of their execution, since each step will only be of a short duration. There is therefore less capacity left to the overall control of the task and to the co-ordination of the various steps. One may rather easily imagine a situation where the task of co-ordinating the various steps becomes so important that it dominates the task of producing the specific change as described by the goal. For example when learning to drive around a corner, you may be so absorbed by the handling of the wheel and the various controls that you end up on the wrong side of the road you were turning into. If, on the other hand, there is only a small number of steps – and perhaps only a few or one step left – the possibilities for adapting the performance to a changing goal are correspondingly small; to regain the necessary flexibility and adaptability it may in fact be necessary to break down some of the steps into smaller parts, corresponding either to an earlier (and therefore less developed state of proficiency, or to a changed comprehension or conceptualisation of what the situation is.

11.1 Interruption and disruption

The interruption of performance plays an important part not only in the way cognition is influenced by stress, but also in the general way in which the person (or the organism) copes with the environment.

> "One of the main avenues for change in existing cognitive and action systems is undoubtedly a consequence of the failure of existing structures. An interruption occurs when a current structure fails in handling available input or action requirements. Thus the adaptation to the requirements of the world, "learning" in traditional terminology, occurs subsequent to interruption. Any satisfactory theory of cognitive structures must contain means whereby structures are changed whenever any ongoing cognitive or behavioral activity fails or is interrupted."
>
> (Mandler, 1975, p. 153-154).

In addition to interruption caused by failure, it may result from the normal completion of a step as mentioned above, or from the appearance of an external signal, which is sufficiently strong to capture the attention of the person. We shall, however, not go into details of the possible causes and effects of interruptions, but instead only look at the way in which interruptions may relate to the controlled execution of a plan. (Various psychological aspects of interruption have been described by, e.g., Kahneman, 1973; Lewin, 1935 or Mandler, 1975).

The appearance of an interruption does not only mean that the current step of performance is suddenly broken (since we do not include the normal end-of-step interruptions in this discussion), but does also lead to a physiological arousal in the person. This physiological arousal is partly related to the motivational aspects of interruption, e.g., the Lewinian theories of tension towards completion, etc.[5] In addition to this it also has some less beneficial effects, since the increased level of arousal may be detrimental to the cognitive functioning and hence to the execution of plans. This is because the increased level of arousal may change, e.g., the threshold for external stimuli or the span of attention, with the result that the cognitive functioning becomes less effective.

To insure the effective performance it is necessary that the time necessary for the completion of a step is available. The duration of a step may naturally vary, according to the way the person has structured the task, but we may assume that for a particular step there is a minimal duration, i.e., a minimal amount of time, which is necessary to execute the step. If the task is predominantly cognitive, i.e., that it involves little if any overt action, then the time necessary may be measured in seconds or parts of seconds (cf. Hollnagel, 1978e). If the task involves the interaction between the person and a physical system (or another person), the minimal time necessary may be in the order of minutes, perhaps even hours. No matter the magnitude of the time needed, it will be impossible for the person to execute the plan and to execute the individual steps in the plan, if he cannot count on sufficient time being available. If he is repeatedly interrupted during the execution of a step, he may abandon the attempt altogether, i.e. a form of stopping by impatience or discouragement.

In this latter situation the task is not only being interrupted, but is disrupted. It may be that the interruptions are so frequent, that the person does not have sufficient time to execute the steps of the task; it may be that the task is organised in such a way, that it is necessary to begin anew after each interruption (cf. Simon’s (1970) story of Tempus and Hora), which may lead to a disruption after a number of interruptions; or it may be that the person forgets how far he had advanced in the execution of the task when he is interrupted, which, of course, would prevent him in continuing it when the interruption had been handled. Disruption is thus the worst consequence of the interruption of a task. Note also, that this is another example of a positive feedback or deviation-amplifying loop. Each interruption will make the person more susceptible to further interruptions, by increasing the level of physiological arousal and stress, and by reducing the processing capacity of the cognitive system.

To quote Mandler:

> “Whenever an organised sequence is interrupted we expect the occurrence of some emotional responses. It, as is often the case, this emotional eruption is incompatible with completion or continuation of the sequence, we would expect some further disruption of organised behaviour to occur.”
> (Mandler, 1975, p. 156).

Another possible instance of interruptions is the occurrence of a number of different interruptions (e.g., if a number of alarms in a control room come on simultaneously or if a new alarm is set before an old one is cancelled), which places the person in a situation where he not only has to find and execute the appropriate plans, but where he also has to decide which interruption should be dealt with first. Such a situation of multiple alarms may easily lead to a disruption of the performance, because the human capacity for short-term retention and processing is very limited.

To recapitulate, the function of an interruption is to alert the person, to tell him that something is wrong, and possibly that his present performance is inadequate. The consequence of an interruption is that the plan presently being executed is stopped or suspended, and that the lever of arousal is increased; the person will try to find another plan which can handle the interruption, but will at the same time be in a state where he is more susceptible to the effect of further interruptions; in the worst case his performance is totally disrupted, which leaves him unable to cope with the situation.

11.2 Interruption and queuing

One of the immediate consequences of an interruption is that the step presently being executed is suspended, i.e., its execution is temporarily stopped to be resumed at a later time. Another way of describing this is to say that the step is put into a queue. Queuing is, however, not something, which only occurs in response to an interruption, but is a more general technique or method used to overcome situations of information overload.

Miller (1960 & 1978) introduced the term information overload which denotes the situation where there is more input to a system than it is able to process. Based on the research by Miller and his associates a number of various reactions or responses to information overload have been described, ranging from the omission of parts of the input to abandoning the task altogether. One commonly used response in systems at all levels is queuing, i.e., retaining that part of the input, which cannot be processed at the current time, in the hope that it is possible to catch up with it later on. In many instances queuing does not involve the actual retaining of the information that has to be processed, but only the retaining of the tasks (steps of information processing) which have been postponed, since the information as such often is permanently represented in some other way or readily available from the environment.

In relation to the execution of plans the crucial question is how large a number of tasks a person is able to queue without getting them mixed or forgetting them; or in more technical terms, how many registers there are in the stack. Another problem is whether the queue functions on a FILO (First In, Last Out) basis, a FIFO (First In, First Out) basis, or whether rearrangement of the tasks in the queue is possible. For a person the main problem seems to be the size of the queue, where a large amount of experimental evidence indicates, that the size is restricted to only a few steps. Evidence on this may be found in a variety of places, e.g., on the comprehensibility of programming languages (Green, 1977; Hoc, 1977), on the size of the so-called short-term memory (Miller, 1956), or the operational memory (Posner, 1967; Hollnagel, 19741; in psycholinguistics in relation to the depth of recursion (Miller & Isard, 1964) or the so-called Yngve Number (Yngve, 1960), and in problem solving (Klahr, 19781). Although there are no definite experimental results on the possibility of rearranging the steps in a queue, the common experience from practical situations indicate that this is only a minor problem.

One may speculate about a possible connection between the STM (short-term memory) and the size of the queue, namely that the temporary retaining of a task would use up one position or chunk in STM; remembering what to do is no different from remembering a word or a number, since what has to be remembered in both cases is a verbal, symbolic representation of some event or object in the real world. If that is so, each step that is remembered (i.e., kept in the queue) will reduce the capacity for information processing, such that a trade-off function between these two can be assumed. Clearly then, if the queue contained the maximum number of steps – say, seven – there would be no capacity left for information processing, and conversely if the need for information processing was great, there would be a reduced capacity for queuing steps. This would fit well into the relation between cognitive capacity and stress, which has been presented so far. And it would provide a consistent description of how the execution of plans might be influenced negatively by the interruption of the current performance. On the one hand queuing would be the only response, which was applicable when an interruption occurred, since naturally the current step could not be abandoned. On the other hand queuing in itself (i.e., without even considering possible affective responses) would impair the cognitive capacity and render the handling of the interruption more difficult. In addition to that, both interruption and queuing may be assumed to trigger an increase in arousal and hence also in the level of stress – which means that the deviation-amplifying loop described previously would once again come into activation. Only the successful handling of the interruption, and thereby the reduction of the queue could return the complicated functional relations to a steady state.

11.3 Fluctuation of attention

One condition for executing a plan is that the person is not interrupted too often, i.e., that he is able to complete a step. Another condition is that he is able to control his attention sufficiently well. Human attention is notably limited in several respects. First of all, we are only able to attend to one source (i.e., a modality or a particular event) fully at a time. If, e.g., you sit and listen to a piece of music, you obviously attend to the music rather than to the way the seat feels against your body, to the temperature of the room, to the smell of the air, etc. You may, however, choose to attend to any one of these sources instead of attending to the music; but if you do so, you will fail to notice the music. You may still notice, that some sounds are reaching you, i.e., you can discern noise from silence, but you are unable to listen to the music in the normal way. Generally, when we attend to something we exclude other things (cf. Kahneman, 1973; Moray, 1969; or Norman, 1976). Secondly, when we attend to something we become less susceptible to influences from other sources or stimuli. One may say that we lower the threshold for the source to which we attend, and simultaneously raise the threshold for other sources. That means that we may fail to notice signals from other sources, even though they may be essential for the performance in question. And finally, we are only able to keep our attention focussed at a specific source for a limited period of time. If we try to listen to something or look at something for an extended period of time, we will invariably find ourselves in the situation, when we suddenly attend to something else. Everyday proof of this is easy to find, e.g., in mind wandering while listening to a piece of music, reading a book or watching a play. This is something, which experimentally is well established, e.g., in experiments on reaction time or vigilance, where it is relatively easy to catch the subject at a moment where his reaction time will be lengthened – and in fact such experiments take elaborate precautions to prevent these situations.[6]

Even though the execution of a step does not need the attention of the person, since a step was defined as that unit of action, which could be performed automatically without demanding the attention of the person, the execution of the plan as such demands attention. First of all it is necessary to attend to the goal and to compare the current state with the goal state; it may be necessary to attend to the execution of certain parts of the task, e.g., if they involve minute visual-motor co-ordination or co-ordination with the work of another person; and it will definitely be necessary to attend to information presented in the environment, e.g., meter readings, visual display units, acoustic signals, etc. If attention fluctuates it means that the pickup of information will be less precise than it ideally ought to be (and certainly less precise than the designer of the systems has foreseen). The result may be that the person does not respond immediately to a signal, but only after some delay; it may be that he only notices that there was a signal or a change in the information without being able to tell what the change was; or it may be that he misses the signal altogether.

The fluctuation of attention is unavoidable and in addition to that it is also variable. Typically the fluctuation becomes more frequent as the person grows tired and as the level of stress increases. The latter is a simple Consequence of the fact that an increase in the level of stress reduces the cognitive capacity and thereby the person's degree of control of what he is doing. The former is something, which we all have experienced, e.g., in trying to read something when we are tired or physically or mentally exhausted. The execution of a plan is thus performed best when the person is not over aroused or in other ways outside the range of normal functioning.

11.4 The organisation of steps

In the discussion of the effects of interruption – and partly also in the discussion of queuing – it was mentioned, that the way in which the various parts of a task was organised might have significance for the ease with which the execution could take place. This is connected to what one might call the transparency Cm contrast to the opacity of the structure of the plan, i.e., the ease with which the operator can comprehend the way in which the various steps of the plan are interrelated.

In the most simple case the plan can be composed of a number of steps in a linear sequence, i.e., each step following another; one may assume that this type of composition is the easiest to comprehend and hence the most transparent. In practice a completely linear structure is quite rare, since there almost always are one or more cases of conditions involved, where the selection of the next step is dependent upon the state of certain variables. This is true for a plan as simple as a cooking recipe, and for the complex operational instructions for the start-up of a power plant. It is no problem to create a plan that is too complicated to comprehend; the problem is rather to avoid this condition as far as possible. The solution to this is, however, not to give all plans a linear structure or to get as close to the linear structure as possible, since it can easily be shown (e.g., Simon, 1970) that a hierarchically organised plan is more robust to interruptions than a linear is. We are thus once more confronted with a problem of a trade-off between two considerations, the efficiency and the transparency of the organisation of a plan.

In the case of retrieved plans, and in particular plans that are produced in advance on an external medium such as an instruction manual or a computer, it is the responsibility of the designer that the organisation is as effective as possible, i.e., that it is both functionally efficient and easy to comprehend. One particular consideration that must be taken is that plans (instructions) for emergencies must reflect the fact that the cognitive capacity of the operator may well be reduced in such situations. This means both that it may be more difficult for him to grasp the structure of the plan so that he may be tempted to execute it step by step without realising or considering in advance what the effect of one step may be on later steps; and it also means that there is an increased probability that he looses control over what he is doing, i.e., that the interruptions turn into disruptions. In both cases the proper organisation of the task may prevent or weaken the possible decrease in the effectiveness of the execution of the task; suggestions as to how this may be done, can be found in the literature on reasoning, e.g., Wason & Johnson-Laird, 1972 or Broadbent, 1977.

In the case of plans that are created in the situation (ad hoc plans), there are no obvious ways in which an optimal organisation of the steps of a plan can be secured. Probably the best way of doing it is to train the operator properly so that he will never encounter a completely unknown situation,. From a psychological point of view the best way 0g doing this is not to train him in a large number of specific activities or tasks, since the set of such actions is logically limited by the imagination of the designer and/or the experience with the particular system. The training should rather aim at higher-order skills, which are generally applicable to a large number of situations and systems and therefore leas vulnerable to the effects of unexpected situations. This is simply an expression of the fact the people with a broad experience are less likely to become functionally fixated, i.e., trapped in a particular way of dealing with the problems, than people who are accustomed to a limited number of methods – and, of course, also an expression of the belief that this ability is something that can be acquired and not something which is unalterably determined by the personality (or biological makeup) of the individual.

12. THE GATHERING OF INFORMATION

In the preceding sections we have discussed the way in which stress might influence the formation and the execution of plans. The execution of plans is, however, not simply the ability to follow the steps of the plan. The operator’s performance is not simply a passive carrying out of a step-by-step procedure, but rather an active interaction with the system, and it is in particular depending upon the information which is either presented by or which can be picked up from the system. The total performance thus also depends upon the way in which the operator can gather – and process – information, as an integral part of the execution of a plan.

It has been mentioned in the beginning of this paper, that one major advantage of the cognitive viewpoint is that it not considers the cognitive functions as only passive information processing functions, but also includes the pickup or gathering of information. The cognitive system is not merely a receiving system, but is also active and searching. The gathering of information, as well as the processing of information, is nevertheless in several important ways influenced by stress. In the following we shall mention three significant types of influence, namely in relation to categories, the inverse-U curve, and the effector-receptor span. The selection of these three types is largely determined by the traditional way of dealing with the influence of stress on information gathering, in theory and in practice.

12.1 The restriction of categories

When discussing the concept of queuing, the phenomenon of information overload was mentioned, and queuing was described as one of the typical and frequent reactions of a system to information overload. Among the other types of responses two are relevant for this discussion, namely filtering and cutting categories. The meaning of filtering is that only certain categories of information are processed, while others are neglected; this naturally reduces the total information-processing load of the system. The meaning of "cutting categories" is that the information, which is taken into the system for processing, is treated in a less detailed way than under normal circumstances. Miller describes it as "responding in a general way to the input, but with less precision than would be done at lower rates (of information), i.e., instead of reporting "I see yellow," saying "I see a light colour" or "I see a colour" (Miller, 1960, p. 697). When we treat both types of responses under the same heading here it is because they functionally produce the same result for the system, namely that the categories used to interpret the information taken into the system are qualitatively and quantitatively different from those normally employed.

The restriction of the number of categories used, corresponding to a simplification of the description of the environment, is something, which may be expected to increase as the level of stress increases. This is matched by a simplification in the way of responding, i.e., that the number of categories of activities – or the number of various plans – is similarly reduced. In the extreme situation of panic there often seem to be only two alternatives, either to stay or to run, And accordingly information may be reduced to be either "good" or "bad", "friendly or "threatening", etc. The advantages of this type of restriction are obvious, since they reduce the demands to cognitive activity; or rather, the reduced cognitive capacity, which is a consequence of an increase in the level of stress, is only adequate for cognitive activities of a reduced complexity. And it is obvious that it is easier to report only "light" or `no light" rather than five or ten different colours or intensities, just as it is easier to select one activity out of two rather than out of a larger number. One may in fact regard both situations, i.e. both the categorisation of input and the selection of possible activities, as a problem of decision making (although the person may not experience it is such). In both cases the restriction of the number of categories reduces the number of alternatives among which the system will have to choose, and accordingly also the amount of cognitive "work" which is necessary for the decision)

Another way in which this has been described is through the concept of one utilisation. Here the word cue does not denote that part of the information available "stimulus" which consciously or unconsciously guides behaviour, but rather the combination of the stimulus and the corresponding activation or response: "A singular cue can be said to have been used when a related response has occurred" (Easterbrook, 1959, p. 188). The concept of cue utilisation thus includes both the way in which information is categorised and the way in which the person responds as a result of this categorisation. It seems quite reasonable to let the concept of cue include both the input and the output side of the system since, as a matter of, fact, we can only derive knowledge of the use of information (the level of discrimination and categorisation from the ensuing performance of the person; the conclusions concerning the person's use of the information available to him can indeed only be a hypothesis, since we have no direct way of knowing it. This is nevertheless no impediment for having quite good and consistent hypotheses about the way in which people gather and use information. Concerning the effect of stress upon cue utilisation, it is generally accepted that stress reduces the range of cue utilisation, analogous with the arguments presented above; a thorough discussion of this may be found in Easterbrook, 1959.

A consequence of this is therefore that one may expect the operator to be less efficient in his information processing, i.e., in the way he interprets and reacts to signals, when the level of stress increases. There are two obvious solutions to this problem. One is to reduce the level of stress in some way and to let the operator regain control over the situation; suggestions as to how this may be accomplished have already been given. The other solution is to reduce the demand for complicated information processing when the operator is stressed. This can be done by reducing the number of categories used in the presentation of information, in increasing the discriminability of the signals used, and in reducing the complexity of the activities required by the operator. This is, however, probably not a viable solution taken by itself, since one possible reason for stress is the inherent complexity of unanticipated situations. There is thus presumably a level of complexity below which it is impossible to design the interaction. The reduction of the demand for information processing may nevertheless have the beneficial "side effect" that the level of stress of the operator is reduced, so that proper control may be regained.

12.2 The inverted-U curve

This concept, which may also be referred to as the Yerkes-Dodson law, is commonly used to denote the empirical fact that the relation between the level of performance of a person (or an animal) and the level of arousal or motivation may conveniently be described by a curve in the shape of an inverted U. The standard way of doing this is shown in Figure 8. The relationship is that the optimal level of performance is reached at an intermediate level of arousal.

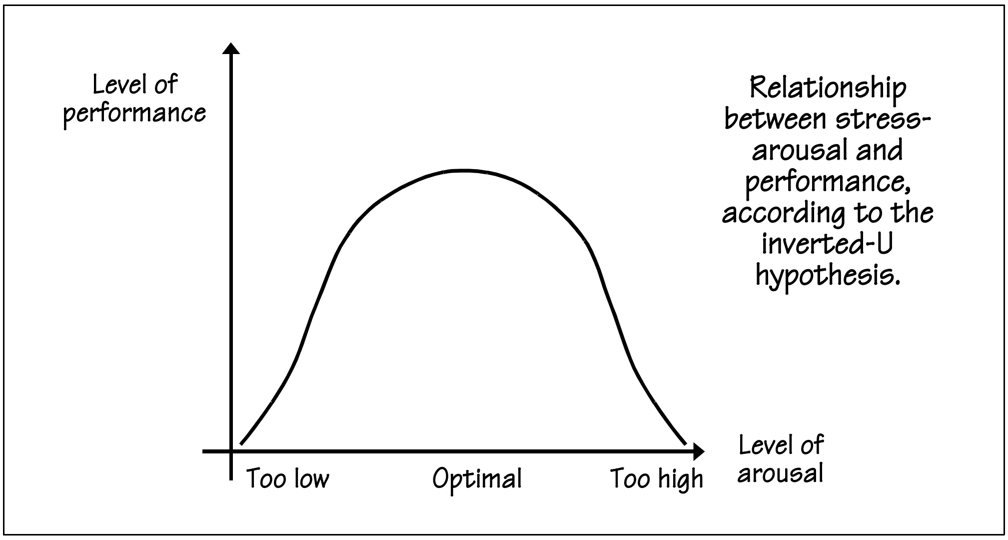

Figure 8: Inverted U hypothesis

Lower levels of arousal lead to lower levels of performance, and higher levels of arousal lead also to lower levels of performance. It is this last relationship, which is (or was) considered surprising since the original hypothesis was that performance would increase proportionally to the level of motivation or arousal. The observations leading to the inverted-U curve are traditionally attributed to Yerkes & Dodson (19081, who investigated the relation between strength of stimulus and rapidity of learning in mice; it is interesting to note, by the way, that they did not formulate the inverted-U hypothesis neither in words nor in drawings in their original paper.

The inverted-U hypothesis is not in itself. of any special interest in this context since it merely is a general way of expressing many of the observations and conclusions which have been mentioned in the preceding. It is, however, of interest in connection with another theory – the theory of signal detection – since this latter may give a more specific meaning to the inverted-U hypothesis, and in a way provide a sort of explanation of it. This matching of the two theories, which has been suggested by Welford (1974) also provides the answer to a question which is relevant when one tries to apply the inverted-U hypothesis, namely whether the performance is the same or identical for “too low” and “too high” arousal conditions, or whether it only is the level of performance or efficiency that is identical while the actual performance may differ.

The theory of signal detection is an attempt to provide a concise description of how an information processing system (such as a person) determines whether or not a signal is present. The general principles of signal detection theory are shown in Figure 9A.

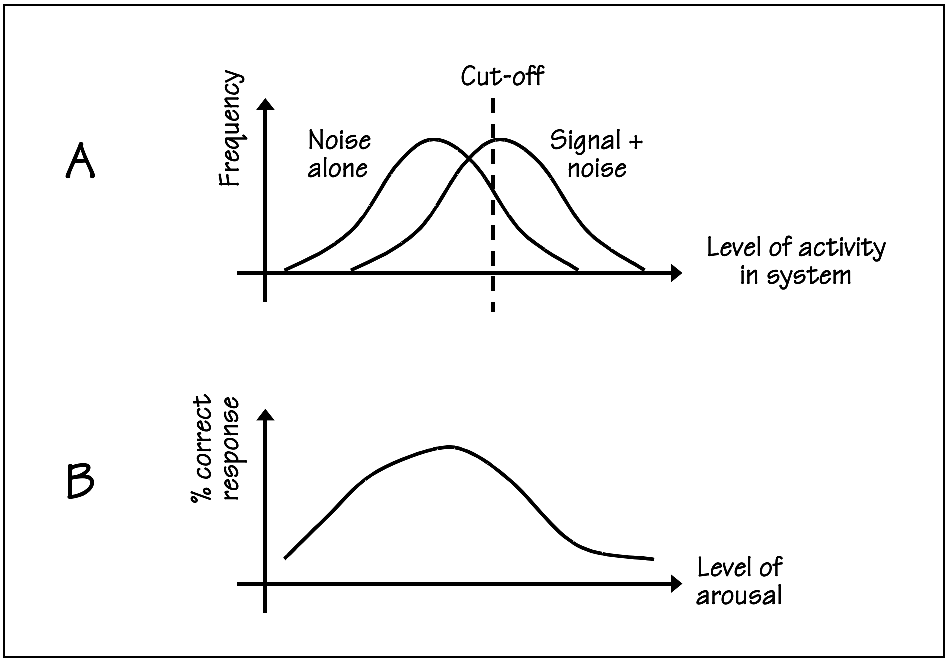

Figure 9: Signal detection and arousal

The basic idea is that the system (e.g., the brain) is considered to be spontaneously active such that there is a background of random neural firing, called the noise (although the noise may also be attributed to the source of the signal). It is assumed that the level of the noise varies from time to tine so that it yields a distribution such as the one on the left side in Figure 9A; this distribution may be the normal distribution, although many other distributions are also possible. The signal is added as a constant to this noise and thus yields the second distribution shown to the right in Figure 9A. It is now assumed that the subject (or the system) establishes a cut-off point such that everything that is above this point (or criterion) is considered a "signal", while everything below it is considered a "no-signal" or merely noise. It is obvious, that the lower (the More to the left) the auto point is, the larger will the number of "signal"-answers be, and consequently also the number of correctly reported "signals"; but it will also be the case, that the number of correctly identified "no-signals" will decrease, since many "no-signal" conditions will mistakenly be identified as "signals". A similar argument can be developed for an increase in the cut-off point, i.e., that the cut-off line in Figure 9A moves to the right. It is evident, therefore, that there must be a auto f point for the subject which is optimal as regards the ratio of "signals" to "no-signals".

The relation between the inverse-U hypothesis and the signal detection theory is based on the assumption that the cut-off, point moves to the left, i.e., is lowered, when the person is stressed (when the system is in a higher state of arousal). This may be explained in the following way (adapted from Welford, 1974, where a more thorough treatment may be found). To say that the auto f point moves to the left is, of course, identical to say that the two curves move to the right, since we are only talking of the cut-off point in relation to the curves. One condition, which could cause these two curves to move to the right, is, however, an increased level of activity and thence readiness to fire in the cells of the brain. A lowered threshold for activation in the cells of the brain will increase the frequency of both the noise and the signal, leaving the standard deviation of the distributions as well as the distance between their mean roughly unchanged. That would have as a consequence that more signals" would be reported as "signals", but also that more "no-signals" would be reported as "signals". In the extreme anything would be reported as a "signal", making the probability of a correct response identical to the frequency of "signals".

Conversely, in situations of reduced arousal the cells of the brain become less ready to fire (the threshold is increased, which, repeating the line of argument given above, would correspond to moving the cut-off point to the right in relation to the curves. More no-signals" would be reported as no-signals", but so would also the majority of `signals". In the extreme no "signals" will be reported correctly but all "no-signals" will, making the probability of correct response of a "no-signal" identical to the frequency of "no-signals". This might possibly result in the curve shown in Figure 9B, where the objective signal frequency is assumed to be 50%. It is this resulting curve, which is similar to the inverted-U curve, and this has made the connection between the two theories.

This is thus an example of a consistent description of a common phenomenon and, given the correctness of the signal detection theory, also an explanation of it. The question of whether performance is identical in conditions of low and high arousal can now be answered. Clearly, the efficiency of the performance may be the same (in the example corresponding to 50% correct response), but the performance is qualitatively different. In conditions of too low arousal the operator will tend to ignore signals", i.e., to report "signal conditions as no-signal" conditions, while in the conditions of too high arousal he may tend to report "no-signals" as signals". In both cases his performance will be inadequate and the effectiveness of his information gathering will be reduced. Whether one should prefer the one type of error to the other is a different question. From the point of view of the machine it is probably preferable that the operator reacts falsely to "no-signal" conditions rather than to "signal" conditions, since it is easier for the machine to disregard operator activity than to substitute it.

12.3 The effector-receptor span

In simple machines or mechanisms, and in simple psychological theories, there is a direct relation between the stimulus (the information) and the response (the activation, namely that the response is a direct consequence of the preceding stimulus. In more advanced machines, and in more advanced psychological theories (such as represented by the cognitive viewpoint), this simple relation is no longer present. This is quite appropriate, since human behaviour itself usually is more complex than the simple theories seem to assume.

Take, for example, the relatively simple human activity of reading a text aloud. Initially this reading aloud may proceed word by word, but as the level of proficiency increases, we read a number of words ahead of the words we speak; this difference between what we speak (the effector) and what we read (the receptor) is generally known as the effector-receptor span. In the extreme case we may even speak words which we have not seen, as, e.g., when we reach the bottom of a page but continues the sentence before turning the page. The effector-receptor span is more generally an expression of the fact that human behaviour is based on anticipation – on guessing the future from the past. The similarity between this formulation and the concept of an internal model as in the cognitive view-point should be obvious.

The example of reading aloud mentioned above is just one instantiation of the general experience that the effector-receptor span can be increased by training. Using the terminology that was introduced earlier we may say, that it is the same as enlarging a step, and thus also as reducing the number of steps in a plan. From the observation of some of the information presented by the system the operator may anticipate a specific change or development, and act according to this anticipation even though the information signalling it has not yet appeared, cf. Rasmussen, 1974. The danger, of course, is that this particular information may never appear, because the anticipations of the operator were incorrect. Even though the effector-receptor span is beneficial to routine performance, it may be stretched to an extent where the benefits disappear. If one compares the three types of performance called target controlled, goal controlled and procedure controlled (cf. Rasmussen, 1979), one will find that the effector-receptor span is largest in target controlled performance, smaller in goal controlled, and smallest in procedure controlled performance. In the target controlled situation a specific pattern of information triggers a familiar plan; in procedure-controlled performance, the operator has to follow a procedure (available as a plan) step by step, with continuous evaluation of the performance after each step.

There have been several different studies of the effector-receptor span and the way it could be developed (cf. Bartlett, 1951; Easterbrook, 1959) but there is a scarcity of information concerning the influence of stress on this span. If we disregard the effect of interruptions, which may prevent almost any kind of integrated performance, it seems reasonable to assume, that the effector-receptor span in the execution of a specific step will not be reduced by stress. This assumption is based on the definition of a step as that unit of activity, which can be performed automatically without demanding attention, and on the assumption used earlier that the influence of stress would be restricted to the conscious cognitive functions and not affect the unconscious functioning. As a consequence of this, studies of the effector-receptor span may throw light on the way in which a person gathers and uses information in general, but will be of minor significance regarding the relation between stress and the gathering of information.

13. THE PROCESSING OF INFORMATION

The first condition necessary for a satisfactory performance was that the operator was able to form an appropriate plan, either by creating it or by retrieving it. The second condition was that he was able to execute the plan, which among other things depended upon how frequently he was interrupted and how well he could keep his attention focussed on the execution of the task. The third condition was that he was able to gather the information necessary for the execution of the task, e.g., that he was not restricted by information overload, excessive arousal, etc. The fourth condition is, that the operator is able to process the information properly.

The processing of information is, of course, something that may be considered to be a part of all that has been mentioned until now. The formation of plans requires processing of information, and so does the execution of plans; the gathering of information is also in many ways processing of information, as, e.g., in the categorisation of information. The meaning of processing of information as the fourth condition is therefore the specific processing of information which is demanded by the execution of a particular plan. It is thus what the execution of the plan does to the information gathered, rather than how the plan was (or could be) executed, which was included under the second condition.

Some of the factors, which have been mentioned in the preceding, do, of course, also influence this specific processing of information. It is obvious that the processing is influenced by interruptions, by information overload, and by the fluctuations in attention. There is, however, a further factor, which is generally considered to be of overwhelming importance for information processing as such: the ability to keep several things in mind simultaneously. One characteristic description of this is the following.

> "The solving of a complex problem in, say, scientific research involves novel combinations of ideas, that is the bringing together of various items of evidence into a unitary pattern of unaccustomed relationships. Now this coherent pattern may comprise a large number of component relationships which must, so to speak, all be brought to mind together and at nearly the same time. Such holding together of components – comprehending – requires the collective recalling of the components. In other words, the activity of comprehending may well be united by short-term memory."
> (Hunter, 1964, p. 651).

13.1 Sequential and parallel information processing.

The suggestion by Hunter, that the activity of comprehension may be limited by the capacity of short-term memory, is commonly regarded as an established fact. Although the hypotheses concerning why the STM-capacity is limited are extremely vague, it is an empirical fact that the capacity is limited, and that the limit is somewhere around the "magical" number seven (Miller, 1956) – even though there is some confusion of what the number seven actually refers to (e.g., Baddeley, 1976; Simon, 1974). This limitation is, however, one which is specifically connected with the processing of several components (or items, chunks, ideas, etc.) at the same time, i.e., the various components have to be processed in parallel rather than in sequence, when man is considered as an information processing system a distinction is generally made between the conscious part of the information processing system and the unconscious part. The unconscious part which performs the primary processing of information, e.g., in the perceptual system, and which characteristically functions in an associative way, is assumed to be working in parallel, i.e., that there is a number of unconscious information processing systems which all work simultaneously, e.g., on the various inputs which reach the organism (cf. Anderson, 1975 or Neisser, 1963 for a further description. In contrast to this the conscious information processing system is assumed to work sequentially, executing one plan at a time or following a single train of though. The unconscious or subordinate information processing system (or systems) seems to be a parallel associative mechanism that is capable of doing more than one thing at a time, while the conscious or superordinate information processing system seems to be single and serial, to operate by willing rather than automatically, and able to do only one thing at a time.

Even though the conscious information processing system works in a sequential way, i.e., that it is unable to execute more than one plan at a time, this may nevertheless involve the simultaneous processing of two or more components (chunks, etc.). In this way the components are processed in parallel rather than sequentially, even though it takes place during the sequential execution of a plan. Strictly considered any kind of information processing probably involves two or more components; this, e.g., is the case for comparisons, arithmetic manipulations, and logic manipulations, all of which are among the basic types of information processing. The simultaneous processing of components does, however, not present a problem at this basic level; the problem arises only when the number of components to be processed reaches the empirically established limit. And the reason for this seems to be in the accessibility of the components, rather than in their absolute number.

13.2 STM-capacity and accessibility

By the accessibility of the components is meant that they may easily be accessed whenever they are needed during the execution of the plan. The most important aspect of accessibility is probably the time needed to access or retrieve a component, i.e., whether it is immediately accessible or not. The human memory is able to store an enormous amount of information and, of course, also able to retrieve it most of the time. This retrieval or access is, however, something which normally takes a certain time – at least several seconds, often some minutes, and possibly even hours. The retrieval generally seems to work by ways of association, which may be triggered either by the current situation and context or by a deliberate attempt to search in memory. Thus the accessibility of a component may vary from situation to situation.[7]

It is, however, not all information used in processing which is stored in human memory (LTM). In many cases the information is needed only for a short time during the execution of a plan or until a certain action has been carried out; the information may only be of temporary value and possibly also difficult to remember, so that it is convenient to store it temporarily rather than permanently. Examples of such information are phone numbers, intermediate results in calculations or data manipulations, changing limits (for alarms or thresholds), upcoming events, etc. The recognition of the need of keeping such information accessible without having to store it in LTM may be seen in, e.g., Posner's (1967) concept of an Operating Memory where information is processed, in addition to the normal Short-Term Memory where information is kept; and in Craik & Lockhart's (1972) distinction between Type 1 processing which is the temporary retention of information, and Type II processing which aims at transferring information from STM to LTM. The Type II processing thus involves a deeper analysis of the information while the Type I processing may be the mere repetition of it.

This repetition is in fact an important phenomenon, both for the explanation of the nature of STM and for the understanding of how stress may influence information processing (as the term is used here). The repetition or rehearsal of information is the method by which STM functions; STM is thus not a memory in the sense of a storage place where one can put something to fetch it later. STM is rather a denomination of the phenomenon that information is accessible because it is continuously processed; this processing may have a purpose of its own, or it may be the repetition or rehearsal which only serves to keep the information available or "alive". This continuous repetition is necessary because the information decays and becomes inaccessible in about 20 seconds, if processing of some kind does not refresh it. The STM capacity limit is therefore one of processing capacity rather than of channel capacity (cf. Craik & Lockhart, 1972; Moray, 1967).

The information needed for the execution of a plan may therefore be accessible either because it is kept in STM by means of processing, or because it is immediately available from LTM due to its close association with the current situational features; this suggests by the way, that the capacity limit is not exclusively that of STM but rather a combination of the two kinds of accessibility mentioned above. The accessibility due to LTM-availability is, however, restricted to information, which is permanently represented, and can therefore not be used to keep information, which is ad hoc to the situation. The limitation due to STM capacity is accordingly very important and puts a severe restriction to the amount of information which can be temporarily retained and accessed in parallel.

In the discussion of the execution of plans the importance of interruptions was pointed out, and it was argued that interruptions could have a progressively disruptive effect on the execution. This, of course, also holds for the information processing mentioned here. One may imagine a normal situation, where the person is executing a plan and as a part of this doing information processing (problem solving, deliberating, judging, deciding, comparing, etc.). This information processing requires

(1) that he has a plan (or a subplan or a procedure) for the steps of processing;

(2) that this plan is not disturbed by external interruptions;

(3) that the STM-capacity is not exceeded, i.e., that the number of components to be retained is below the empirical limit (say, seven; and

(4) that the execution of the plan allows for the internal interruptions necessary for refreshing STM, specifically that none of the steps in the plan takes longer time to execute than the time of decay in STM, since that would effectively prevent further processing.

If the situation is not normal, but rather one of stress, it is easy to see how this could influence the four conditions for processing mentioned here; condition (1) and (2) as discussed earlier, condition (3) by introducing information overload, and condition (4) by preventing the automatic refreshing (repetition or rehearsal) necessary for keeping the information accessible. It is in fact unnecessary to assume that the STM-capacity is reduced under stress, in the sense that the number of chunks or components available becomes smaller; it is quite sufficient to assume that the smooth, automatic interaction between processing proper and refreshing is disturbed. Because of this the person may vividly experience that he is unable to remember the necessary information long enough to use it and this may evidently in itself increase the level of stress in the situation.

To summarise, the influence of stress on information processing Cm the restricted sense used here) may be described satisfactorily by the way in which interruptions of the execution of a plan degrades performance. Since the possibility of processing information as required by the plan is dependent upon the amount of information which can be accessed in parallel, and since this is again dependent upon the smooth and uninterrupted interaction of more basic cognitive processes, then the ability to withstand interruptions or to counteract them is again shown to be very important.

14. STRESS AND PERFORMANCE

In the preceding sections an attempt has been made to describe systematically the various ways in which cognitive capacity, and through that performance, could be influenced by stress. Nothing has been said of the way in which the labelling of the stressing situation, i.e., the identification of it as being caused by a specific emotion, has any influence on cognitive capacity and performance. The reason for this is not that such an influence is completely lacking, but rather that this is of a qualitatively different nature and that the effect of it on information processing is considerably less than the effect of, e.g., interruptions. We shall return to the possible effect of the labelling of situations in a following section, but shall before then try to present an integrated view of the relation between stress and performance based on the points taken up in the preceding.

In the discussion of the four conditions, which were necessary for a satisfactory performance, several factors were mentioned. Of these the following five may be considered to be the most important:

(1) The interruptions. These interruptions of the ongoing behaviour had a positive function in alerting the person and thus providing the possibility for adapting to a changing environment, but could also be detrimental if they became so frequent that they prevented normal performance.

(2) The physiological arousal. Arousal, stress, and – to a certain extent – emotion, are closely related phenomena, which may be difficult to separate in terms of cause and effect. The relation between arousal and performance is frequently described by the inverse-U curve as being either beneficial or detrimental, depending on circumstances.

(3) The cognitive capacity. This is a comprehensive concept which includes STM-capacity, general accessibility of information, attention control, span of attention, etc.

(4) The search for plans. This activity was essential for coping with the unexpected situations, as, e.g., interruptions, but was also an important for the performance under normal circumstances.

(5) The execution of plans. This may seem to be the same as what it meant by performance. There is, however, a significant difference since performance refers to the overall activity of the operator, e.g., his success in handling a specific disturbance or bringing the system to a specific state. The execution of a plan is only a part of this, directly or indirectly being influenced by the other factors and itself influencing them. Some of the plans, which are executed, may be for the sake of stabilising the performance system rather than for the sake of the goal.

Together these five factors make up the system on which performance is based. This system is controlled by a number of negative and positive feedback loops, and the overall purpose of this system may be assumed to be to produce performance (to obtain a specified goal) at a steady level, in spite of possible external influences on the system. It may thus be described as a homeostatic system, in analogy with the many other types of homeostatic systems, which characterise biological organisms in general, and humans in particular. The system is, however, not something, which one may expect to be able to identify empirically as a separate entity, but is rather a consistent system, which may be used to describe and explain a number of phenomena, connected with human performance, and in particular how a person may react to stress.

15. A HOMEOSTATIC PERFORMANCE SYSTEM

Perhaps the simplest and most straightforward way to describe the details of this homeostatic performance system, as it will be called in the following, is to consider the five variables in combinations to see how their mutual influence is, and conclude this by a schematic representation which contains all the significant relationships. In order to keep the description to a manageable level only binary combinations will be considered although both their direct and indirect relations will be examined.

15.1 Interruption

The first factor under consideration is interruption. There is obviously a relation between arousal and interruption in several respects. First of all an increased level of arousal (and hence readiness for activation) will facilitate interruptions; there is thus a direct influence from level of arousal to susceptibility to interruptions. In addition to that, a sufficiently high level of arousal may itself lead to an interruption of performance. There is also an indirect relation between interruptions and level of arousal, in that the level of arousal may increase as a result of interruptions; this influence is, however, indirect, since it takes place through the effect of interruptions on the execution of plans. Both the direct and the indirect relation is positive or synergetic, i.e., an increase in one variable corresponds to an increase in the other, while a decrease in one corresponds to a decrease in the other.

The relation between interruption and the search for plans is also straightforward; in a previous section it has been discussed how interruptions may lead to a search for alternative plans. This relation is, of course, synergetic. There is no corresponding relation between the search for plans and interruptions.

The relation between interruptions and the execution of plans is direct, but negative or antagonistic, i.e., that an increase of interruptions reduces the possibilities for executing a plan, while a decrease of interruptions facilitates the execution; this has previously been described in some detail. The corresponding relation between execution of plans and interruptions is indirect and antagonistic; a successful execution of a plan may reduce the level of arousal and thereby also the susceptibility to interruptions.

The final relation is between interruption and cognitive capacity; this relation is direct and antagonistic, since interruptions may have a negative influence on many of the components of cognitive capacity such as STM-capacity (accessibility of components), attention control, etc. There is no corresponding relation between cognitive capacity and interruptions

15.2 Arousal

The second factor to be considered is arousal, the physiological level of activity and readiness. There is first of all a direct relation between arousal and cognitive capacity. This relation is, however, neither simply synergetic nor simply antagonistic, but rather a mixture of both, traditionally being described by the inverse-U curve. Thus at low levels of activation an increase in arousal may increase the cognitive capacity, e.g., by making the person more alert to signals from without. But if the level of activation is normal (i.e., optimal), a further increase in arousal will be detrimental to cognitive capacity, as described previously. The definition of where the "normal" level lies is fairly easy to determine empirically, since it can be defined operationally from the performance; it is on the other hand almost impossible to define theoretically, since it will depend upon situational as well as individual characteristics.

There is another important relation, the one between the execution of plans and arousal. This relation is direct and antagonistic, because a successful execution of a plan may lead to a reduction in the level of arousal. This is actually the way in which the person can restore control in a stressing situation – at least according to the model presented here. The opposite relation between arousal and the execution of plans is indirect, via cognitive capacity. This indirect relation is, of course, also best described by the inverse-U curve, similar to the relation between arousal and cognitive capacity.

15.3 Cognitive capacity

The third factor, cognitive capacity, has a direct relation to the execution of plans. This relation is synergetic since a reduction in cognitive capacity necessarily will diminish the control of the execution of the plan. The opposite relation between performance and cognitive capacity is indirect, being mediated by arousal

There is also a direct relation between cognitive capacity and the search for plans, and this again is synergetic. This is especially important in the case of creation of plans, since this obviously is a cognitive activity, which puts a considerable load on the information processing system. It may, however, also have some bearing on the retrieval of plans since the retrieved plans have to be evaluated in some way before they are executed (cf. the following section on selection of plans

15.4 The search for plans

In addition to the influences from interruption and from cognitive capacity on the search for plans mentioned until now, the search for plans does itself exert an influence. If the search is successful it will lead to the execution of a plan, and that may again influence the level of arousal. The relation between the search and the execution is thus synergetic. If the search is unsuccessful, the level of arousal will increase since the beneficial influence from the execution of a plan is lacking, and since the person may become stressed through the experience of not knowing what to do. This could be described as a direct, antagonistic relation between search and arousal, but it is probably more correct to describe it as an indirect relation, mediated through the execution of the plan (or rather, the lack of execution of a plan.

15.5 The execution of plans

Since this is the last variable, the possible relations between this and the other variables have already been described. Concerning the details in the important relation between the execution of a plan and the level of arousal, they may be found in the previous section on the formation of plans.

The system put together. Having described the details of the system, these descriptions may conveniently be put together by means of a figure such as shown in Figure 10. It contains the five variables and their direct relations, i.e., relations connecting two variables. The indirect relations mentioned in the preceding are those, which connect two variables via an intermediate, third, variable. Also shown are the type of the relations, whether they are synergetic or antagonistic; an exception from this is the relation between arousal and cognitive capacity which is of the type described by the inverse-U curve

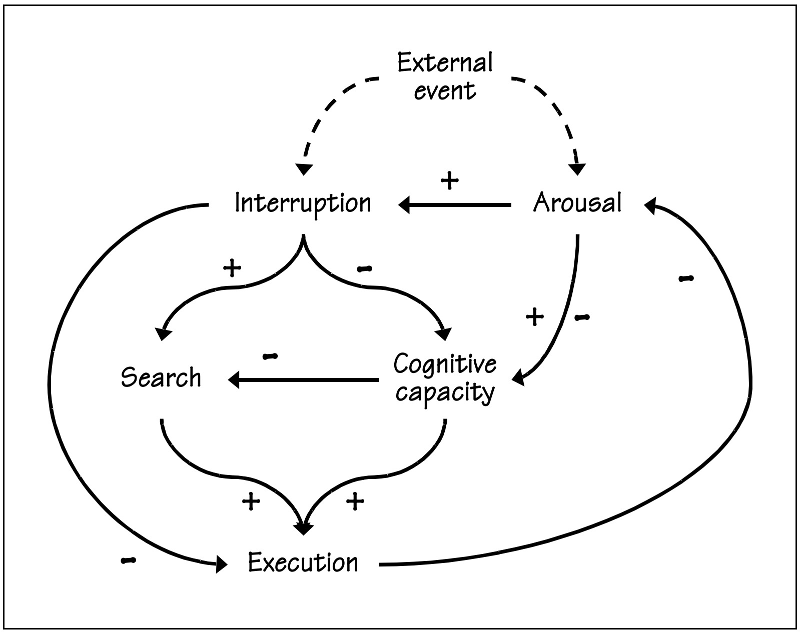

Figure 10: Homeostatic performance system

In addition to the five variables a sixth element, called an external event, has been introduced. The reason for this is obvious: since the system is homeostatic, it will tend to keep a steady level if not influenced from outside, i.e., the performance of the system will either be constant or vary within narrow limits. This equilibrium may, however, be disturbed through signals from the environment; this could, e.g., be alarm indications in a process control room. When such signals occur they will cause a change in the performance of the system, and the system will react in such a way that the performance is restored to its normal level. This homeostatic performance system thus describes the way in which the reactions or responses of the operator may be described in a consistent way (and perhaps even explained) The performance is not the specific performance of the operator vis-à-vis the system, i.e., the task which he is supposed to accomplish, but rather his general activity as a cognitive system. It is thus part of a model of the operator, which can be used to analyse his performance in a specific situation, as well as to ad the design of his working environment. One important consequence of this model is that an increased level of arousal/stress can only be compensated through the execution of an adequate activity. Accordingly the machine part of the system should try to assist the operator in this, i.e., it should require him to carry out a specific assignment rather than just present him with further alternatives. One advantage of the machine in comparison with the operator is, that the machine is less likely to become confused as the situation gets more stressing.

16. THE SELECTION OF PLANS

One aspect, which has only been mentioned briefly, is the way in which a person decides to execute one plan rather than another. It is well-known that different person may choose to do the same thing in the same situation, but also that the same person may choose to do different things in presumably identical situations. Situations are, however, never perfectly identical, and the assumption is that one might be able to identify those differences between two situations which makes the person behave differently.

This assumption is easily recognisable as an assumption of causality: the person selects plan A rather than plan B, because of some unknown factor X. The specific behaviour of the person is therefore caused by the presence of X. Or, referring to the discussion of causality in the beginning of this paper, one may consistently describe the behaviour of the person as if it was caused by X. The major problem is, however, in encircling the possible causal factors in the first place. Various psychological theories present different alternatives, ranging from the internal and unconscious factors in psychodynamic theory, to the external (but possibly also unconscious) factors in the various learning theories. The following will present the point of view consistent with the cognitive paradigm used here.

16.1 Subjective versus objective factors

One aspect of the causal factors is whether they are predominantly subjective or predominantly objective, i.e., whether they are determined mainly by something which is within the person, or by something which is in the environment. According to the cognitive viewpoint the factors are of a subjective nature, since it is on the person’s model of the world, rattier than on the world per se (if such a thing is possible), that his behaviour is based. That the factors are of a subjective nature does, however, not mean that they are completely isolated from the environment of the person, but rather that it is the way in which he perceives or conceptualises events in the environment which determine how he responds. A case in point is the Schachter & Singer experiments described previously, which clearly demonstrated that the person’s own attribution of the causes for his behaviour might completely miss the target.

These experiments did, however, also demonstrate that it is possible to manipulate the person's conceptualisation of the environment and its causal structure. In this case the purpose was to deceive the subjects, but in other cases it may be to help him instead. The field of problem solving can provide a large number of examples of how the way in which the information is presented may facilitate the appearance of the solution (e.g., Adams, 1974). It also tells us, that this kind of manipulating the presentation of information may have a much larger effect than that of instructing the subject to think in a particular way or to use a specific method. Many people (including myself), do in fact know quite well how one ought to solve a problem, but may nevertheless repeat the same mistakes time after time if the circumstances are right (or wrong?). The way in which we perceive our environment is largely an automatic process, hence unconscious, determined but not caused by environmental, objective factors (cues), as well as internal, subjective factors.

16.2 The labelling of emotions

One way in which the environmental factors may play a role is in the way in which the person labels some situations as being emotional and some as not. It has already been stated that emotions do not exist per se in the cognitive viewpoint, but only as a convenient way of describing certain affective processes or physiological states. In an overview of emotions as a psychological phenomenon Mandler (1962) concluded that:

> "It appears that the prevalent notion that emotions are highly specific mental events, that they are *sui generis*, is not only typical of common-sense descriptions, but may also have ensnared the psychologist of emotion. Emotion is less a mental act than a chapter heading which summarises many different aspects of behaviour collected under the name emotional behaviour. The particular combination of environmental events, physiological response, and prior experience that determines emotional behaviour is often specific to that behaviour, but it is unlikely that any special laws will have to be invoked for a particular "emotional" explanation. At the same time it is too early to specify the laws that operate within the confines of emotional behaviour. The major laws governing behaviour – and thus emotional behaviour – are still to be pronounced to the satisfaction of most psychologists. But the layman will be disappointed if he expects to find any special emotional "things" in those laws."
> (Mandler, 1962, p. 338).

(One might add, that the psychologist will be equally disappointed, since the concept of emotions as something *sui generis* is still very much alive, e.g., Persson & Sjöberg, 1978.)

Emotions, as conceptualised states rather than as separate processes or phenomena, do, however, have a significant influence on the person's behaviour since they may determine how he perceives information, which type of information he will try to pick up, which criteria he will consider important in his decision-making, as well as his general conception of the causal structure of the environment. Some persons will remain calm where others are caught by fear or even panic, and that will, of course, have a considerable effect on their behaviour.

In particular the labelling of a specific situation as being a specific emotion may be very important for the plans, which are selected by the person. The labelling of an emotion is a part of that general phenomenon which one may call the identification of a situation. Under normal circumstances a person will known in which situation he is, e.g., by being able to describe it to another person. The identification of a particular situation as being situation X rather than situation Y does nevertheless imply a lot of things, in particular which criteria are important and which are not. An operator may, e.g., consider the aspect of time as more important than the aspect of economy and select a plan that is fast but expensive to implement; the reasons for this may be that he is in a dangerous (e.g., radioactive) environment, or that he wants to go home because he is tired. In terms of emotions he may label the situation as stressing and try to get away from it as soon as possible, or he may label it as exciting and try to solve the problem as elegantly as possible.

It is probably impossible to overestimate the significance of the person's choice of a plan (or a strategy), since his way of attacking the situation may completely determine the results. It is therefore ironical that the major part of our knowledge concerns the strategies which may be employed, rather than the way in which they are selected; the prime example of this is the psychology of problem-solving which efficiently analyses and explains strategies but rarely mentions how these strategies are chosen (e.g., Wickelgren, 1974).

16.3 A model for selection

Even though it is difficult to be very specific about the process of selecting a plan, one may nevertheless make some suggestions concerning the types of factors, which can play a role. Obviously some of the criteria will be situational criteria since they are directly dictated by the situation; although the cognitive viewpoint emphasises the importance of the person's internal model of the environment, this model does nevertheless reflect the distinguishing characteristics of the environment. If a signal indicates that a danger is imminent, a time pressure is practically unavoidable; if the process is a complicated one (e.g., a power station), the criterion of economy of performance is likely to be prominent, etc. It may thus be assumed that there are certain criteria which are determined by the situation as such and which are perceived in a similar way by all persons, independent of personal differences.

It follows that there should also be certain criteria which are determined by the individual characteristics of the person rather than by the situation. Such criteria may be named personal preferences or attitudes. By habit, by training, or by personality a person will consider some criteria as more important than others, e.g., meticulousness rather than speed; or he may be inclined to use one type of methodology rather than another, e.g., be a cognitive leveller" rather than a "sharpener". This may hold as well for the plan itself, i.e., what type it is and the way in which it is executed, as for the way in which is selected, cf. the many different decision-rules, which can be described (e.g., Montgomery & Svenson, 1976).

A third category of criteria is those that are determined by the situation as well as by the characteristics of the person. An example of this is the differences, which stem from the variations in personal experience with a specific type of situation; thus a well-trained operator may behave differently from a novice even though they may agree in their description of the situation. Each person will have a certain degree of knowledge and experience which is pertinent in the situation, e.g., the plans which can be retrieved, and which will determine the way in which he responds depending upon the way in which he perceives the situation; this may be called personal experience. The personal experience thus plays a double role in providing criteria to be used in the selection of plans, as well as a large part of that set of alternatives among which the selection must be made.

The result of applying these criteria will be the selection of a specific plan. Rather than trying to enumerate examples of different plans, one can describe them as belonging to one of three types called target controlled, rule controlled, and goal controlled (Rasmussen, 1979) referring to whether they are predefined automatic responses, controlled by relations between identified states of the system a.k.a. rules, or guided by causal reasoning as, e.g., heuristic problem solving strategies.

Combined with the three types of criteria mentioned, this may result in a model for the selection of plans as shown in Figure 11. This model describes the selection from the time where the situation has been perceived and identified to the time where a plan has been selected. It is thus a development of the element called "search" in Figure 10.

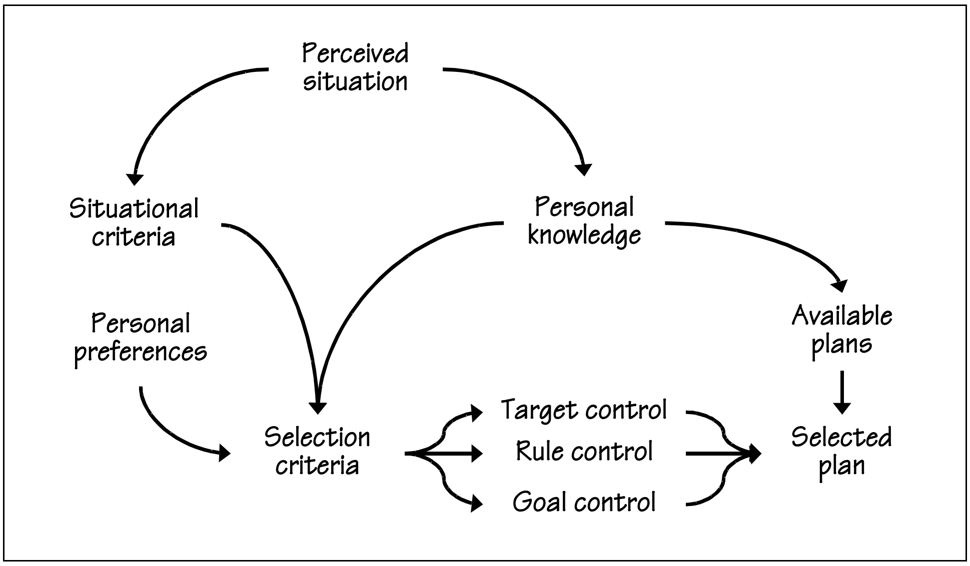

Figure 11: A model for selection of plans

It should perhaps be mentioned that this process of selecting a plan need not be conscious to the person. This is, e.g., the case with plans, which are target controlled. The selection of such plans is based upon the fast (and perhaps even premature) identification of the situation as being a familiar one, and the following activation of a well-known response or plan. This whole sequence may be automatic and unconscious, as when a person stops his car when the traffic light changes, without realising that the change was from yellow to green. Even in the case where the selection itself is conscious, as in the case of a goal controlled plan, some of the previous steps may be unconscious. The influence of personal preferences, for example, is normally not something of which the person is conscious unless he is specifically asked to consider it.

The model presented here is rather simple, and should only be considered as a first step towards a more detailed description of how a person comes to select one plan rather than another. If the assumptions on which the model is based are correct one may nevertheless draw some conclusions from it. Concerning the shaping of the selection criteria themselves, this may best be accomplished through the situational criteria, i.e., through the information, which is presented and available to the person. The personal preferences are not something, which are easily changed, as we know from the psychology of attitudes and attitude change. They are thus not of any direct importance, although one may indirectly compensate for them in the way the presented information is structured – provided, of course, that they are known to the system. The personal knowledge is in the same way something, which it is difficult to change. Knowledge and experiences can be changed, but this change takes time. The personal knowledge is to a certain extent shaped through the training given in preparation for a job, but even this shaping is less controlled than one might ideally wish. This is both because there is insufficient knowledge as to how a training program should be constructed in order to provide the proper knowledge structures (and even insufficient knowledge of what the proper knowledge structures are), and because the same training program may have different effects on different persons.

This leaves the situational criteria that, by definition, were determined by the situation and independent of personal differences. By presenting the information in an adequate way one may facilitate a particular conceptualisation of the situation, and thereby also a particular range of criteria; this is in agreement with the experience from problem-solving situations mentioned before. Such an adaptive way of presenting the information does, however, require, that the presenting system is able to behave intelligently. The minimal requirement is probably that the system itself contains a model of the person who is to receive the information, and possibly also that the system is self-referent (cf. Hollnagel 1978b for a further discussion of this aspect).

Another conclusion which may be drawn from this model for the selection of plans, concerns the plans which are available to the person. In the model the availability is dependent upon the personal knowledge as well as on the way the situation is perceived. In addition to this one may separately present the person with alternative plans, since the plans, which are available to him through his personal knowledge necessarily, will be only a subset of the larger number of plans, which might be applied in the situation. It is important that such a menu of alternative plans is presented to the person rather than just made available to him. They could, e.g., be available in a manual of operating instructions, but this would probably not be of any advantage, not even in a normal, undisturbed situation; the large number of possible instructions in even a moderately complicated system would indeed make the problem of unaided retrieval formidable. If, on the other hand, the alternatives were presented to the person in a way, which took the present situation into consideration, i.e., without increasing the level of stress that he might experience, that could be a genuine help to him. This would, of course, require that the system, which generated the alternatives and presented them knew, i.e., had a model of, how the person conceived the present situation. This thus reinforces the importance of letting the system be as intelligent and as flexible as possible. The problem of compensating for the influence of stress (and emotions) in a man-machine system should not be made by having the person adapt to the requirements deriving from the nature of the process and the machine, but rather by having the machine adapt itself to the known limitations of operator. The ingenuity of man should be used to make work easier for him, and not for the machines.

17. SUMMARY

The starting point for this paper was the wish to provide an analysis and a description of the way in which emotions may influence performance. The situation which has specifically been in mind, has been the work of the process control operator This may be viewed as a rather unique activity which takes place under rather unique circumstances; even so the emphasis has not been laid on the distinguishing features of this work, but rather on the general characteristics of it, the elements which this kind of work shares with other kinds of work.

The framework for the analysis was the cognitive viewpoint, which is an expansion of the traditional information processing psychology to include a more active person who not only processes the information which reaches him, but who also actively seeks and selects information in the environment. The person is constantly seeking actively to organise the various kinds of information – from the environment, from his experience and knowledge, and from his expectations – into a coherent and consistent pattern. This means that his experience of any phenomenon, including emotions, is based on a far from simple interaction of various processes, and probably no experience is the simple result of a specific stimulus which has forced itself on the organism. One consequence of this is that an uncritical use of the concept of causality should be avoided.

In order to analyse emotion as a psychological concept, a brief review of the traditional theories of emotion was given. The most important: theory has been the James-Lange theory which held that emotions or feelings were produced by our physiological reactions rather than being the cause for them. This theory was, however, inadequate because it assumed that for each emotional reaction (each type of emotion) there should be a specific pattern of physiological activation. It is nevertheless significant that this almost 100-year-old theory clearly rejected the traditional idea of emotions as a priori given phenomena, but rather stressed the mediated nature of emotions.

The modern, cognitive view of emotions was largely the result of a series of investigations begun in the early 1960s (although a similar experiment is known to have taken place already in 1924). These investigations clearly demonstrated that emotion – or rather: the identification of a particular experience as being a particular emotion – is a product of the physiological state, of the "known" (or rather believed) causes for the physiological state, and the way the situation is perceived and comprehended. Whether or not a specific experience is identified as being a particular emotion is something, which depends on several factors. Emotion is therefore not a. basic psychological phenomenon, which is *sui generis*, but may rather be described and explained in the same way that is used for other phenomena subsumed under cognitive psychology. This means that the apparent qualitative difference between emotion and cognition is an artefact, since emotion is a part of the way in which we cognise and recognise the situations we encounter. Instead of talking about emotions one should rather talk about affective processes, which can be interpreted in various ways depending on the circumstances. The affective processes would then be the basic physiological reactions of the person, which may influence as well as be influenced by his cognitions.

Instead of looking at the influence of emotion on performance, the focus was changed to consider the influence of affective processes on cognition; the discussion was further restricted to consider only that particular set of affective processes, which are known as stress (or stressors). By cognition was meant the conscious processing of information, which in whole or in part is the basis for human performance. This is consistent with the general view of human performance as planned, i.e., as being controlled by a hierarchy of plans. The influence of stress on cognition was discussed in relation to the conditions, which are necessary for a person to give a satisfactory performance.

The first condition is that the plan can be formed; aspects of this were how plans could be created or retrieved, and how various criteria for goal completion could play a role. The second condition was that the plan could be executed as intended; aspects discussed here was the effect of interruption and disruption, the fluctuation of attention, and the ways in which steps in a plan could be organised. The third condition was that the necessary information could be gathered; aspects hereof were the possible restriction of categories with information overload, the relationship between physiological arousal and performance described by the inverted-U curve, and the effector-receptor span. The fourth and final condition was that the information could be processed properly; the discussion here included the concepts of sequential and parallel information processing, and the relationship between short-term memory capacity, accessibility, and performance.

The general conclusion from this discussion was that the influence of stress on cognition and performance could be described satisfactorily by the way in which interruptions of the execution of a plan could degrade performance. The concept of interruption was also important in an explanation of how stress could occur, how it could increase, and how it could be neutralised. The various concepts and conclusions from the discussion were presented together in a hypothetical homeostatic performance system, which was able to provide a description of all the essential phenomena. The main elements in this system were

(1) the interruptions of ongoing activity,

(2) the physiological arousal,

(3) the cognitive capacity of the person,

(4) the search for plans or activities, and

(5) the execution of plans.

Together they made up a homeostatic system including both positive and negative feedback loops, which could account for the way in which a person performing a particular task could react to a disturbance. The system model pointed to the interruptions as a central factor, but did thereby also emphasise the importance of maintaining control (and thereby reducing stress) through the execution of an appropriate plan. This indicated that the machine part of a man-machine system may support the operator in stressed situations by providing him with a specific assignment to carry out.

The last part of the paper contained a discussion of how the selection of plans could be influenced by various factors in the situation. One particular factor was the “emotional” character of the situation, i.e., the possible recognition of the situation as corresponding to a particular emotion. The selection of a particular plan was considered to be determined by (1) situational criteria, (2) personal preferences, and (3) personal experience. of these the situational criteria were the easiest to control, which means that the best way to influence (and thereby partly direct) the way in which the operator selects a plan is through the way in which the information is presented to him, i.e., through the way in which he experiences the situation. This influence and control can, of course, only be partial, but seen in connection with the model of the homeostatic performance system it may suggest some ways in which the detrimental effect of stress on performance can be reduced.

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1 The theory of emotions has jokingly been referred to as "a whale among the fishes" (Meyer, 1933). The meaning of this is that the whale, when it is seen from a distance, appears to be the biggest of fish; but upon closer examination it turns out not to be a fish at all. Likewise the theory of emotion has traditionally been considered to be an important and necessary part of the set of psychological theories, i.e., the set of theories that is needed to provide an adequate explanation of human behaviour. The point taken by Meyer is that the theory of emotion may not be necessary at all, since emotions are "a humbug which has established itself within psychology during its infancy" (Meyer, 1933, p. 292).

This verdict of Meyer's may be too harsh, and it was certainly premature. It is, however, interesting to note that a substantial critique of the concept of emotions was presented as early as the 30s and 40s, although the impact of it was almost nil (Duffy, 1941a & b; Leeper, 1948). This critique was in many ways an anticipation of the critique from cognitive psychology, which came 30 years later.

2 The discussion of rationality is quite important for the whole field of man-machine system, since operators (and machines) are known to make mistakes, i.e., that some of the actions later turn out to be inadequate or inappropriate. Thus we speak of a human error in the case where a state of system malfunctioning can be attributed to a specific activity of the operator: that specific activity is therefore called erroneous. An activity of the operator is, however, seldom erroneous in itself, but only if certain conditions are present, e.g., that the machine is in a specific state (possibly as the alleged result of another "human error").

This is not to deny the empirical fact that humans often do things, which they ought not to have done, and which they probably would not have done if their comprehension of the situation had been different. It is, however, important to maintain that human behaviour is essential rational rather than irrational. It is not rational in any normative sense of the term, as we can find it in, e.g., theories of economic rationality. Nor is it rational in a purely descriptive sense of the tem, a sort of *post hoc* rationality which defines any activity as rational simply because it has occurred. It is rather rational in what one might call a cognitive sense of the term (cf. Hollnagel, 1977; Neisser, 1963) because it is planned rather than random, and because the person is able to explain afterwards why he planned the activity as he did. Accordingly the irrationality of human behaviour is a result of not being able to execute the activity as planned, possible because of the influence from affective processes or external disturbances; these aspects are treated in detail in the latter part of this paper. The basic assumption is, and indeed ought to be, that the operator tries to behave rationally in accordance with the way in which he has perceived and comprehended the situation. This underlines the importance of cognitive processes as in the cognitive viewpoint. And it furthermore implies that the only reasonable way to improve the quality of the operator's performance, or in other words to reduce the number of human errors, is to manipulate the factors which determine his conceptualisation of the situation, rather than to teach (or drill) him to work in a specific way. The latter is the Procrustean approach, which is certain to fail (Taylor & Garvey, 1959).

3 The use of the term "directly proportional", and later "inversely proportional", is, of course, not the same as the use in arithmetic, but is only intended as a convenient short description instead of the rather long verbal description which accompanies it in the text. Although the terms may be misleading, they are certainly much to be preferred for terms such as a "positive" respectively a "negative" influence. The two types of influence are, of course, positive and negative, but only in the specific way in which these terms are used in cybernetics to describe various kinds of feedback. Since this is often at odds with the common use of "positive" and "negative", I have tried to avoid a mixing of terms. Maruyama (1963) has suggested the term "deviation amplifying" to signify the positive feedback loop (in the cybernetic sense of the word), but even that is a terminology which carries unwanted technological connotations. From the point of view of a behavioural scientist it might be preferable to use the terms synergetic and antagonistic which, although borrowed from neurophysiology, are convenient terms, which have a specific meaning that precisely corresponds to the cybernetic concepts of positive, and negative feedback.

4 The terminology, which is commonly used to designate the different ways in which an activity can be carried out, and thereby also the various kinds of activity, is unfortunately often confusing. As suggested in the remarks leading to this note, one may talk about ballistic versus guided activity, or of goal controlled versus procedure-controlled activity. Rasmussen (1979) has suggested a tripartite terminology using the terms target controlled, rule controlled, and goal controlled behaviour ("operator's processes"). The categories of rule controlled and target controlled corresponds to what I have called procedure controlled in this context. The essential characteristic of this kind of activity is that it is highly automated so that the person can carry it out without having to focus his attention to it, i.e., without attending to it. That does not mean that he is not conscious of what he is doing, but rather that he is not conscious of the precise way in which he is doing it (on how he is doing it). In fact one may reasonably assume, that he will be unable to do it, if he attends to it; there are many things, which we have to direct our attention away from, so to speak, in order to be able to do it (e.g., tying a knot on a tie, opening a combination lock on a bicycle, etc.). The application of conscious control may

completely spoil the execution of an automated activity.

5 The investigations of the various effects of interrupted activities were mainly carried out in Lewin's laboratory in Berlin in the 1920s and have been described in detail in Lewin (1935). Some of the general effects were the tendency to resume and complete interrupted activities, called the Ovsiankina-effect, as well as the higher retention of interrupted than of uninterrupted or completed activities, a.k.a. the Zeigarnik-effect.

6 In relation to this it is interesting to note that the theories which have been suggested to explain such phenomena as mind-wandering and daydreaming (e.g., Antrobus, Singer, Goldstein & Fortgang, 1970; Singer, 1975) – which more technically are called "stimulus-independent thought" – employ the notion of a central cognitive processor or "operator", which is used to process both stimulus-dependent and stimulus-independent information. According to this view mind wandering is not something, which takes place in addition to, and independent of controlled thinking, but is a cognitive activity which itself puts a demand on the limited cognitive capacity. The theories do, however, not explain why mind-wandering or fluctuation of attention occurs, and we must therefore content ourselves by acknowledging it as an empirical fact.

7 The introduction of terms such as *accessibility* into the discussion of memory phenomena signifies an important change in cognitive psychology. Accessibility is not simply the speed of retrieval in the measurable sense, but rather a phenomenal quality. Even though the time for retrieval may be the same in two cases, there may be differences in the accessibility, i.e., in the person's experience of how easy or how difficult it was to remember or become aware of an item. It seems in particular that there is a difference between (1) information, which is immediately accessible, i.e. which is accessible without the experience of any effort or delay, and (2) information which is accessible with the experience of various degrees of effort or delay or difficulty of access. The first category of information may either be that of which a person is aware (that which is in his consciousness, or that of which he is conscious), or that of which he can become aware immediately and without any experience of effort (e.g., his own name or what he is hearing, seeing, etc. at the moment). Information held in short-term memory belongs to this first category; but so does other types of information, as mentioned in the text. Therefore the concept of accessibility enlarges the idea of cognitive capacity to involve more than just the (theoretical) notion of a short-term memory. Instead of relying on a theoretical entity (what Tolman would call a hypothetical intervening variable), it seeks its base in the person's phenomenal world, in his experience of what he does and of what happens. This need not lead (back) to a strict phenomenology, but it does secure a necessary link between the world of experience and the world of theories without which no sound scientific development can take place.