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# ON THE MECHANISM OF INSTRUMENTAL CONDITIONING

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## I

*Mr. Chairman, Ladies and Gentlemen,*

I would like to begin by saying how very great an honor and privilege it is for me to be invited to deliver an address at the International Congress of Psychology. Since my scientific training has not been in psychology, but only in neurophysiology, and in particular in brain physiology, and since in my own country nobody would ever dream of regarding me as a psychologist, I can only conclude from this invitation that the boundary between psychology and brain physiology is becoming more and more illusory. As a matter of fact, we are *all* concerned with the same task of striving to understand the behavior and mental processes of both animals and men, and the difference between various groups of investigators lies solely in the diversity of their experimental approach and in the problems which they are trying to solve.

And so, there is a big group of investigators who are chiefly concerned with the *experimental* analysis of behavior rather than the mental or physiological processes determining it; other investigators, at present perhaps not so very numerous, are mainly interested in describing and categorizing the *mental* processes underlying our behavior as thoroughly and precisely as possible, and lastly, there is still another group, to which I belong, which attempts to infer from various outward behavioral effects in animals, and also from mental events in human beings, those physiological processes in the brain which are responsible for them.

A major part of my investigations both in the past and at present has been and is devoted to problems of *motor* behavior in animals, that is that form of behavior which in experimental practice was labelled as either instrumental, or operant, or else as type II conditioned reflex. The experimental work dealing with this sort of behavior, originating from the classical Thorndikeian study undertaken at the turn of this century, may now be roughly divided into two categories. One, more numerous at present, makes use of instrumental responses as a *tool* with which to examine particular endowments of animals' brain activity, such as the perceptive and discriminatory ability for various modalities of stimuli, memory, motivation, and so on. In all these studies the instrumental response is an outward and rather convenient index of certain cerebral or mental processes which the investigator may be trying to explore. The other category

of research, which is now less numerous although the older Thorndikeian experiments already belonged to it, aims at the elucidation of the *mechanisms* themselves belonging to this type of responses by trying to understand their physiological organization.

This is the line of investigation in which I have been engaged for many years and which I started in collaboration with my close friend and colleague, Dr. Stefan Miller, who was murdered by Nazis exactly 20 years ago for no other reason than that he was a Jew. Let us all see to it that such wicked and inhuman crimes never happen again in our world. Perhaps this is also our professional duty because all of us, whether we call ourselves psychologists, or behaviorists, or brain physiologists, we are all concerned ultimately with the study of human nature, and obviously its improvement should be considered as one of our aims.

But the subject of my talk today is much more modest and will be concerned with the continuation of our work on type II conditioning by my present associates who have made considerable progress in disentangling those problems in which we were hitherto helpless, and who have contributed so much to the better understanding of the mechanisms of motor behavior. And so, my aim is to show you some recent experiments performed by them which throw some light on certain aspects of these mechanisms.

## II

We shall not deal today with the very interesting and obscure problem of the *formation* of instrumental conditioned reflexes but rather with another problem no less interesting and obscure, namely that of the *structure* of these reflexes when they are already established.

To make the following discussion less abstract I shall give you quickly some idea of the experimental *methods* commonly used in our laboratory, because most of the experimental evidence will be based on our results. Usually the experiments are performed on dogs in a sound-proof conditioned reflex chamber (fig. 1). The animal is placed on the Pavlovian stand, the experimenter being in a pre-chamber from which he operates the conditioned stimuli, puts into position the successive bowls of food located in the foodtray, and observes the animal's motor and salivary reactions being recorded on the kymograph. The instrumental conditioned response mostly used in our work with dogs consists of the flexion of the foreleg (fig. 2a), or of the hindleg (fig. 2b), in response to auditory, visual or tactile conditioned stimuli. This response is established either by passive movements of the leg or by some other methods not relevant in our present context. After a few experimental sessions, the dog is taught to perform

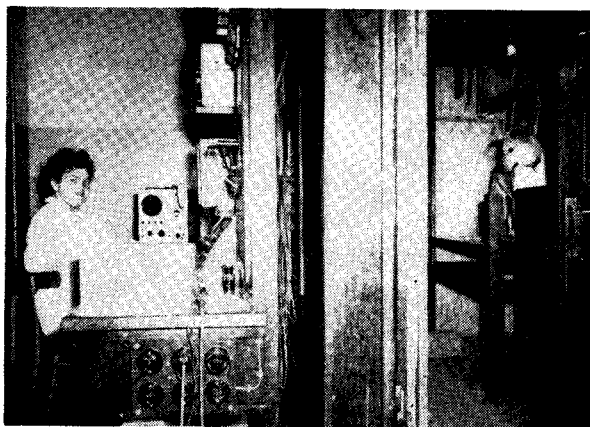


Fig. 1.

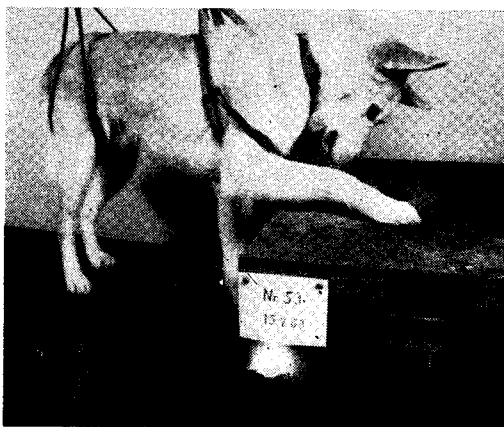


Fig. 2a.



Fig. 2b.

actively the movement of the given leg to various conditioned stimuli and does so quite regularly with a very short latent period. The presentation of food or the avoidance of a noxious stimulus, such as an electrical shock administered to the skin or an airpuff into the ear, etc., are used as reinforcing agents.

As is accepted by many students of animal behavior, the course of events in a well established instrumental conditioned reflex is roughly this (fig. 3). A conditioned stimulus (CS), represented either by an external

*First paradigm of Instrumental CR*

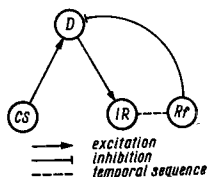


Fig. 3.

sporadic agent or by an experimental environment (for instance the Skinner box), after being associated with a definite unconditioned stimulus, starts to produce by way of conditioning a corresponding *drive* (D) (such as hunger, thirst, fear, etc.), which from the physiological point of view consists in the excitation of particular structures of the limbic system. This drive, in turn, elicits a definite instrumental conditioned response (IR), which had been established to the conditioned stimulus. The response is then followed either by the presentation of food (or any other positive unconditioned stimulus) or by omitting the noxious stimulus (Rf). The consummatory reaction in alimentary conditioned reflexes, that is feeding or drinking, or the cessation of the state of fear in defensive conditioned reflexes temporarily inhibits the corresponding drive; such an event is indispensable for the formation and preservation of the instrumental reflex.

For lack of time I shall not deal here with the evidence concerning the last link of this chain indicating that reinforcement does indeed inhibit the drive centre, but I shall concentrate for a while on the statement that excitation of the drive centre *intervenes* between the conditioned stimulus and the performance of the instrumental act. Here are some of the facts substantiating this view.

*First.* It is generally known that blocking the drive centre temporarily decreases or may eventually abolish the instrumental response. Thus, if we deal with alimentary reflexes, the more satiated the animal is the smaller and more delayed is the instrumental response to the conditioned stimulus, until it disappears completely. This also happens when the appetite is lost

because of indigestion, a state of fear, etc. Similarly, the calming of the fear centre with chlorpromazine temporarily decreases or abolishes the instrumental defensive response.

*Secondly.* In experiments performed by Wyrwicka and Dobrzecka, goats were trained using food reinforcement to execute a certain movement, for instance, to lift a foreleg. Electrodes were then implanted into the hypothalamic feeding centre. In the crucial session the animal was fed before the experiment, and when it totally refused both to perform the trained movement and to eat food presented to it, electrical stimulation of the hypothalamus was given. The goat immediately started to lift the foreleg and did so throughout the period of stimulation eating voraciously the food offered after each movement.

*Thirdly.* We have repeatedly shown that in the experimental situation we can easily train the animal to perform two different motor acts in response to two conditioned stimuli, each mediated by a different drive (fig. 4). For instance, we can teach a dog to lift the right foreleg in

*Instrumental CRs based on two drives*

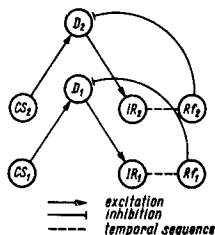


Fig. 4.

response to a buzzer under food reinforcement and to lift the left foreleg in response to the sound of the metronome by an avoidance procedure; these two responses were hardly ever interchanged, because they belong to different conditioned reflex. As we shall see later, this does not apply to the situation where two instrumental acts are mediated by one and the same drive, e.g. food.

The next question to be asked is whether the chain of events represented in our paradigm is *sufficient* to account for the occurrence of the instrumental conditioned reflex acts. The following considerations will lead us to the conclusion that it is not so.

It is easy to see that if the pathway passing through the drive centre were the *only* link connecting the conditioned stimulus with the instrumental response, it follows that an animal subjected to a given drive should always perform *all* instrumental movements which have once led to its satisfaction. But the evidence drawn both from everyday observation and from ex-

perimental data shows that animals may be taught up to a point to *select* different instrumental acts in response to different stimuli under the same drive depending upon which of these acts led to its satisfaction in the given situation. This compels us to assume that there exists in our paradigm another association linking *directly* the conditioned stimulus centre with the instrumental response centre, this association being responsible for the selection of a *proper* response to a particular stimulus. This association is shown in fig. 5.

*Second paradigm of instrumental CR*

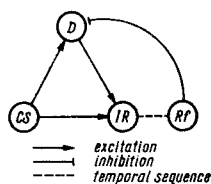


Fig. 5.

Although the two pathways connecting the centre of the conditioned stimulus with the centre of the instrumental response, namely one mediated through the drive centre and the other by-passing this centre, run parallel, it can be proven that their *joint* operation is indispensable for the elicitation of the instrumental response. In fact, we have already noted in our earlier discussion that when the drive centre is blocked, the presentation of a conditioned stimulus will not elicit the instrumental response, although the pathway CS→IR is intact. On the other hand, we have ample evidence to show that if the animal is brought to a situation totally distinct from that in which a given instrumental conditioned reflex has been established, it will never perform the corresponding trained movement, even when under a strong drive. For instance, it never happens that dogs fed in the animal house perform the alimentary instrumental movements learnt in the conditioned reflex chamber. This shows that the pathway D→IR alone is also not sufficient for the occurrence of the trained instrumental response.

### III

We shall pass now to the next problem, namely that of the mechanism of *inhibition* of an instrumental conditioned reflex when positive reinforcement is withdrawn. It is well known that if an alimentary conditioned reflex ceases to be reinforced by food, it will be *extinguished* after a number of trials, or if another stimulus similar to the conditioned stimulus is applied without reinforcement, it will be *differentiated* from the previous

one and will cease to elicit the instrumental response (the so-called "go-no go" procedure).

We shall not go into a discussion of the much disputed problem concerning the *intimate nature* of such inhibitory conditioned reflexes, since this would be far beyond the scope of this lecture. We shall, however, try to answer the question as to *which* centres are inhibited by inhibitory training (fig. 6) that is, whether inhibition affects directly the centre of the

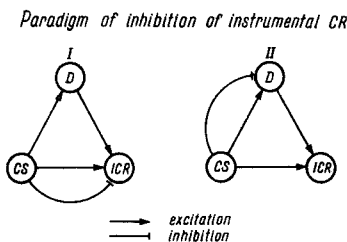


Fig. 6

instrumental response through the pathway  $CS \rightarrow IR$ , as indicated in graph I or whether it affects the drive centre through the pathway  $CS \rightarrow D$ , as indicated in graph II.

If inhibition occurred along the pathway  $CS \rightarrow IR$ , then in order to restore the extinguished instrumental reflex one should revert again to its original training, that is to compel the animal to perform the movement in the presence of the conditioned stimulus and to reinforce it by food. If, however, inhibition occurs along the pathway  $CS \rightarrow D$ , the restoration of the instrumental reflex should be quite different, because in that case the mere re-reinforcement of the stimulus should be enough for the reappearance of the learnt movement, since it would unblock the drive centre and thus reopen the pathway leading to the centre of the instrumental response.

The unequivocal answer to this question has been given by Wyrwicka. This author has shown the mere reinforcement of the conditioned stimulus subjected previously to extinction or differentiation is entirely sufficient for the restoration of the instrumental reflex. This indicates that in this type of inhibitory training the mechanism of inactivation of the conditioned stimulus occurs by inhibiting the *drive centre* and thus blocking the pathway leading through it, as shown in graph II of fig. 6.

There are other facts fully corroborating this conclusion. As was shown long ago by Miller and myself, if in the process of extinction of "go-no go" differentiation we recorded both the instrumental response and the salivary response to a conditioned stimulus, we observed that their decrease and eventual disappearance occurred at much the same time. This fact again



suggests that the disappearance of the instrumental response is closely related to the inhibition of the feeding centre. Another even more impressive fact becomes obvious when after a prolonged non-reinforcement of a given stimulus the food is again offered, the animal often refuses to take it for a few seconds or even longer. This is again a visible sign of the strong inhibition of the feeding centre produced by the inhibitory stimulus.

Thus the extinction of the instrumental reflex or its differentiation by the "go-no go" procedure occurs in exactly the same way as extinction or differentiation of the classical conditioned reflexes, namely by inhibiting the drive centre and not the centre of the instrumental response.

It may be added that quite a different situation takes place when the instrumental response to the given conditioned stimulus is abolished not simply by non-reinforcement of that stimulus, but by its reinforcement when the instrumental movement is not performed. In this case the alimentary response to this stimulus together with salivation is totally preserved, while inhibition of the instrumental response occurs along the direct pathway  $CS \rightarrow IR$ . To restore therefore the instrumental response to the stimulus we must return to the original training and teach the animal anew to perform the given movement.

#### IV

We have discussed so far the organization of the simple instrumental reflex and its extinction or differentiation through the so-called "go-no go" procedure. Now we shall pass to another type of experiment in which we teach the animals to perform two different movements each in response to a different stimulus under *one and the same* reinforcement. We may recall that the task is quite an easy one and does not require any special differential training if both movements are mediated by two *different* drives such as hunger and fear. However, the situation is much more complicated when only one drive is in operation and the animal has to select the proper response only on the basis of clues provided by the appropriate conditioned stimuli, as is schematically represented in fig. 7.

These experiments were performed by Lawicka who applied a double choice technique in which one stimulus ( $CS_1$ ) signaled a locomotor response to the left food tray ( $IR_1$ ) and the other one ( $CS_2$ ) signaled a locomotor response to the right food tray ( $IR_2$ ). Two tones of different pitch sounding from the same loud-speaker were used. We thought that such a task would be extremely easy for dogs who, as is well known from early Pavlovian times, are great experts in tone discrimination and can solve the "go-no go" differentiation very promptly, even with quite a small difference in tones. To our great amazement, however, the task of "go left-go right" differenti-

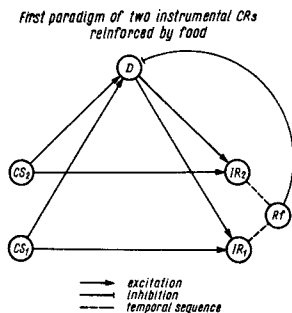


Fig. 7.

ation to two tone frequencies appeared to be almost insolvable unless the difference between them was greatly increased.

However, if two *identical* tones were given from *two different places*, for instance one sounding from the floor and the other from above, the "go left-go right" differentiation was promptly established. But if these tones were applied in "go-no go" differentiation, the task appeared to be on the contrary very difficult, and when the angular distance between them was relatively small there was no sign that the dogs were able to cope with the task at all.

The results from all these experiments are represented in fig. 8. Each graph is the mean of data obtained from several dogs.

The upper graph on the left represents the tone frequency differentiation

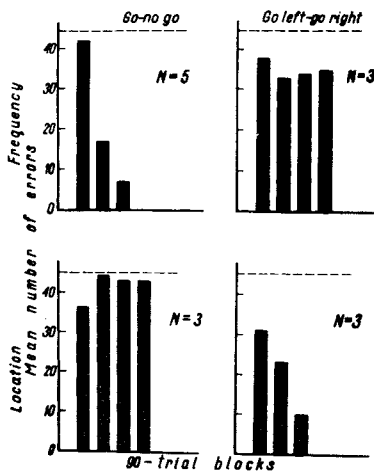


Fig. 8.

in the "go-no go" procedure taken from Brutkowski's and Dabrowska's experiments. The positive tone was 1000 cps, the negative one was 700 cps. In spite of this rather small difference training occurred rapidly, and already in the third 90-trial block the criterion was reached. Even if two tones much more remote from each other (300 cps versus 900 cps) were used in "go left-go right" differentiation—as can be seen in the upper right graph—the task seemed to be insolvable for the dogs, because no progress was made after four 90 trial blocks, that is after 360 trials. Only when in further training the difference between the tones was increased by replacing the tone of 900 cps by 1500 cps did the performance of the animals improve. But it was noticed that this improvement was due to the fact that the high tone caused the animals to develop a strong orienting reaction consisting of a slight startle and pricking up of the ears. If for some reason this response failed to appear or it appeared to the low tone, the animal was sure to commit an error and go to the wrong food tray.

The lower graphs represent the tone location differentiation, one and the same tone coming from two loud-speakers, one placed on the floor and the other hanging 6 feet above the floor. You see on the left graph that in the "go-no go" procedure there was no progress in the training even after four 90 trial blocks. On the other hand, when the same stimuli were used in the "go left-go right" procedure, the animals reached the criterion in the third block, that is after 180 trials.

In order to show you how much the dog is directed by the different places of the sounds with a total disregard of their quality in the "go left-go right" differentiation, I shall briefly describe another experiment by Lawicka performed at a time when the above relationship had not yet been discovered.

The dog was taught to go to the left food tray in response to the buzzer and to the right one in response to the metronome. Both stimuli were placed on the starting platform, but since the table put there was too small only the buzzer was placed on it, while the metronome had been located on the floor. In one experimental session the metronome was put on the table and the buzzer on the floor. The dog ran without hesitating to the left food tray in response to the metronome and to the right in response to the buzzer. While the experimenter has learnt that the metronome meant presenting the bowl on the right food tray and the buzzer in the left one, regardless of the location of the apparatuses, the dog paid attention only to the position of the apparatuses and not to the sounds produced by them.

In view of the high significance of these findings it seemed important to verify them by our usual methods, that is, to place the dog on a stand in the sound-proof chamber and to use the lifting of the leg as an in-

strumental response. These experiments have recently been performed by Dobrzecka and myself.

First, we tried to teach the dog under food reinforcement to lift his right foreleg in response to the metronome and his left foreleg in response to a sound similar to the buzzer, both stimuli being placed closely together in front of the animal. This proved to be unsuccessful and the animal developed a heavy neurosis becoming unfit for further experimentation. A similar procedure was followed with another dog, but this time the stimuli had been located in different places, the buzzer being placed behind the stand and the metronome in front of it. In this case the differentiation was established, and the animal learnt to perform the movement of the right foreleg in response to the metronome and of the left foreleg in response to the buzzer. It was observed that the lifting of the right foreleg was always preceded by the animal's looking forward toward the place of the metronome, and the lifting of the left foreleg was preceded by a backward orienting reaction in the direction of the buzzer.

Now again the crucial experiment was performed in which the places of the stimuli were interchanged: the metronome was located behind the dog and the buzzer in front of him. The responses of the animal were quite unequivocal: to the metronome he displayed now a backward orienting reaction followed by the movement of the left foreleg, while in response to the buzzer he looked forward and lifted his right foreleg.

The present results force us to discard a long-held view on the mechanism of differentiation or discrimination as the procedure is usually called in American literature. Most psychologists have been accustomed to think that any differentiation, be it the "go-no go" procedure or the "go left-go right" procedure, simply reflects the *perceptual capacity* of the animal, and what the subject actually learns is merely to *discriminate* between the two cues presented to him. Once the cues are discriminated the task was thought to be solved, and a certain experimental procedure was supposed to serve merely as a tool to reveal this very fact. Only a few students under the influence of Pavlov's ideas have been ready recently to admit also the role of inhibition of not reinforced responses as a factor determining the course of the differentiation training.

Taking into account our present results we see that there is still another factor hitherto not suspected at all, which to a large extent influences the course of differentiation. The animal uses quite different cues when confronted with a "go-no go" differentiation than those it utilizes when confronted with a "go left-go right" or a "lifting the left leg-lifting the right leg" differentiation. In the first procedure it principally utilizes the differences in the *qualities* of both stimuli, while in the second case the decisive role is shifted to the difference in the *orienting reaction elicited*

by each stimulus. This is why the tone frequency differentiation is easy for a dog in the "go-no go" procedure but not in the "go left-go right" procedure, while with the tone-location differentiation the opposite is true.

## V

These facts which seem to be rather puzzling for our present concepts yield themselves to a natural explanation by means of our schemes.

For this purpose it is sufficient to slightly modify our last paradigm by supplementing the direct pathway  $CS \rightarrow IR$  by an additional link consisting of an orienting reaction to the conditioned stimulus and the proprioceptive stimulus generated by it (fig. 9). As seen from this modified

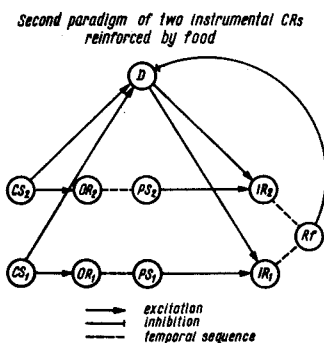


Fig. 9.

paradigm the pathways connecting both conditioned stimuli with the drive centre start directly from the CS centres. Since, as stated earlier, the "go-no go" differentiation just as the "food-fear" differentiation is based on these very pathways, it is clear that in *this* differentiation the quality of the conditioned stimulus plays a decisive role. On the other hand, the "go left-go right" differentiation is based on the pathways linking the conditioned stimuli *directly* with respective instrumental responses, and therefore, according to the new version of our paradigm, in *that* differentiation the decisive role is played by orienting reactions elicited by these stimuli.

A possible misunderstanding which needs to be explained concerns the so-called *simultaneous* discrimination of visual stimuli by the "go left-go right" procedure. It is well known from numerous experiments performed on cats and monkeys that, when two food wells are marked by two different figures or objects and only one of them is signaling the well as filled with food, the animals easily learn to approach the correct cue. In this

case the "go left" or "go right" response is totally determined by the visual cue with no intervention of any proprioceptive stimulus.

The essential difference between this procedure and that described in our experiments seems to be obvious. Since approaching one of the figures leads to food and approaching the other one does not, the animal gradually learns to display a positive response towards the first figure and to inhibit the response to the second figure. Thus, as a matter of fact, we are dealing here with the "go-no go" differentiation which, as pointed out above, may be totally determined by exteroceptive stimuli. The only difference between this procedure and the classical Pavlovian "go-no go" procedure is that in the latter case there are separate "go" and "no go" trials, while in the procedure now under discussion both a "go" response and a "no go" response are squeezed, so to speak, in a single trial. As is well known, it is easy to separate these two responses simply by presenting in a single trial only a positive figure or only a negative figure, a procedure identical to the Pavlovian differentiation.

## VI

The major conclusion which seems to arise from the work described here is the following: It appears that in different types of conditioning different aspects of stimuli are preferentially picked out by the animal as guiding clues: in classical conditioning represented in our paradigm by  $CS \rightarrow D$  connections, the animal prefers to utilize the exteroceptive cues, while in instrumental conditioning represented by  $CS \rightarrow IR$  connections, it makes use primarily of proprioceptive cues.

Now the important problem arises, namely what is the scope of applicability of this general principle which we would like to call the cue-specificity principle.

As far as classical conditioning is concerned, there is plenty of evidence to show that not only exteroceptive but also interoceptive and proprioceptive stimuli may be used for the differentiation training, although it is almost certain that exteroceptive stimuli are the most adequate. However, the situation is much less clear with respect to the instrumental conditioning.

First, we do not know whether the proprioceptive link intervening between the exteroceptive stimulus and the response is really indispensable for *all* modalities of stimuli and all types of instrumental responses. In experiments with Dobrzecka we have recently shown that when tactile stimuli applied to the distal parts of the limbs are used as conditioned stimuli, it is very easy to teach the dogs under food reinforcement to lift selectively that leg to which the touch is being applied. It seems that here

the cues determining the instrumental response are provided by the tactile stimuli themselves, and we have now some evidence that the anatomical connections between the sensory and the motor cortex contribute to the specificity of the given response. Thus the principle stated above has some restrictions even for a dog.

Secondly, the problem arises as to whether this principle is also valid with respect to other species, especially those situated higher in the phylogenetic scale. There is no doubt that in man different motor responses can be easily established to different auditory signals, and here the intervention of the orienting reaction for selecting the proper motor act seems to be superfluous. But whether the same is true for monkeys we do not know.

To sum up, since the present experiments are only first steps along this line of investigation, many further experiments have to be done and many questions have to be answered until this whole field is made clear.

## VII

Ladies and Gentlemen. I am coming now to the end of my talk, and all that remains for me to do is to try to give you, on the basis of what you have heard, some general picture concerning our experimental technique, our approach to the problems of animal behavior, and the ideas directing our work.

As far as *our technique* is concerned, it seems to me rather crude, maybe even too crude, but it is consistently characterized by one feature. This is that we try to have all variables we are dealing with, whether they are conditioned stimuli, instrumental responses, drives, or reinforcing unconditioned stimuli, as clearly defined and comprehensible as possible from the physiological point of view.

*Our approach* is to try to make only such experiments which we think will throw some light on *the mechanisms* of the behavioral events with which we are dealing.

And now a few words about *our ideas*. I realise, of course, that there may be and in fact there has been a lot of argument and questioning whether our concepts are true physiological concepts, and whether we are studying the physiological processes underlying animal behavior or whether we only fool ourselves and other people. It is claimed that, since we concern ourselves mainly with the outward effects of physiological processes going on in the brain, we have no right to draw any conclusions about these processes, and it is also claimed that those offered on the basis of our experiments are only products of our imagination.

Obviously I cannot agree with such a criticism, otherwise I would not give this lecture. I cannot deal here with the problem in its full extent, but

I would like to stress some essential points. In my opinion the chief misunderstanding lies in the widespread assumption that only those results should be considered physiologically for which a clear cerebral localization has been established. In this context I would like to remind you of a very wise idea presented by Erich von Holst in one of his last papers, namely that "the investigation of the physiological questions of 'how' and 'why' are usually deflected much too soon into the morphological question 'where.' " I fully agree with this statement, and I would like to stress that in our experimental work we start with the questions of "how" and "why," while the question of the "whereabouts" emerges in due time and constitutes not the beginning but the crowning end of the whole study. When I spoke during my lecture of the "centres" of stimuli, of drives, or of conditioned responses I was not concerned with and did not even bother about their precise localization, since to our present knowledge, all of them are dispersed in various parts of the brain and constitute more complex and highly organized functional systems rather than focally localized nuclei.

By using these terms we understand only *functional* but not *morphological* units, and when speaking about their connections we are again not concerned with the exact localization of the respective pathways which in most cases are quite unknown. On the basis of my experience I am convinced that the question of the "whereabouts" crowning the given research should be reasonably asked only when the questions of "how" and "why" have been already answered. Such was the development of the study of integrative action of the spinal cord, and such should be, according to my own deep belief, also the development of the study of integrative action of the brain.

## THE CONCEPT OF ADAPTATION IN PERCEPTION

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(No text available)