ACTA NEUROBIOL. EXP. 1975, 35: 431-445

Memorial Paper in Honor of Jerzy Konorski

THE PROCESS OF CONDITIONING: AN EVOLVING CONCEPT

Wanda WYRWICKA

Department of Anatomy and the Brain Research Institute
University of California, School of Medicine
Los Angeles, California, USA

Abstract. Various explanations of the process of conditioning and some models of the postulated connections between brain centers are discussed. Some results of research on conditioning processes at the neuronal level are reviewed. A hypothesis is put forth that conditioned behavior is a result of activation of neural patterns of associations between the sensory traces of stimuli; such neural patterns may be stored in polysensory neurons. Models based on this hypothesis are presented.

The use of electrophysiological methods as well as an increase in variety of experimental design in conditioning studies have led to fundamental changes in the original concept of the conditioned reflex. According to Pavlov (1927, Ch. 3), the phenomenon of conditioning consists in the formation of new neural connections between those brain centers which become activated at the same time. As a result, "such external stimuli as have been from the very birth of the animal transmitted to a definite centre, can, notwithstanding, be diverted and made to follow another route becoming linked up by the nervous connection to another center, provided that this second centre is physiologically more powerful than the first" (Pavlov 1927, p. 37). Pavlov believed that these new connections are established in the cerebral cortex. He supposed that "stimuli which lead to activity of an organ gain direct representation in the cortex independently of the simultaneous excitation of a subcortical area" and that "the cells predominantly excited at a given time become foci attracting to themselves the nervous impulses aroused by the new stimuli — impulses which on repetition tend to follow the same path and so to establish conditioned reflexes" (Pavlov 1927, p. 37–38).

The notion that formation of new connections between brain centers is a basis of conditioned reflexes can also be found in post-Pavlovian literature. For instance, according to Konorski (1948, Ch. 6) the process of conditioning consists in an increase of synaptic contacts between two coupled neurons or centers. The number of new synaptic contacts between the centers of the conditioned stimuli (CS) and unconditioned stimuli (US) is a function of the length of training. The number of new synaptic contacts also depends on the strength of the conditioned stimulus: the weaker the conditioned stimulus, the smaller the number of new synaptic connections. As a result, the conditioned reaction (R) to a weak stimulus is weaker than the conditioned reaction to a strong stimulus, even when they are coupled with the same unconditioned stimulus. In his later theoretical studies, Konorski (1967, 1973) concentrated on the functional relationship between the centers of conditioned activity and the centers of unconditioned activity rather than on the generation of the new synaptic connections between these centers. Konorski (1967, 1973) proposed that there are two kinds of reflexes: consummatory reflexes and drive reflexes. The appearance of the conditioned reflex depends not only on the acquired conditioned connections between the center of conditioned reflex and the center of unconditioned reflex, but also on the inborn connections between the center of unconditioned drive reflexes (such as the hunger system in alimentary behavior or the fear system in defensive behavior) and the center of unconditioned consummatory reflex (such as the gustatory system in alimentary behavior or the nociceptive system in defensive behavior). The center of drive reflexes is inhibited by the center of consummatory reflexes during the act of eating; this leads to an inhibition of the conditioned reflex (see Sołtysik 1960).

Because in his latest studies Konorski concentrated mostly, on the relationship between the drive and consummatory reflexes he did not pay as much attention to the classification of all conditioned reflexes into type I (classical or Pavlovian type) also called respondent behavior by Skinner (1938), and type II (instrumental) also called operant behavior by Skinner (1938) as he did in his earlier years (Miller and Konorski 1928, Konorski and Miller 1936, Konorski 1948, 1967, 1973). According to Konorski (1973, p. 2) "both types of conditioning are based on the general laws of associations – connections between the centers involved. Whereas the experimental procedures of classical conditioning expose mainly the CS–US connection, those of instrumental conditioning expose the CS–R connection. Thus, the main differences between the two types of conditioning are those associated with the different centers involved in each, not the associative-connective laws themselves".

A view that both classical and instrumental type of conditioning are formed according to the general rules governing the formation of associations between stimuli, is also maintained by the author of this article. This author claims, however, that the differences which doubtlessly exist between the two types of conditioning, pertain to the origin of the conditioned reaction: while the classical reaction is one of post-reinforcement origin, the instrumental reaction is one of pre-reinforcement origin (Wyrwicka 1972, 1973).

Asratyan (1967) put forth a hypothesis that there exists two-way connections between the cerebral neural foci corresponding to stimuli involved in the process of conditioning. He and his associates combined pairs of stimuli which evoked easily observable and precisely recordable unconditioned reflexes. Such stimuli included food, electric cutaneous stimulation, air-puff into the eye, passive flexion of a limb and local skin cooling. They found that when two stimuli, more or less equal in strength, were paired in an alternating sequence, each of them applied separately evoked both the reaction typical of this stimulus and the reaction typical of the other stimulus. For instance, when food and electrocutaneous shock were paired, electric shock to a limb evoked not only lifting the leg but also salivation and chewing movements, while food alone evoked not only salivation and chewing but also lifting the leg. When stimuli were paired in a stereotyped sequence; e.g., when stimulus S1 always preceded stimulus S2, the "forward" connection was always stronger than the "backward" connection; i.e., reaction typical of S2 evoked by S1 was stronger than reaction typical of S1 evoked by S2. Nevertheless, S2 applied alone, evoked both reactions typical of S2 and S1. That way Asratyan and his associates demonstrated the existence of so-called "backward conditioning"; similar findings were also reported by Dostalek and Dostalkova (1964) and by Gormezano (cit. by Wyrwicka 1973).

The interrelations among various "centers" of the brain were also considered a basis of instrumental conditioning by this author (Wyrwicka 1952, 1958, 1960). It was proposed that the occurrence of the instrumental reaction is dependent on an activation of two kinds of connections (Fig. 1): One of them, CS—R is a direct pathway (*3*) between the center of conditioned stimulus (CS) (acting against a stable situational background) and the center of the instrumental reaction (R). The other, an indirect connection consists of two parts. One of them is a link between the center of the conditioned stimulus (CS) and the center of the unconditioned stimulus (UCS), denoted as link *1* in Fig. 1; another part of this indirect connection is the connection between UCS and R, denoted as link *2* in Fig. 1. The center of unconditioned stimulus is that corresponding to food in alimentary behavior, and to a noxious stimulus (e.g., a shock) in defensive behavior.

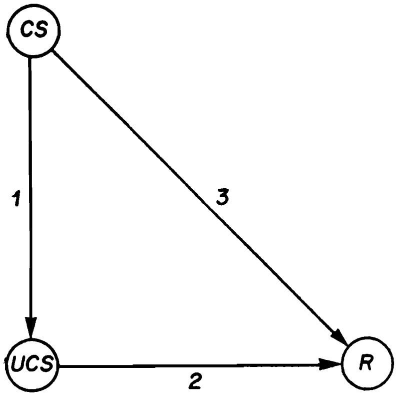

Fig. 1. A model of interrelations between the brain centers involved in instrumental conditioning. CS, center of conditioned stimulus; UCS, center of unconditioned stimulus; R, center of instrumental reaction. *1–3*, connections between the centers. Arrows denote direction of excitatory impulses. (From Wyrwicka 1958.)

The hypothesis about the existence of the connection which involves the UCS center is based on experimental data. It has been observed that the alimentary instrumental reaction does not occur to the action of CS at a low level of alimentary excitation (e.g., during satiation) (Wyrwicka 1950); this suggests that the occurrence of the instrumental reaction depends on the level of excitability of the center representing food. This supposition was supported by the results of experiments with electrical stimulation of the hypothalamic "feeding center" (Wyrwicka, Dobrzecka and Tarnecki 1959, 1960). When the feeding center was electrically stimulated in fully satiated goats, the animal first performed the previously trained instrumental reaction and only then started to eat; the animal kept repeating the instrumental reaction and consuming the offered food as long as the electrical stimulation continued.

In a non-satiated animal, a conditioned stimulus acting through its brain center CS, produces an increase in excitation in center UCS, through connection *1* on Fig. 1; the excited UCS center sends its impulses to all centers which are connected with it, such as salivary and other autonomic centers, as well as to the motor system, producing general motor arousal. Part of these impulses go through connection *2* to the center of the trained reaction, R. The latter, which at the same time has been obtaining excitatory impulses directly from the CS center through connection *3*, reaches a higher level of excitation than that of other motor centers; as a result, the instrumental reaction is elicited.

Similarly, in avoidance behavior, impulses produced by CS lead to an increase in excitation both in center R (through connection *3*) and in the center of defense, UCS (through connection *1*). In turn, the UCS center sends its impulses to all autonomic and somatomotor centers, connected with it, including the center of the trained response, R (through connection *2*). As a result, center R, by obtaining impulses from both CS and UCS, reaches a higher level of excitation than that of other motor centers and releases the avoidance reaction R.

The indirect connection (CS–UCS–R), therefore determines the character of the activation (e.g., alimentary or defensive) while the direct connection CS–R determines the motor reaction to be elicited.

The experiments using recording of electrical brain activity directed the attention of investigators toward changes in the electrical activity of particular structures during the process of conditioning. Galambos and Scheatz (1962) recorded evoked responses from various cortical and subcortical structures during conditioning in monkeys. They found that pairing a click with an air-puff produced a significant increase in the amplitude of the response from all electrode locations. This increase in response amplitude was also observed in a number of subsequent applications of the click alone, without the air-puff. This result suggests that the conditioning process is not limited to some specific structures only, but that it may involve the whole brain.

Sakhulina and Merzhanova (1966) demonstrated that after establishment of an alimentary conditioned response which consisted of a movement of a foreleg in a rabbit, a new permanent EEG configuration in the recruiting response recorded from the cortical area corresponding to the foreleg (contralateral gyrus sigmoideus postero-lateralis) was observed. John (1967), Begleiter and Platz (1967), and others also observed changes in the shape of the evoked responses in the process of conditioning. John et al. (1969) recorded electrical activity of various brain areas during conditioning procedures in cats. The animals were trained to press one of the two levers during presentation of a flicker at frequence V_1 in order to get milk, and to press another lever during presentation of a flicker at frequency V_2 in order to avoid an electric shock. The shape of the evoked potential during the action of stimulus V_1 was completely different than the shape of the evoked potential recorded during the action of stimulus V_2. Then, a third stimulus, a flicker at frequence V_3, midway between the frequencies of V_1 and V_2, was introduced. It was found that this new stimulus, which was obviously similar to the two other stimuli, sometimes evoked approach to food and sometimes evoked an avoidance reaction. When an approach reaction occurred to V_3, it was accompanied by an evoked potential very similar to that of stimulus V_1; and, when an avoidance reaction to V_3 was observed, the evoked potential resembled that elicited by stimulus V_2. This phenome-

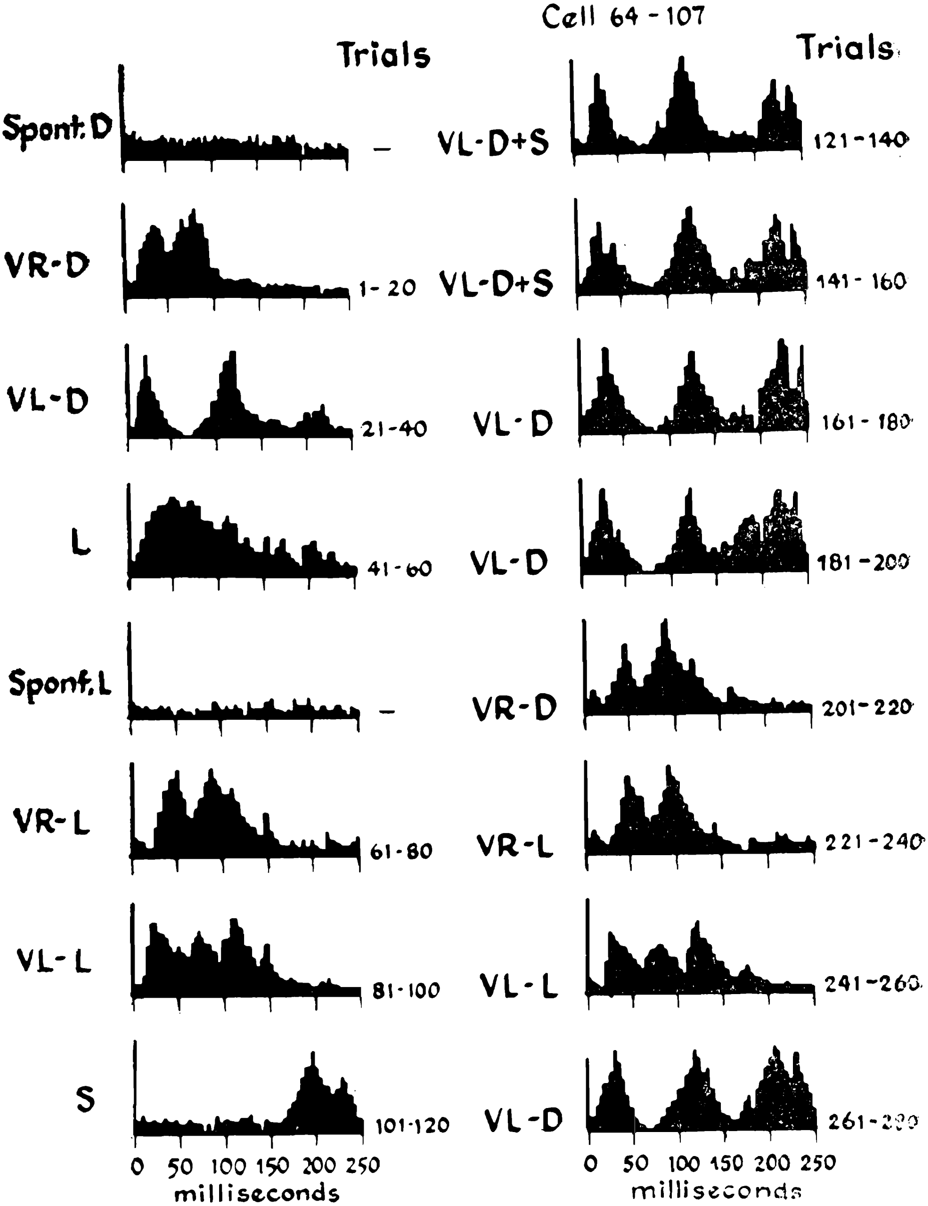

Fig. 2. Response modification in a polymodal neuron. Post-stimulus-time histograms obtained during the action of the following stimuli: VR-D, vertical light bar moving from left to right and VL-D, the same stimulus moving in the opposite direction, in a dark room; VR-L, vertical light bar moving from left to right and VL-L, the same stimulus moving in the opposite direction, with the room lights on; S, an electric shock to the contralateral hind limb. Each histogram represents

non was observed not only in the visual system (lat. geniculate, visual cortex) but also in other brain regions.

The authors concluded that the response to the new stimulus was not fully determined solely by the actual physical stimulus but contained an endogenous "readout component", specific to the response established to former stimuli; this endogenous component was, however, dependent on the meaning attributed by the animal to the signal.

These data led John (1972) to believe that storage of information and retrieval may be mediated by a cooperative action of a huge number of neurons in many brain areas, while "firing of any specific cell is insignificant, except insofar as it contributes to these cooperative processes".

On the other hand, other experimental evidence suggests that the process of conditioning takes place already at the neuronal level. Fessard (1960) on the basis of his experiments on posttetanic potentiation and other experimental data, has suggested that the phenomenon of conditioning may be a result of convergence of discharges deriving from the neurons which receive impulses from the conditioned stimulus and the neurons which receive impulses from the unconditioned stimulus, on multisensory interneurons. The repetitive discharge of impulses circulating within the interneuronal circuits eventually leads to an integration of these impulses.

Morell (1967, 1972) demonstrated that some parastriate neurons responded to various stimuli. Each of the stimuli used produced a different response histogram in the same neuron. As shown in Fig. 2, a visual stimulus in the form of a vertical bar of light moving to the right with the room lights dimmed (VR-D) produced a different response histogram than that produced by the same bar of light moving to the left with the room lights bright (VL-L). The same neuron also responded to an electric shock applied to the contralateral hindlimb (S); the response histogram to S was different than histograms to the visual stimuli. When stimulus VL-D was paired with the shock (VL-D + S), a combined response histogram was obtained. After 40 successive applications of these combined stimuli, the visual stimulus VL-D alone evoked the combined response histogram (see VL-D at 161–200 and 261–280 trials). This combined response histogram for VL-D alone persisted for almost 60 min after pairing the shock with the light stimulus. The author observ-

---

a sum of 20 trials. Response pattern is specific for each stimulus. Combined stimulation, VL-D + S, produces a combined response pattern (trials 121–160). After 40 combined stimulations, VL-D alone elicits the combined response pattern (trials 161–200 and 261–280). (From Morrell 1967.)

ed, however, that the response of a particular cell was not always the same, and on any single trial the response was "probabilistic rather than absolutely deterministic with respect to both timing and pattern". However, it is probable that the information is processed in parallel in thousands of cells which need not all carry the same information. "It is only necessary that the nervous system receive enough information about an experience to identify it even if some aspects are left out or are distorted". The author supposes that the first exposure of the nervous system to a stimulus may result in a less precise specification than that obtained after many further exposures when the stored pattern of information is more stable and spatially distributed (Morrell 1967, p. 468).

On the basis of the obtained data, Morell (1972) hypothesizes that new information is first preserved as a temporal pattern of neuronal activity and constitutes a basis for short-term memory. After this initial storage period, the permanent storage phase begins. This permanent phase may consist in anatomical or chemical changes at a molecular or even submolecular level.

The nature of such changes at the neuronal level still remains unclear. Electrical mechanisms are considered responsible for short-term changes produced by conditioning, or, in other words, for short-term memory (Morrell 1967, 1972; Kandel 1967, and others), while changes in synthesis of macromolecules (Toenen and Otten 1974), glial and myelination processes of the presynaptic region (Roitbak 1970), maturation of the microneurons during the individual development and the related increase in the number of synaptic connections (Altman 1967) or rearrangement of dendrite shafts into dendrite bundles (Scheibel and Scheibel 1971) are considered responsible for long-term central processes related to conditioning. This topic cannot be, however, further discussed within the limits of the present article.

The observations of events at the neuronal level during conditioning procedures have also influenced the theoretical modeling related to the process of conditioning (see Wyrwicka 1972, 1973).

Let us try to extrapolate to the behavioral level from the data of Morell described above. In the classical type of conditioning, the combined application of the conditioned stimulus (CS) and unconditioned stimulus (UCS) evokes a definite combined sensory change in polysensory neurons and this change does not disappear with discontinuation of the two stimuli but remains for some time. Each further application of CS + UCS facilitates the combined sensory change and prolongs retention time. This eventually leads to an establishment of permanent associations between the combined sensory changes in a form of a definite sensory pattern. Since then, an action of any of the two previously combined stimuli may activate the stored pattern of associations. This was the case in experiments of the Laboratory of Asratyan (Asratyan 1967) described above: when CS and UCS were more or less of the same strength (e.g., food as CS and electric shock to the animal's leg as UCS, or vice versa), an application of any of these stimuli evoked a combined effect: salivation and lifting the leg. Similar results were obtained by Dostalek and Dostalkova (1964) and by Gormezano (cit. by Wyrwicka 1973).

In standard laboratory practice, however, stimuli such as a moderate intensity tone or a change in illumination, which initially produce only a slight orienting reaction are chosen as conditioned stimuli, while stimuli, such as food or electric shock, which produce a strong approach or escape reaction, respectively, are chosen as unconditioned stimuli. In this case, the sensory changes produced by a strong UCS dominate in the pattern of associations over the changes produced by a weak CS. As a result, either CS or UCS produces only the reaction typical of strong UCS. This is shown in Fig. 3. The lack of any visible reaction specific to the weak CS during the action of UCS alone, does not prove that sensory changes related to CS are completely absent. Such changes may not be strong enough to produce any overt reaction.

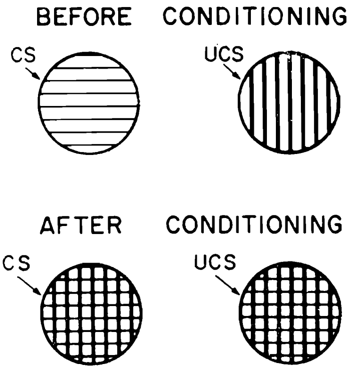

Fig. 3. A diagram of possible sensory changes occurring in polysensory neurons of the brain in response to a conditioned stimulus (CS) and an unconditioned stimulus (UCS) before and after pairing these two stimuli. Sensory changes produced by CS are denoted by thin horizontal lines and sensory changes produced by UCS are denoted by thick vertical lines. As a result of repetitive pairing CS and UCS (i.e., conditioning) sensory changes evoked by these stimuli intermingle, leading to an establishment of a permanent pattern of associations between the sensory traces of CS and UCS. Subsequently, an application of either CS or UCS alone activates the whole pattern. This leads to a release of both the reaction typical of CS and the reaction typical of UCS when CS (e.g., an electric shock) and UCS (e.g., food) are approximately equal in strenth. When, however, UCS (e.g., food) is stronger than CS (e.g., a tone), the sensory changes produced by UCS dominate in the pattern and the application of either CS or UCS evokes only the reaction typical of UCS. (Modified from Wyrwicka 1973).

In the instrumental type of conditioning three elements are combined: CS, an instrumental act, and UCS. A simple example of instrumental conditioning is combining a tone, an instrumental movement (e.g., pressing a lever) and food. Not only the tone and food, but also the instrumental act produce sensory changes which, through the repetition of these three elements together, become permanent as a definite pattern of associations. This pattern may then be activated by one of the participating stimuli (Fig. 4). There exists some experimental evidence that supports this hypothesis. For instance, it is generally known that the "priming" procedure in self-stimulation experiments (giving "free" desired brain shocks) results in the animal approaching the lever and pressing it. Similarly, when in alimentary conditioning experiments the trained movement was fully extinguished by withholding food, and food was then given "free", the trained reaction reappeared spontaneously (Wyrwicka 1952). Or, when a portion of food was offered "free' to a hungry dog in the experimental compartment, the animal frequently did not consume it immediately, but first performed the trained movement in front of food and only then started to eat. This suggests that an electrical stimulus in self-stimulation experiments or food in alimentary experiments evoked the whole established pattern of associations.

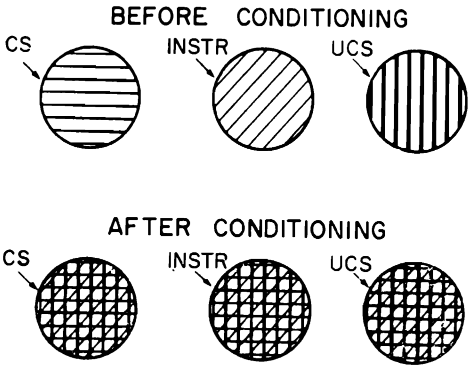

Fig. 4. A diagram of possible sensory changes occurring in polysensory neurons in response to a conditioned stimulus (CS), instrumental reaction (INSTR) and unconditioned stimulus (UCS), before and after combining these three factors. Horizontal lines denote sensory changes produced by CS; diagonal lines correspond to sensory changes produced by the instrumental act; vertical lines show sensory changes produced by UCS. After repetitive combining CS, INSTR and UCS, a permanent pattern of associations between the sensory traces of these elements is established. This pattern can be activated by an action of any of the three involved factors. Sequence relationship between SC, INSTR and UCS cannot be shown in this diagram. (See Fig. 3 and the text for further explanations). (Modified from Wyrwicka 1973).

It must be taken into account, however, that the chances of establishing a given pattern of associations and then of evoking this pattern depend on more factors than the principal stimuli involved. First, these stimuli cannot be separated from their environmental "context". For instance, a tone is always acting against a definite situational background. It was found that the same conditioned stimulus can be used to evoke two different instrumental responses, on condition that this stimulus is applied in two different situations, respectively. For instance, a dog was trained to an acoustic stimulus (metronome beats) to lift its right hind leg to obtain food in the Pavlovian experimental compartment, and to lift its left foreleg to the same conditioned stimulus to get food in an office room. These two reactions were obtained without difficulty (Wyrwicka 1958). This suggests that "identification" of the conditioned stimulus depended on the situational background against which the stimulus was presented. Similarly, when after combining a tone, instrumental response and food in a particular experimental compartment, food alone is offered in the same situation it may evoke an instrumental response before eating starts (as described above). But, when the same food is offered outside the experimental situation; e.g., in an open space, a different pattern of associations is evoked, namely the pattern established earlier in the history of the animal, when food was offered "free" on the ground and the animal had only to appraoch it and eat it.

Another example: the sight of a table setting in the dining room before the meal or the noise related to preparation of the table for dinner may produce some alimentary excitation in a hungry person, but seeing a spoon or fork separate from the dinner setting and outside the dining room may not evoke any alimentary reaction.

The sequence of stimuli represents another problem. It was found in Pavlov's laboratory that dogs learned to differentiate between two groups of the same stimuli arranged in different order (Pavlov 1927). The sequence of stimuli was also found to be an important factor in the experiments of Asratyan's laboratory (Asratyan 1967). When the sequence of two stimuli of the same strength had been reversed, the reaction obtained was weaker and not so stable as when the sequence was always the same. This suggests that the sequence of stimuli must be an important part of the pattern of associations between these stimuli.

While not discussing the electrical or chemical nature of the associations between the sensory traces of CS, UCS and R in the neural pattern, we may nevertheless ask whether the particular components of the pattern are uniformly blended into an unseparable whole, or are they only loosely connected with each other with a possibility of being separately activated?

The following experiments may contribute to our understanding of this problem. (i) In a fully satiated dog a strong acoustic CS (whistle) still evoked an instrumental response although the animal refused to eat food offered as a reward (Wyrwicka 1950). (ii) Cats in which bilateral lesions in the rostral hypothalamus had resulted in aphagia and in somewhat increased general activity, performed their instrumental pressing a lever but ignored the food reward (Wyrwicka 1967).

This is how the old model of instrumental conditioning (Fig. 1) explains this phenomenon: (i) center R must usually obtain excitatory impulses from both CS and UCS centers to produce the instrumental reaction; (ii) performing the reaction without accepting the food reward suggests that center UCS was inactive in the above described cases and, therefore, the instrumental response was elicited in center R only by impulses coming from CS center. This indicates that the particular centers of the conditioning paradigm may be activated independently from each other in some circumstances.

The same may apply to the sensory traces of CS, UCS and R in the neural pattern (Fig. 4). In special circumstances (such as satiation, aphagia, motor excitation, etc.) the level of activation of some components may be different than that of the other components of the pattern. This leads to a hypothesis that the associations between the traces of CS, UCS and R in the neural pattern must be loose rather than inseparable.

Finally, there is a question as to where in the brain the neural patterns of associations are located. The lesion studies have shown that small, restricted lesions of the brain usually produce only a temporary disturbance in conditioned behavior and sooner or later recovery of the reaction takes place. Considerable changes in behavior were observed only after large lesions. Diamond et al. (1962) found that the avoidance reaction disappeared and the cats were unable to relearn discrimination between the two groups of tones only after removal of auditory area I, II and the neighboring zone. When even a small portion of area I and its thalamic connections were spared, however, the discrimination could be relearned. Similarly, long ago Lashley (1930) in his studies of cortical ablations observed that when some remnants of the visual cortex were left, the rats were still able to discriminate between various degrees of brightness.

It has also been found that learning is still possible in decorticated animals (Poltyreff and Zeliony 1930, Ten Cate 1934, Bromiley 1948, Oakley 1971, and others) or in thalamic animals (Villablanca and Marcus 1971, Norman et al. 1974). Some signs of conditioning within the isolated mesencephalon in chronic cats have also been observed (Żernicki et al. 1970).

These data suggest that the integrative processes of conditioning may take place simultaneously in many polysensory neurons at practically all levels of the brain. It does not mean that the changes related to conditioning are exactly the same in each neuron. Specificity of neuronal responding depends on various factors, such as connections with the receptive areas (see "preferred" and "nonpreferred" stimuli discussed by Morrell, 1967, 1972) and environmental influences. A cooperative action of many single neurons results in complex behavioral actions that may engage a large part of the brain in each case (see Morrell 1967, 1972, John 1972, Galambos and Sheatz 1962).

It is this point of view which is reflected in the models of conditioning presented above (Fig. 3 and 4). In these models not new connections between the distant brain centers but changes within single neurons are the essence of conditioning processes.

This study was supported by USPHS Grants No. MH 13958 and AM 17328-01.

REFERENCES

ALTMAN, J. 1967. Postnatal growth and differentiation of the mammalian brain, with implications for a morphological theory of memory. *In* G. D. Quarton, T. Melnechuk and F. O. Schmidt (ed.), The neurosciences, A study program. The Rockefeller Univ. Press, New York, p. 723–743.

ASRATYAN, E. A. 1967. Some peculiarities of formation, functioning and inhibition of conditioned reflexes with two-way connections. Progr. Brain Res. 22: 8–20.

BEGLEITER, M. and PLATZ, P. 1969. Modifications in evoked potentials by classical conditioning. Science 166: 769–771.

BROMILEY, R. B. 1948. Conditioned responses in dog after removal of neocortex. J. Comp. Physiol. Psychol. 41: 102–110.

DIAMOND, I. T., GOLDBERG, J. M. and NEFF, W. D. 1962. Tonal discrimination after ablation of auditory cortex. J. Neurophysiol. 25: 223–235.

DOSTALEK, C. and DOSTALKOVA, J. 1964. To the associative character of backward conditioning. Act. Nerv. Super. 6: 69–70.

FESSARD, A. 1960. Le conditionnement considerė a l'echelle du neurone. Electroenceph. Clin. Neurophysiol. Suppl. No. 13: 157–184.

GALAMBOS, R. and SHEATZ, G. C. 1962. An encephalograph study of classical conditioning. Amer. J. Physiol. 203: 173–184.

JOHN, E. R. 1967. Electrophysiological studies of conditioning. *In* G. C. Quarton, T. Melnechuk and F. O. Schmidt (ed.), The neurosciences, A study program. The Rockefeller Univ. Press, New York, p. 690–704.

JOHN, E. R. 1972. Neural correlates of learning and memory. *In* A. G. Karczmar and J. C. Eccles (ed.), Brain and human behavior. Springer-Verlag, New York, p. 291–301.

JOHN, E. R., SHIMOKOCHI, M. and BARTLETT, F. 1969. Neural readout from memory during generalization. Science 164: 1534–1536.

KANDEL, E. R. 1967. Cellular studies of learning. *In* G. C. Quarton, T. Melnechuk and F. O. Schmidt (ed.), The neurosciences, A study program. The Rockefeller Univ. Press, New York, p. 666–689.

KONORSKI, J. 1948. Conditioned reflexes and neuron organization. Cambridge Univ. Press, London. 267 p.

KONORSKI, J. 1967. Integrative activity of the brain. An interdisciplinary approach. Univ. Chicago Press, Chicago. 531 p.

KONORSKI, J. 1973. On two types of conditional reflex: General laws of association. Cond. Reflex 8: 2–9.

KONORSKI, J. and MILLER, S. 1936. Conditioned reflexes of the motor analyzer (in Russion). Tr. Fiziol. Lab. I. P. Pavlova 6: 119–278 (English summary, p. 285–288).

LASHLEY, K. S. 1930. The mechanism of vision. II. The influence of cerebral lesions upon the threshold of discrimination for brightness. J. Genet. Psychol. 37: 461–480.

MILLER, S. and KONORSKI, J. 1928. Sur une forme particuliere des reflexes conditionnels. C. R. Seanc. Soc. Biol. 99: 1155–1158.

MORRELL, F. 1967. Electrical signs of sensory coding. *In* G. C. Quarton, T. Melnechuk and F. O. Schmidt (ed.), The neurosciences, A study program. The Rockefeller Univ. Press, New York, p. 452–467.

MORRELL, F. 1972. Integrative properties of parastriate neurons. *In* A. G. Karczmar and J. C. Eccles (ed.), Brain and human behavior. Springer—Verlag, New York, p. 259–289.

NORMAN, R. J., VILLABLANCA, J. R., BROWN, K. A., SCHWAFEL, J. A. and BUCHWALD, J. A. 1974. Classical eyeblink conditioning in the bilaterally hemispherectomized cat. Exp. Neurol. 44: 363–380.

OAKLEY, D. A. 1971. Instrumental learning in neodecorticated rabbits. Nat. New Biol. 233: 185–187.

PAVLOV, I. P. 1927. Conditioned reflexes. Translated and edited by G. V. Anrep, New Dover edition, 1960. Dover Pub., New York.

POLTYREFF, S. S. and ZELIONY, G. P. 1930. Grosshirnrinde und Assoziations--funktion. Z. Biol. 90: 157–160.

ROITBAK, A. I. 1970. A new hypothesis concerning the mechanism of formation of the conditioned reflex. Acta Neurobiol. Exp. 30: 81–94.

SAKHULINA, G. T. and MERZHANOVA, G. K. 1966. Stable changes in the pattern of the recruiting response associated with a well-established conditioned reflex. Electroencephal. Clin. Neurophysiol. 20: 50–58.

SCHEIBEL, M. E. and SCHEIBEL, A. B. 1971. Developmental relationship between spinal motoneuron dendrite bundles and patterned activity in the forelimp of cats. Exp. Neurol. 30: 367–373.

SKINNER, B. F. 1938. The behavior of organisms. Appleton-Century, New York.

SOŁTYSIK, S. 1960. On the intercentral connections in the reflex arc of the alimentary conditioned reflexes (in Russian). *In* E. A. Asratyan (ed.), Tsentral'nye i perifericheskie mekhanizmy dvigatel'noi deyatel'nosti zhivotnykh. Izdat. AN SSSR, Moscow, p. 58–60.

TEN CATE, J. 1934. Konnen die bedingten Reaktionen sich auch ausserhalf der Grosshirnrinde bilden? Arch. Neerl. Physiol. 19: 469–481.

THOENEN, H. and OTTEN, U. 1974. Trans-synaptic regulation of neuronal enzyme synthesis by nerve impulses. Proc. XXIV Int. Congr. Physiol. Sci. (New Delhi) 10: 71–72. (Abstr. of Lectures and Symposia.)

VILLABLANCA, J. and MARCUS, R. 1971. Sleep-wakefulness, EEG and behavioral studies of chronic cats without neocortex and striatum: The "diencephalic" cat. Arch. Ital. Biol. 110: 348–382.

WYRWICKA, W. 1950. The effect of diminished alimentary excitability upon conditioned reflexes of the second type. Acta Biol. Exp. 15: 205–214.

WYRWICKA, W. 1952. On the mechanism of the motor conditioned reaction. Acta Biol. Exp. 16: 131–137.

WYRWICKA, W. 1958. Studies on the effects of the conditioned stimulus applied against various experimental backgrounds. Acta Biol. Exp. 18: 175–193.

WYRWICKA, W. 1960. An experimental approach to the problem of mechanism of alimentary instrumental conditioned reflexes. Acta Biol. Exp. 20: 137–146.

WYRWICKA, W. 1967. Manifestations of alimentary instrumental reactions in aphagic cats with lesions of the rostral hypothalamus. Acta Biol. Exp. 27: 177–183.

WYRWICKA, W. 1972. The mechanisms of conditioned behavior. Charles C. Thomas, Springfield. 179 p.

WYRWICKA, W. 1973. The organization of classical and instrumental conditioned reactions. Cond. Reflex 8: 28–40.

WYRWICKA, W., DOBRZECKA, C. and TARNECKI, R. 1959. On the instrumental reaction evoked by electrical stimulation of the hypothalamus. Science 130: 336–337.

WYRWICKA, W., DOBRZECKA, C. and TARNECKI, R. 1960. The effect of electrical stimulation of the hypothalamus on the conditioned reflexes type II. Acta Biol. Exp. 20: 137–146.

ŻERNICKI, B., DOTY, R. W. and SANTIBANEZ-H., G. 1970. Isolated midbrain in cats. Electroenceph. Clin. Neurophysiol. 28: 221–235.

Received 3 December 1974

Wanda WYRWICKA, Department of Anatomy and the Brain Research Institute, University of California, School of Medicine, Los Angeles, California 90024, USA.