Summary

1. Our understanding of the localization, formation, and arousal of memory traces, of the process of abstraction and generalization and of the psychophysical relations of all these processes is still very unsatisfactory in spite of thousands of relevant investigations. The author comments several findings of different researchers, gives a summary of his and his coworkers' relevant investigations and discusses briefly some possible hypothetical conceptions.

2. Up to now the extension of nervous structures which are involved in the formation of engrams is not sufficiently known. It is also not clear whether or not brain regions of sensations and regions of corresponding mental images are identical (Fig. 1).

   During learning processes excitations in relatively extensive brain regions occur (Fig. 2). In mammals the brainstem and the midbrain and especially the hippocampus formation can be involved. These statements strengthen the opinion that the formation of a simple memory trace takes place in a network which comprises very many neurones.

3. Numerous experiments proved that larger species of vertebrates can simultaneously master more optical tasks and retain such tasks for a longer period than smaller species of the same relationship, which have absolutely smaller brains and less dendritic ramifications of their smaller neurones (table 1). In mammals this increased ability to produce more engrams also depends upon the fact that the 5–7-layered cortex, the isocortex, is relatively more expanded than in related smaller species (table 2). This fact strengthens the assumption, that in mammals memory traces mainly originate in the cortex.

   In mammals mainly the cortex of the forebrain is involved in forming visual engrams, in fishes the midbrain, and in Hymenoptera and Cephalopoda central nervous systems of totally different structure. In spite of this fact the learning capacity of large fishes is similar to that of small mammals like mice, and the capacity of small fishes is similar to that of bees, bumble-bees and Octopus. This statement indicates that the special structure of a brain is not so important for visual learning as its absolute size and the number of neurons and possible synapses.

B. Rensch et al., Probleme der Gedächtnispuren.
Was kann der Biologe noch von der Elektronenmikroskopie erwarten?
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4. It was possible to demonstrate the probable extension of simple visual engrams in the tectum opticum of fishes and frogs by autoradiographic methods. The animals were treated with curare, injected with $3\cdot \text{H}$-histidine which becomes incorporated in brain neurones, and fastened in a special device (Fig. 6). Then one eye was alternately stimulated by one or two vertical stripes of light. Later autoradiographic analysis of the brain sections showed an increased protein synthesis in the anterior region of the tectum opticum when the eye had been stimulated by one stripe of light, and also a second maximum when two stripes of light had been applied (Fig. 3–9).

The autoradiographic method has the advantage that no motoric reactions are connected with the optical excitations (no operant conditioning) and that the deeper cell layers in the tectum opticum seem to be the endstations of optical excitations.

5. When vertebrates with totally crossed optical tracts like fishes or birds are monocularly trained, they will recognize the learned pattern also with the other eye, which was covered during training. If later-on the learned patterns are successively altered the animals show much better results when seeing with the learning eye than with the formerly covered one. These results indicate that an engram is probably produced in both hemispheres, but in the ipsilateral hemisphere by way of commissures in a weaker manner. It was possible to train two geese monocularly, first with one then with the other eye in such a way that they reacted to the same pair of pattern in an opposite manner, when they saw the patterns with the left or the right eye (Fig. 10, 11).

6. The biochemical basis of memory traces is not yet sufficiently known. If an animal is trained to learn a task the production of RNA as well as of proteins increases. It is, however, more probable that engrams are based on protein compounds because longterm-memory can be prevented by puromycin or acetoxycycloheximid which blocks protein synthesis. Up to now glykoproteins reacting by "recognition functions" on the synapses can be regarded as the most probable basis of engrams ("Learnein": S. Bogoch).

Direct transfer of brain extracts of RNA of trained animals into untrained ones did not prove the transfer of special engrams but only an opposite reaction to two kinds of stimuli. It may be that such easy alternation between turning towards a pattern or away from it or between positive and negative phototaxis occurs in the brainstem (for instance: ritualized in the zig-zag dance of the male of the stickleback).

In fishes and guinea-pigs the period of retaining a learned optical task could be enlarged by application of chlorpromazine after training or by keeping the fishes in darkness after training (Fig. 12–14). These results indicate that forgetting is primarily caused by abolition of synapses.