

# A Brief History of the Reticular Formation

By David D. Olmsted (Copyright - 1998)

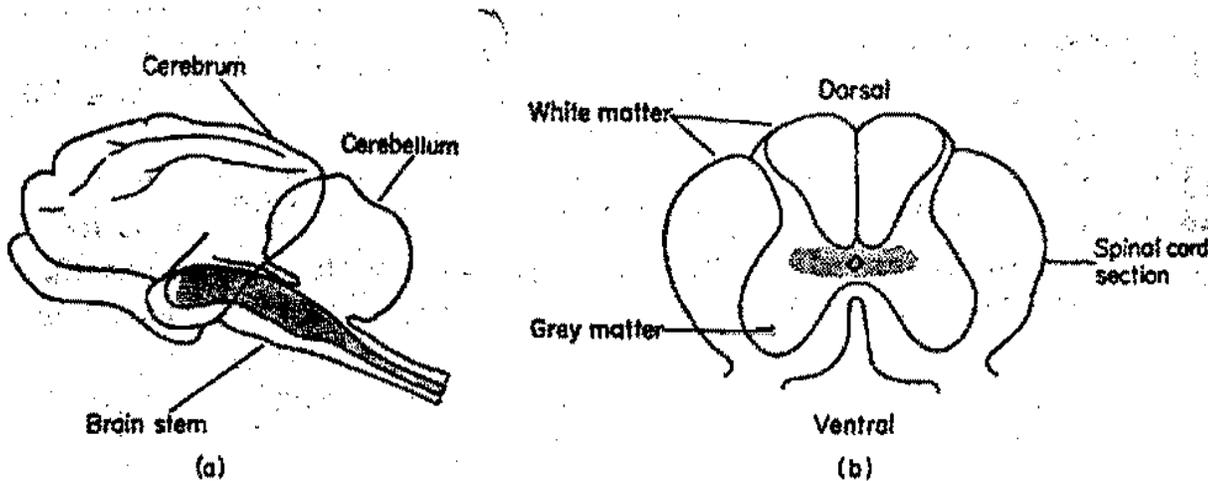


FIG. 1. Cat brain (a) and section of spinal cord (b) with R.F. regions hatched in. The RF extends from the head of the brain stem throughout the core of the spinal cord.

## Downward (Tailward) Projections

The reticular formation (RF) began to receive attention in 1909 with the anatomical brain investigations of Santiago Ramon y Cajal of Spain. Using the new silver chromate staining method first developed by Golgi he revealed the shapes of individual neurons for the first time. Because of his careful work Cajal realized that the brain was composed of individual cells (neurons) and was not a continuous net (reticulum) of fibers as was believed by Golgi. Cajal commented on the extensive multiple branchings of the reticular formation neurons as they ascended and descended through the middle of the brain stem. Building on some earlier German work, J.W. Papez in 1926 published a definitive work describing the reticular formation's projections down to the spinal cord in cats.

## Upward (Headward) Projections

That the reticular formation had ascending projections to higher brain centers was inferred in 1935 by F. Bremer of France. He demonstrated that severing the brain from the reticular formation produced a sleep like state now called a coma which lasted until the animals died. The early 1940's saw a series of papers published by Morison and Dempsey (Dempsey, et al -1941), (Morison, et al - 1942a, 1942b) of the U.S.A. describing the mammalian thalamic projections to the cortex which were under reticular formation influence and which presumably were responsible for producing the coma.

**ARAS  
Proposed &  
then  
Discredited**

By 1950 researchers were localizing various ascending effects by lesioning different regions of the reticular formation (see Lindsley, Schreiner, Knowles, and Magoun, 1950). The conclusion reached by all of these studies was that the ascending reticular formation signals kept the animal alert and awake with the result that this projection came to be known as the Ascending Reticular Activating System of ARAS. Consequently, sleep was assumed to be produced by a lack of ascending reticular formation signals yet in 1953 this assumption was challenged by Hess, Koella, and Alcart of Germany who found that sleep could be produced by stimulating certain sites within the reticular formation.

**First Motor  
Effects**

The first clue that the reticular formation had an influence on motor activity was provided in 1946 by Rhines and Magoun of the U.S.A. Electrical stimulation of the reticular formation in anesthetized cats or in restrained cats having having their brain stem severed from the rest of the brain (decerebrate) and thus in a coma produced changes in muscle tone.

**Motor  
Actions  
Produced in  
Mammals**

The first electrical stimulation studies of the reticular formation in free-moving unanesthetized can were undertaken by Americans Sprague and Chambers in 1954. Stimulation at one site in a cat sitting or standing produced the pre-rest actions of circling and lying down. the lying down ended when the stimulation ended. Stimulation of another site with the cat initially in a reclining position produced the action of standing and then circling.

**Motivation  
Releasing  
Strategy  
Demonstrated  
in Birds**

The electrical stimulation experiments of the mammalian reticular formation by Hess inspired fellow Germans Eric von Holst and Ursula von Saint-Paul to try the same procedure in chickens with their report appearing in English in 1961. Since birds do not have a large cerebral cortex to plan motor actions these experiments more clearly exhibited the motivation releasing strategy of the reticular formation. In his work on birds von Holst was following the ethological tradition established by fellow Germans Konrad Lorenz and Nikolaas Tinbergen who together first developed the concept of the "Innate releasing mechanism" from their observations of bird behavior. This concept states that whenever the motivation is the same, a defined set of stimuli will always release a specific motor response. Lorenz was the first to propose this concept in a 1935 German paper but not until 1948 and 1951 did Tinbergen introduce this concept to the English speaking world.

**Error  
Criterion  
Effect in  
Object  
Recognition**

The region of the brain actually stimulated by von Holst and von Saint-Paul involved the whole motivation system ranging from the septum to the hypothalamus and down to the reticular formation and their report does not precisely identify the locations of each stimulation. Still the error criterion effect of the level of motivation on object triggered motor actions is clearly shown in one experiment. When a stuffed polecat (a small predator of chickens) was placed next to an unstimulated rooster the rooster made no response yet the same stuffed polecat was attacked by the rooster when its brain was stimulated (page 18). Under strong stimulation the rooster would even attack the face of the human handler. Notice that these actions are target directed behaviors and not simply inflexible reflexive behaviors. Often a sequence of actions could be produced by gradually increasing the level of the stimulation. One sequence begins with the chicken exhibiting "fear" as

indicated by its rapidly looking about and progressing to clucking, standing, walking around or defecating, and finally flight. Instead if the stimulation is suddenly increased to maximum the chicken will abruptly fly off screaming (page 16).

### **Strongest Motivation Gains Access to Motor Actions**

Their stimulation of two sites simultaneously shows that the strongest stimulation gains access to the motor actions. Stimulation of one of these sites produced the escape sequence of standing, walking about, and then jumping off a ledge while stimulation of the other site produced a sitting action. Simultaneous activation of these sites resulted in the sitting action but gradually increasing the stimulation of the escape sequence site resulted in the chicken suddenly jumping off the ledge (page 16).

### **More Mammalian Projections to the Reticular Formation**

The early 1960's produced more information about the reticular formation's inputs in mammals. These advances were based upon the nerve degeneration method in which the cell body is destroyed leading to the degeneration of its axon which can then be stained and observed. The major inputs originated from the spinal cord (body state information), the solitary complex (gastro-intestinal information), vestibular nuclei (balance and motion information), and the trigeminal nuclei (body state information from the head and neck). (See Brodal & Rossi, 1955; and Valverde, 1961). Another major input to the reticular formation originated in the tectum which provides visual, auditory, and tactile pattern information (Altman and Carpenter, 1961). A smaller input arrives from the fastigial nucleus of the cerebellum (Walbery, et al, 1962)

### **More Non-Mammalian Projections**

Not until later were the reticular formation connections in non-mammals investigated. In the late 1960's the tectum projections to the reticular formation were confirmed in a wide variety of non-mammals (see Foster and Hall, 1975, for references). Yet not until the late 1980's were the descending reticular projections to the spinal cord confirmed (see Prasada, Jadhao, and Sharma, 1987, for references). The ascending reticular formation projections to the thalamus have only been found in reptiles (see ten Donkelaar and de Boer-van Huizen, 1981).

### **Projections from the Hypothalamus**

Yet even better neural axon tracing methods were needed before projections from the hypothalamus were reported in 1981 with the publication of a paper by Morrell, Greenberger, and Pfaff. This work relied upon methods developed during the mid 1970s which used special dyes which are taken up by neurons and transported down their axons. Discovering these projections using axon degeneration methods would have required massive destruction of the hypothalamus which in turn would have killed the animal.

### **Early Hint of the Hypothalamic Projection**

Yet even as early as 1968 hints existed for a hypothalamic projection to the reticular formation. The posterior hypothalamus (the end of the hypothalamus nearest to the reticular formation) was shown to be required for avoidance types of operant conditioning. American Quentin Register destroyed the posterior hypothalamus on only one side of a fish previously trained to escape from a square image of black dots in order to avoid a shock. When the square was presented to the eye on the side opposite that of the destroyed hypothalamus (the optical path from the eyes cross over to the opposite side of the brain) the fish either didn't respond or responded only very slowly.

**Conventional  
View of the  
Reticular  
Formation**

**In 1967 M.E. Scheibel and A.B. Scheibel produced the now classic pictures of the neural structure of the reticular formation. Their suggested functions of the reticular formation were:**

"a determination of operational modes, gating mechanism for all sensory influx, modulation and monitor of cortical function, readout mechanism for cortical differentiative and comparative processes, and gain manipulator for motor output."

**Such general conclusions were little changed in a 1984 review by A.B. Scheibel.**

**First (and  
only?) Model  
Until the One  
Presented at  
This Site**

**Using the anatomical data from the Scheibels, W.L. Kilmer, W.S. McCulloch, and J. Blum presented several papers on their Difference Enhancement Models of the reticular formation (S-RETIC and STC-RETIC) which culminated in their 1969 paper coinciding with the end of the first phase of interest in neural networks. While their models have many problems their view of the reticular formation as an animal's central command system was accurate as shown by this excerpt:**

No animal can, for instance, fight, go to sleep, run away, and make love all at once. We have listed as mutually incompatible modes of vertebrate behavior:

- sleep
- eat
- drink
- fight
- flee
- hunt (for prey or fodder)
- search (or explore)
- urinate
- defecate
- groom
- mate (or sex)
- give birth (or lay egg)
- mother the young (including suckling or hatching, retrieval, perineal licking, and so on)
- build or locate a nest
- and special innate forms of behavior such as migrate, hibernate, gnaw, and hoard, depending on the species

Some may challenge this particular list, but the point is that there are not more than about 25 such modes. An animal is said to be in a mode if the main focus of attention throughout its central nervous (CNS) is on doing the things of that mode. We hypothesize that the core of the reticular formation (RF) is the structure in vertebrates that commits the animal to one or another mode of behavior.

**In 1973 the reticular formation region called the Mesencephalic Locomotor Region (MLR) responsible for releasing locomotion actions in the cat was found by Grillner and Shik of the U.S.S.R. It is located just below the auditory tectum (inferior coliculus in mammals). After severing the brain stem just behind the hypothalamus to prevent interfering signals from**

**The Releasing  
Center for**

## Locomotion in Cats

entering the reticular formation stimulation of the MLR always produced a locomotor action. If a part of the hypothalamus is included in with the reticular formation then spontaneous locomotion actions and other actions are observed. If instead if the cut is made lower in the reticular formation below the red nucleus then no amount of stimulation of the MLR will produce locomotion suggesting that body state information is blocking the triggering signal. Since the red nucleus receives most of its inputs from the cerebellum it very likely is responsible for modulating these body state signals. After all, the body must be in an upright posture before walking to begin or in a state which the cerebellum can transform to an upright posture.

## Activity of Neurons in the Reticular Formation

The 1970's saw the introduction of micro-electrodes capable of recording the activity of single cells. These studies found that most cells of the reticular formation were responsive in some way to sensory stimulation yet they also found that the activity of the cells correlated best with motor activity (see Siegel and McGinty, 1977). A few tonically active cells were also found which increased their firing rate in response to sound or light stimuli associated with a shock in a classical conditioning situation (Vertes and Miller, 1976).

## References

- Altman, J. and Carpenter, M.B. (1961) fiber Projections of the Superior Colliculus in the Cat. *Journal of Comparative Neurology* 116:157-178
- Bremer, F. (1935) Cerveau "isole" et Physiologie du Sommeil. *C.R. Soc. Biol.* 118:1235-1241
- Brodal, A. and Rossi, G. (1955) Ascending Fibers in Brain Stem Reticular Formation of Cat. *Arch. Neurol. Psychiatry* 74:68-87
- Dempsey, E.W., Morison, R.S. and Morison, B.R. (1941) Some Afferent Diencephalic Pathways related to Cortical Potentials in the Cat. *American Journal of Physiology* 131:718-731
- Grillnew, S. and Shik, M.L. (1973) On the Descending control of the Lumbrosacral Spinal cord from the "Mesencephalic Locomotor Region" *Acta Physiol. Scnd.* 87:320-333
- Hess Jr. R., Koella, W.P. and Alcart, K. (1953) Cortical and Subcortical Recordings in Natural and Artificially Indiced Sleep in Cats. *Electroencephalogr. Clin. Neurophysiol.* 5:75-90
- Kilmer, W.L., McCulloch, W.S., Blum, J. (1969) A Model of the Vertebrate Central Command System. *International Journal of Man-Machine Studies* 1: 279-309
- Lindsley, D.B., Schreiner, L.H., Knowles, W.B., and Magoun, W. (1950) Behavioral and EEG Changes following chronic Brain Stem Lesions in the Cat. *Electroencephalogr. Clin. Neurophysiol.* 2:483-498
- Lorentz, K. (1935) Der Kumpan in der Umwelt des Vogels. Der Artgenosse als auslösendes moment sozialer Verhaltensweisen. *Journal fur Tierpsychologie* 5:235-409
- Magoun, H.W. and Rhines, R. (1946) An Inhibitory Mechanism in the bulbar Reticular Formation. *Journal of Neurophysiology* 9:165-171
- Morison, R.S. and Dempsey, E.W. (1942a) A Study of Thalamo-cortical Relations. *American*

Morison, R.S. and Dempsey, E.W. (1942b) Mechanism of Thalamo-cortical Augmentation and Repetition. *American Journal of Physiology* 138:297-308

Morreell, J.I., Greenburger, L.M., and Pfaff, D.W. (1981) Hypothalamic, other Diencephalic and Telencephalic Neurons that Project to the Dorsal Mid-brain. *Journal of Comparative Neurology* 41:365-399

Papez, J.W. (1926) Reticulo-spinal Tracts in the Cat, Marchi Method. *Journal of Comparative Neurology* 41:365-399

Prasada Rao, P.D., Jadhao, A.G., and Sharma, S.C. (1987) Descending Projection Neurons to the Spinal Cord of the Goldfish, *Carassius auratus*. *Journal of Comparative Neurology* 265:96-108

Ramon y Cajal, S. (1909, 1911) *Histologie du Systeme Nerveux de L'homme et des Vertebres Maloine, Paris; volumes 1 and 2*

Regestein, Q.R. (1968) some Monocular Emotional Effects of Unilateral Hypothalamic Lesion in Goldfish, pages 139-144 in *The Central Nervous System and Fish Behavior*, edited by David Ingle; University of Chicago Press, Chicago, IL

Rhines, R. and Magoun, H.W. (1946) Brain Stem Facilitation of cortical Motor Responses. *Journal of Neurophysiology* 9:219-229

Scheibel, M.E. and Scheibel, A.B. (1967) Anatomical Basis of Attention Mechanisms in Vertebrate Brains, Pages 577-602 in *The Neurosciences: A Study Program*, edited by G.C. Quarton, T. Melnechuk and F.O. Schmitt; Rockefeller University Press, New York

Schiebel, A.B. (1984) The Brain Stem Reticular Core and Sensory Function, pages 213-256 in *Handbook of Physiology; the Nervous System volume 3, part 1*, edited by S.R. Gieger; American Physiological Society, Bethesda, MD

Siegal, J.M. and McGinty, D.J. (1977) Pontine Reticular Formation Neurons: Relationship of Discharge to Motor Activity. *Science* 196:678-680

Sprague, J.M. and Chambers, W.W. (1954) Control of Posture by Reticular Formation and Cerebellum in the Intact, Anesthetized and Unanesthetized and in the Decerebrated Cat. *American Journal of Physiology*. 176:52-64

ten Donkelaar, H.J and de Boer-van Huizen, R. (1981b) ascending Projection of the Brainstem Reticular Formation in a Non-mammalian Vertebrate (the Lizard *Varanus exanthematicus*) with Notes on the Afferent Connection of the Forebrain. *Journal of Comparative Neurology* 200:501-528

Tinbergen, N. (1948) Social Releasers and the Experimental Method Required for Their Study. *Wilson Bulletin* 60:6-52

Tinbergen, N. (1951) *The Study of Instinct*. Clarendon Press

Valverde, F. (1961) Reticular Formation of the Pons and Medulla Oblongata. A golgi Study. *Journal of Comparative Neurology* 116:71-99

Vertes, R.P. and Miller, N.E. (1976) Brain Stem Neurons that Fire Selectively to a Conditioned Stimulus for Shock. *Brain Research* 103:229-242

von Holst, E. and von Saint-Paul, U. (1961) On the Functional Organization of Drives. *Animal Behavior* 11:1-20

Walberg, F., Pompeiano, O., Westrum, L.E. and Hauglie-Hanssen E. (1962) Fastigiotectal Fibers in Cat. An Experimental Study with Silver Methods. *Journal of Comparative Neurology* 119:187-199

## **Revision Log**

(8-26-98) Added figure 1 and first model description