The Design of a Sensation-generating Mechanism in the Brain:

A first step towards a quantitative definition of consciousness

Authors:

Alan Rosen
Machine Consciousness Inc.
1917 Clark Lane #B
Redondo Beach, CA, 90278
e-mail: arosen@mcon.org
Tel. 310 367-3881

David Rosen
Machine Consciousness Inc.
e-mail: dbenrosen@mcon.org

Submitted to the Consciousness and Cognition International Journal

The authors would like to thank the Consciousness and Cognition International Journal for granting permission to publish in the ASSC e-print archive

ABSTRACT

Subjective experiences called sensations, described as modalities of biological receptors, have been correlated with the receptors, the afferent axons, and the central connection in the brain that they activate. The central connections, represented by a neuronal circuit, may be viewed as a sensation generating mechanism that generates the sensation defined by the modality of the receptor. The sensation generating circuit, consisting of the afferent axons and the central connections in the brain activated by the receptor, is studied by reverse engineering the “itch-feeling” modality of a mechanoreceptor. The study is performed on a robotic model, called a itch-scratch robotic model, that is designed to reverse engineer the sensorimotor control functions of human “itch-scratch” behavior patterns. The subjective experiences of the robot, viewed as modalities of robotic sensors, may form a basis for a quantitative definition of “consciousness” that consists of modalities described as sensations and emotions.

I. INTRODUCTION

In the field of psychophysics[1], sensations have been correlated with the modalities of biological receptors for over 150 years (Weber, 1846; Felchner, 1860). The sensations range from touch-feel, pain-feeling, visual seeing, auditory hearing, olfactory smelling and gustatory tasting.

A sensation is a subjective experience, experienced by a person, correlated with the receptor, and measurable only to the extent that the incident energy falling on the receptors, and the response of the receptor to that incident energy, is measurable. The subjective experience of a sensation is often described as a psychophysical phenomenon, not to describe "consciousness", but to denote that there are measurable parameters correlated with the "conscious" psychological experience of the sensation[1].

These sensations, described as modalities of receptors, have been correlated with the receptors, the afferent axons, and the central connection in the brain that they activate.

The central connections in the brain, that are activated by the receptors, may be viewed as a neuronal circuit in the brain.

The authors postulate that the neuronal circuit in the brain, represented by the central connections, is a sensation generating mechanism that generates the sensation defined by the modality of the receptor. This neuronal circuit, called a Neuronal Correlate of a Modality (NCM)-circuit, may be regarded as the Sensation-generating Mechanism (SgM) that generates the sensation defined by the modality of the receptor.

A study of an itch-Sensation-generating Mechanism, and the connectivity of a NCM-circuit associated with it, was published by Rosen and Rosen (2006a,b) and presented at the IEEE-IJCNN WCCI-Vancouver 2006 conference and the ICONIP-2006 Hong Kong conference[2]. The connectivity of the NCM-circuit was determined by reverse engineering the connectivity of mechanoreceptors, the afferent axons and the central connections in the brain activated by the receptors. The study was performed on a robotic model, called a itch-scratch robotic model, that is controlled by a neural net based controller that is designed to reverse engineer the sensorimotor control functions of human "itch-scratch" behavior patterns[3]. The design of the NCM-circuit is based on the neurophysiology of the brain, and the connectivity of the mechanoreceptors, the afferent axons, and the central connections activated by the receptors. The mechanical itch-NCM-circuit sheds light of the neurophysiology and operational functions of the brain (Rosen & Rosen, 2006a.b).

The mechanoreceptors and their connectivity is assumed to adhere to the biological "labeled line" principle (Guyton, 1991), or the "Law of Specific Sense Energy" first enunciated by Johannus Müller (1826). The Law of specific Nerve Energy (Haines, 2002) ensures that each type of sensor responds specifically to the appropriate form of stimulus that gives rise to a specific sensation. In the biological system the specificity of each modality is maintained in the central connections of sensory axons. Thus the term "stimulus modality" encompasses the receptor, afferent axons, and the central pathways that are activated by the stimulus. It is noted that the central connections associated with sensory modalities often form neurological topographic mapping, or brain modules, in various regions of the brain. The paper published by Rosen and Rosen (2006a, b) shows that these brain modules may be used to form a coordinate frame in the brain that is utilized to design the itch-NCM-circuit and the biological sensorimotor control system that controls the itch-scratch robotic model.

The significance of the itch-NCM-circuit is a) the discovery of added-receptor NCM-circuits may expand the studies of the neurophysiology of the brain to additional regions in the brain, b) expand the study of sensory psychophysics, generally regarded as a sub-discipline of psychology, into the study of neural physiology and functionality of the human brain, and c) lead to a first step in the definition of “consciousness” in terms of the totality of NCM-circuits that have modality-sensations correlated with them.

II. METHOD: THE DESIGN OF A SENSATION GENERATING MECHANISM

The design of the itch-NCM-circuit is identical to the design of the itch scratch Relational Robotic Controller (RRC) that controls the itch-scratch robotic model (Rosen & Rosen, 2006a,b). Both the NCM-circuit and the RRC-circuit convey the four basic attributes of a “sensation;” modality, location, intensity, and timing[1]. The following sections present the design constraints imposed on an itch-NCM-circuit to assure that it is also an itch-Sensation-generating Mechanism (SgM). The constraints show that the primary characteristic of a reverse engineered itch-modality is that it gives rise to a sensory form of “robotic self knowledge” (“self” location and identification) in a coordinate frame defined by the itch sensors and located within the controller. The detailed design of the NCM-circuit has already been published (Rosen & Rosen, 2006a.b;

1. THE BUILDING PATH OF THE ITCH-NCM-CIRCUIT

The building path presented by Rosen and Rosen (2006b) is based on topographic mappings and patterns of organization within the brain that are called “brain modules”. Purves et al (1992) write that “Patterns of organization within the sensory cortices may be a fundamental feature of the cerebral cortex, essential for perception, cognition, and perhaps even consciousness.” The brain modules may be used to form a coordinate frame and a sensorimotor control circuit within the robotic controller. Figure 1 shows a coordinate frame within the controller associated with the patterns of organization in the somatosensory cortex, and the somatic sensors used to locate the “robotic self” in that coordinate frame (Rosen & Rosen, 2006b). The robotic sensorimotor control circuit may be utilized to define a mechanical sensation generating mechanism that is the analogue to the biological sensation generating mechanism.

2. THE REVERSE ENGINEERED BODY AND BRAIN

The reverse engineered model consists of a) a mechanical robotic body controlled by position locating motors (simulating the biological muscles and position measuring proprioceptors), b) a neural network based robotic controller, c) an array of pressure transducers uniformly distributed along the peripheral surface of the robotic body (simulating biological mechanoreceptors), and d) thin electrical low voltage wires (simulating the afferent and efferent somatic pathways) between the pressure transducers and the controller and between the controller and the motors.

Neural network models for the sensorimotor control functions of the brain have been studied by Stephen

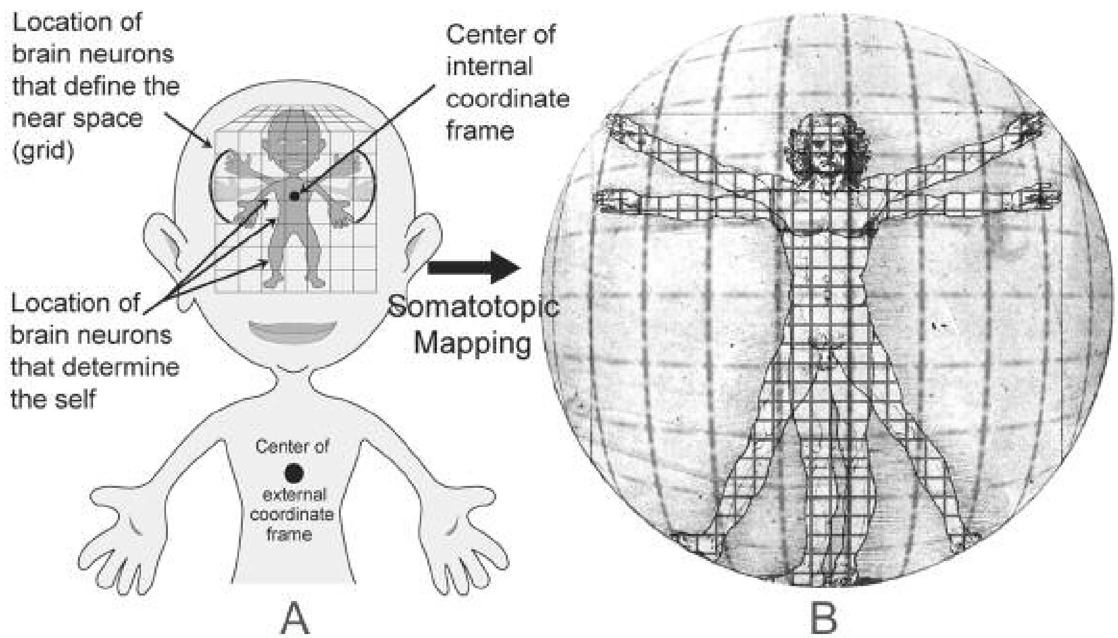

Fig. 1 A coordinate frame within the controller. The neuronal coordinate frame (world map) shown in A, encompasses the total region of space (the near space) defined by flailing limbs shown in B. All motion of limbs, head, shoulders, and hip is determined relative to the origin-center of the internal coordinate frame, and the corresponding thoracic cavity-center in the external coordinate frame.
(figure courtesy of MCon Inc.)

Grossberg (1987a,b, 1988, 1998)[4], Teuvo Kohonen (1982a,b,c), and many others (Ritter et al, 1992), (Guenther et al 2001). The building path for the sensorimotor control of the itch-scratch robotic system is described in a paper titled “Sensorimotor control by Reverse Engineering biological Modalities (Rosen & Rosen, 2006a.b). A Dennett type building path (Dennett, 1997, 1995) is specified for a complete system consisting of a robotic controller, controlled by neural network equations (Ritter et al, 1992), and a robotic body controlled by motors with one torque generating motor per degree of freedom.

2.1 The Robotic Body

The robotic body is a reverse engineered functional model of the muscle-motors of the human body. Thus, the model consists of an array of motors placed at the analogous positions of every joint of the human body, with the same number of degrees of freedom and range of motion as the human body. Each degree of freedom is implemented by a motor and angle measuring transducer. The motor generates a torque about a single axis coincident with the shaft of the motor, whereas the angle measuring transducer records the rotary-angular position of the shaft. Figure 2 is an illustration of the 21-joints of the robotic body. There are as many as 3-motors and 3-angle measuring transducers associated with each joint (a total of 39-motors associated with the 21-joints shown in the figure). During each frame period (selected to be 1/30-seconds), the robotic controller controls all 39-motors simultaneously (39-output signals per frame period).

2.2 The Robotic Controller

The controller is a hybrid circuit made up of electronic neural networks and microprocessors that execute sequential algorithmic programs. The input to the controller originates from sensors that are distributed on the

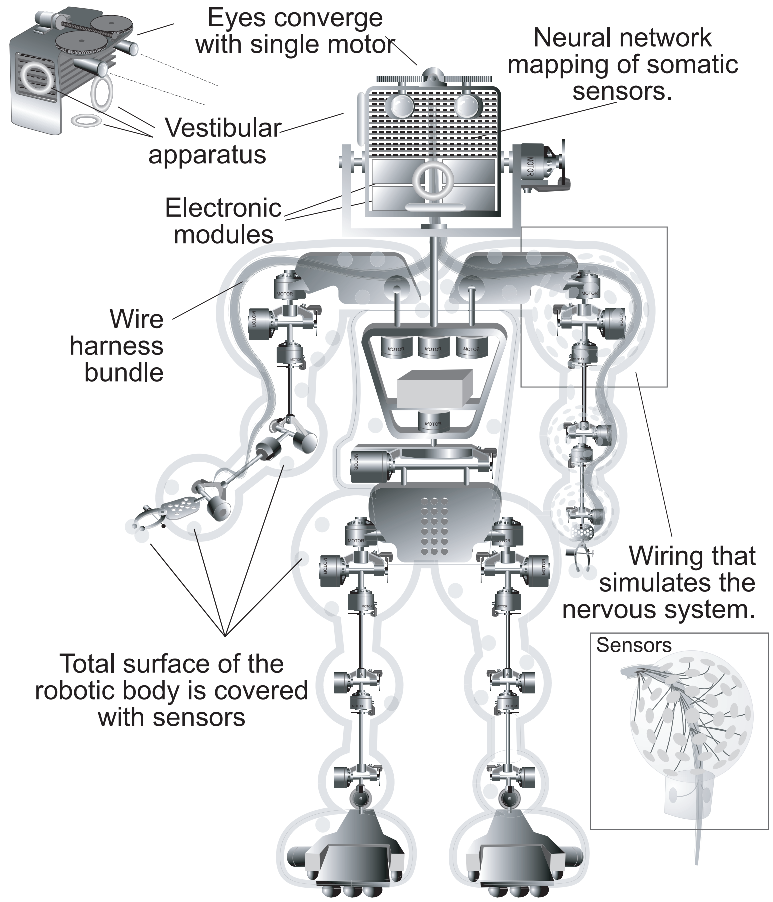

Fig. 2. A reverse engineered building path for the major muscles and sensors that are used to control locomotive functions. The mechanoreceptors and nociceptors, the proprioceptors, and the vestibular sensors, are reverse engineered by pressure transducers uniformly distributed on the robotic (skin) surface, the angle measuring transducers associated with each motor, and the circular rings on the controller (head) section of the robot, respectively. The nervous system is reverse engineered by thin wires that connect all the sensors, via cable wire bundles, to the controller (see insert) The modalities of the camera/eyes (not discussed in this paper), have been studied by Rosen and Rosen (2003c)(figure courtesy of MCon Inc.)

surface of the robotic body. The outputs of the controller are control signals that are simultaneously directed to the motors located at each of the joints of the robotic body. Figure 3 shows a graphic representation of the configured input and output circuits of the neural network portion of the controller. The afferent pathways originate on the robotic body and go to the topographic organization associated with the somatosensory cortex. The efferent pathways originate in a topographic organization associated with the motor cortex, and terminate at all the motors located at all the joints of the robotic body. A robotic controller, called a Relational Robotic Controller (RRC) has been designed, reduced to practice and patented (Patent no. US 6,560,512B dated May 6, 2003). The reverse engineered input and output portions of the RRC are faithful functional emulations of neurological topographic distributions within the organic brain. The intermediate organic connectivity between the input and output has been designed to conform to functional neurobiological constraints. The neurophysiology of the intermediate circuit, not determined in this paper, is a vibrant field of neuroscience research.

The controller is a giant parallel processing unit that simultaneously controls all the joints present in the mechanical body. An internal representation of human motion must accommodate all the joints and all the motors located at those joints (more than 65-biological joints; 34-arm, 26-leg and 5-hip shoulder and neck joints (Rosen & Rosen, 2003b).

An overview description of the engineering constraints imposed on an itch-scratch-type RRC-robot is presented in the following sections. The design of the neural net circuits, and the programming solutions of both the micro-processor based and neural network based portions of the system have been published by Rosen & Rosen (2006a,b).

2.3 The Reverse Engineered Somatic Sensors and the "Robotic self" of the System

The nociceptors and mechanoreceptors of the human body are reverse engineered by pressure transducers that are uniformly distributed on the surface of the robotic body. A single pressure transducer is used to simulate both the mechanoreceptor and nociceptor at a single location. A low-pressure activation threshold is used to simulate the modality of mechanoreceptors, whereas a higher-pressure activation threshold simulates the modality of nociceptors. The uniformly distributed pressure transducers serve as a sharp boundary between the internal mechanisms of the robot and the external environment in which the robot is operating. The pressure transducers and the internal structure and mechanisms, bounded by this sharp boundary, are defined to be the "robotic self" of the system. The region external to the "robotic self" is defined to be the environment in which the robot operates.

The biological proprioceptors are reverse engineered by the angle measuring transducers, located on the shaft of each motor. For each joint of the robotic body, the angle measuring transducers may be used to determine the angular location of the shaft-end emanating from that joint[5].

2.4 The Reverse Engineered Nervous System: The law of specific nerve energy.

The wiring between the pressure transducers and the controller, and the controller to the motors, consists of thin electrical, low voltage-wires that reverse engineer the human nervous system. The connectivity of the system is assumed to adhere to the biological "labeled line" principle (Guyton, 1991), or the "Law of Specific Nerve Energy" (Haines, 2002), which ensure that each type of sensor responds specifically to the appropriate form of stimulus that gives rise to a specific sensation (in this case a low level or high level activation threshold). In the biological system the specificity of each modality is maintained in the central connections of sensory axons, so that stimulus modality is represented by receptors, afferent axons, and the central pathways that they activate.

The thin wires from the pressure transducers to the controller reverse engineer two afferent pathways; from the body mechanoreceptors through the spinothalamic tract, and from the head mechanoreceptors through the trigeminal ganglions, thence both pathways converge and pass through the brain stem and thalamus to the topographic distribution of neurons in the somatosensory cortex (see Figure 3).

The thin wires from the controller to the motors reverse engineer the efferent pathways; from the topographic distribution in the motor cortex through the pyramidal tract (with termination points in the brain stem), and thence branching from the spinal pathway to all the motor/muscles distributed on the body (Brodal, 2004) (see Figure 3).

3. THE CONSTRAINTS IMPOSED ON THE OPERATION OF AN ITCH-SCRATCH ROBOT

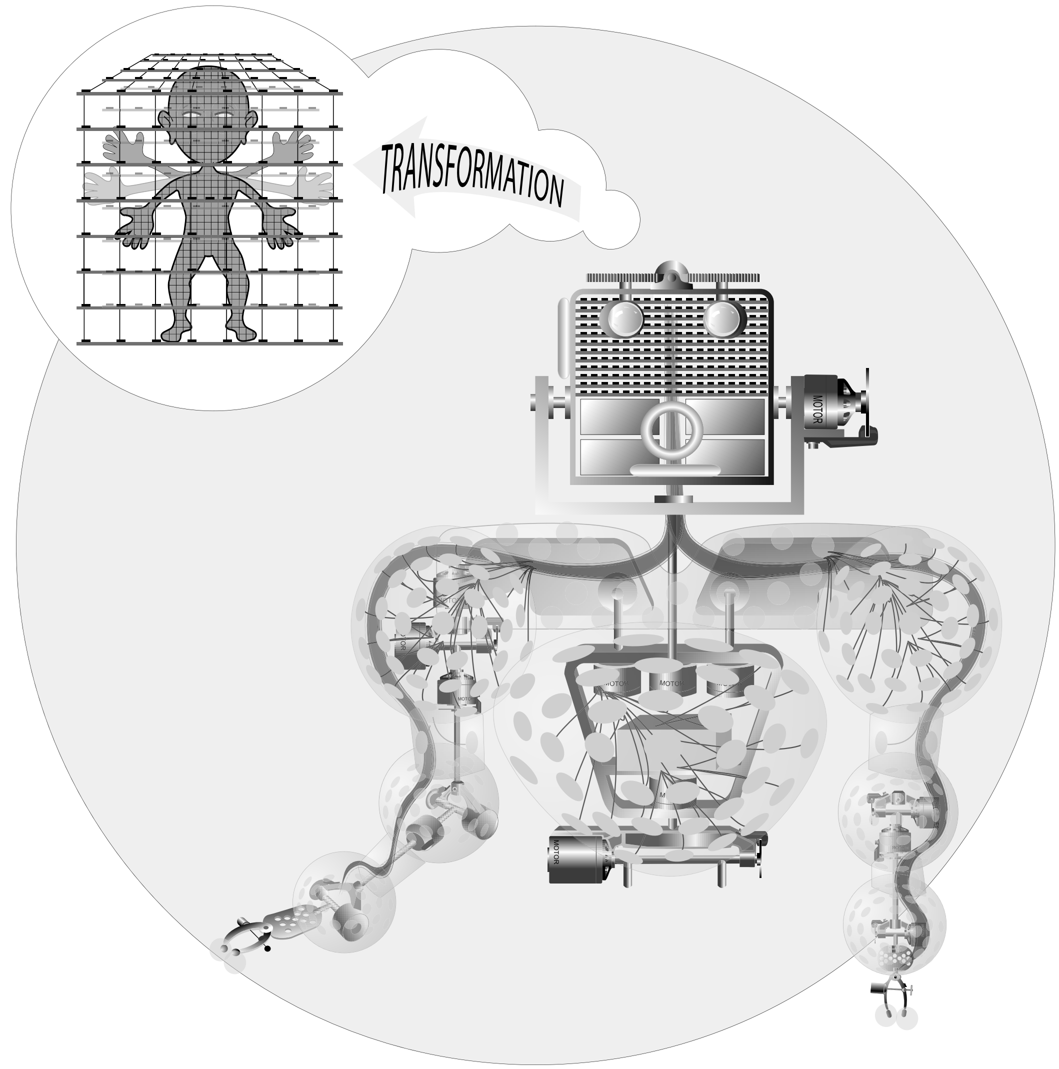

Fig. 3. A graphic representation of the configured input and output circuits of the neural network portion of the controller. The afferent pathways originate on the robotic body and go to the topographic organization associated with the somatosensory cortex.The transformation of the topographic distribution of neurons in the neural network into a humonculous is shown in the figure. This is analogous to the transformation of the organic folds of the somotosensoty cortex into a humonculous.

CONTROLLED BY THE MODALITIES OF MECHANORECEPTORS

The following operational constraints are imposed on a robotic system that is controlled by the itch-type modalities of mechanoreceptors and designed to perform a scratch-type trajectory to alleviate the itch-sensation: a) The system must perform tactile sensory monitoring of all the pressure transducers (mechanoreceptors) uniformly distributed on the robotic body. The "robotic self monitoring" performed by the system may be analogous to biological perception of itch-type activations b) The controller must locate and identify all body parts. For example, all possible itch-points and all possible end-joints used for scratching must be located and identified by the controller. "Robotic-self" location and identification may be analogous to biological self-awareness of itch-type activations. c) The robot must be programmed/taught to perform all possible itch-scratch trajectories. A robot that learns all possible itch-scratch trajectories is said to exhibit a form of "robotic self knowledge" analogous to the biological knowledge of the itch-scratch operations.

4. FOUR ENGINEERING CONSTRAINTS DERIVED FROM THE BIOLOGICAL ITCH-SCRATCH RESPONSE

The sensorimotor controlled robotic system adheres to following four engineering constraints.
These constraints are derived by reverse engineering the itch-scratch behavior pattern of biological organisms. The engineering constraints, expressed in the form of four engineering problems, have been selected to be representative of the biological system's response to itch-scratch type activations.

4.1 Constraint Associated With Tactile Monitoring for Itch-scratch-type Activations: A coordinate frame within the controller

The activated tactile sensors that are uniformly distributed on the skin surface also activate the central connections in the brain. In this paper, the central connections are reverse engineered by a neural network located within the controller. This neural circuit must monitor, locate, and identify each itch-type activation and all the biological parts used to scratch each itch-point. The first step for achieving this goal is to design a coordinate frame within the controller.

Problem 1. How to build a neural network within the controller that includes a coordinate frame defined by the pressure transducers distributed on the surface of the robotic body. The selected approach is to transform the layers of the mechanoreceptors distributed on the robotic body into a "homunculus" within the controller (similar to the transformed homunculus discovered in the somatosensory cortex (Purves et al, 1997)). The coordinate frame within the controller, associated with the region around the homunculus, is defined by electronic receiving neurons that sometimes receive signals from mechanoreceptors that are located on the flailing limbs of the robot. (See Figures 1,2 and 3)

4.2 Constraints Associated With the Location and Identification of all Body Parts: "Robotic self-identification and location"

Problem 2. How to program the robotic controller to control the trajectory of motion (scratch trajectory) of robotic limbs. The limb must move towards any identified itch-goal-point defined by an activated pressure transducer. The selected approach is to assume that a mechanical form of "self knowledge" is gained if the robot has the capability to move a robotic limb towards any and every other part of the robotic body. The robot is programmed to locate each of its surface parts (itch points) with respect to and related to the location and motion of other parts (the scratching motion of the scratch trajectory). The robot has the capability to perform an "itch-scratch" response, by moving a limb through a goal directed trajectory aimed at an "itch"-point on the robotic body.

Problem 3: How to design the RRC so that the trajectory of motion is pre-planned and goal directed with the option of re-planning (obstacle-avoiding) the pre-planned trajectory. This requirement, obstacle avoidance along the trajectory, derived from studies of biological motor control (Kandel, Schwartz & Jessell, 1991; Gazzaniga, Ivry & Mangun,1998), assures that the designed itch-scratch trajectory of motion adheres to the biological characteristics of volitional motor control[6] . The constraint for re-planning is satisfied by dividing the trajectory of motion

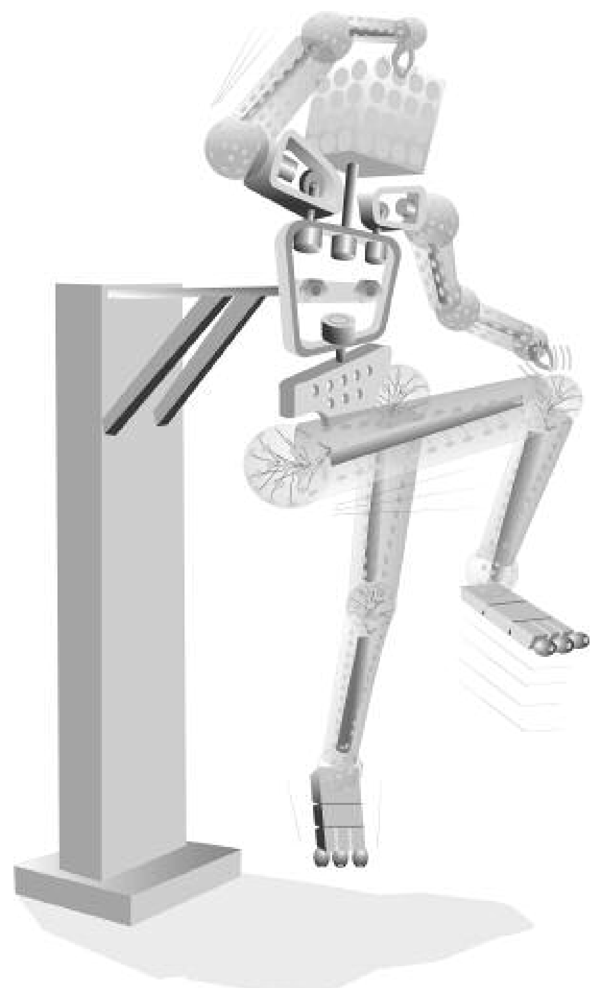

Fig. 4. A pictorial representation of a laboratory setup used to train an "itch-scratch robot. The robot is pictured with three trajectories of motion: scratching the head with the right hand calipers and scratching the knee with the left hand calipers while lifting the right leg. (figure courtesy of MCon Inc.)

into small transitions to adjacent “nodes”. During each frame period, the total goal directed trajectory is pre-planned by the RRC as a sequence of small (nodal) transitions. However, only the first small nodal transition is activated by the controller and the maximum speed of operation of the robot is one nodal transition per frame period.

Problem 4: How to train/program the RRC so that location and itch-scratch type actions executed in the internal coordinate frame correspond to movements in the “real” environment. This training or programming requires that the robot learn by means of repeated multiple itch-scratch activations the location of each of its surface parts with respect to and related to the other surface parts. This requirement may be satisfied by state of the art techniques for training/programming the neural networks system. A pictorial representation of a laboratory set-up to train the itch-scratch robot is shown in Figure 4.

A detailed technical solution to each of the four problems has been published (Rosen and Rosen, 2003a,b, 2006a,b) .

III. RESULTS: SIMILARITIES BETWEEN THE ROBOTIC CONTROLLER AND THE BIOLOGICAL BRAIN

Studies of the connectivity of sensorimotor control functions have been used to shed light on the sensory motor control neurology of the brain (Guenther et al, 2001; Grossberg, 1998; Kohonen, 2001; Ritter, 1992). A well-defined building path for the itch-scratch robotic model consisting of a robotic body controlled by a robotic controller is shown in Figure 5 (Rosen & Rosen, 2006a,b). The robotic body and controller are designed to have some functional and mechanical characteristics similar to the human body and brain. The functional similarities of the controller to the operation of the brain include:

1. The controller is a giant parallel processor that controls all the motors and joints of the robotic body simultaneously with a response time of 1/30 second and with synchronization and coordination of all body parts.

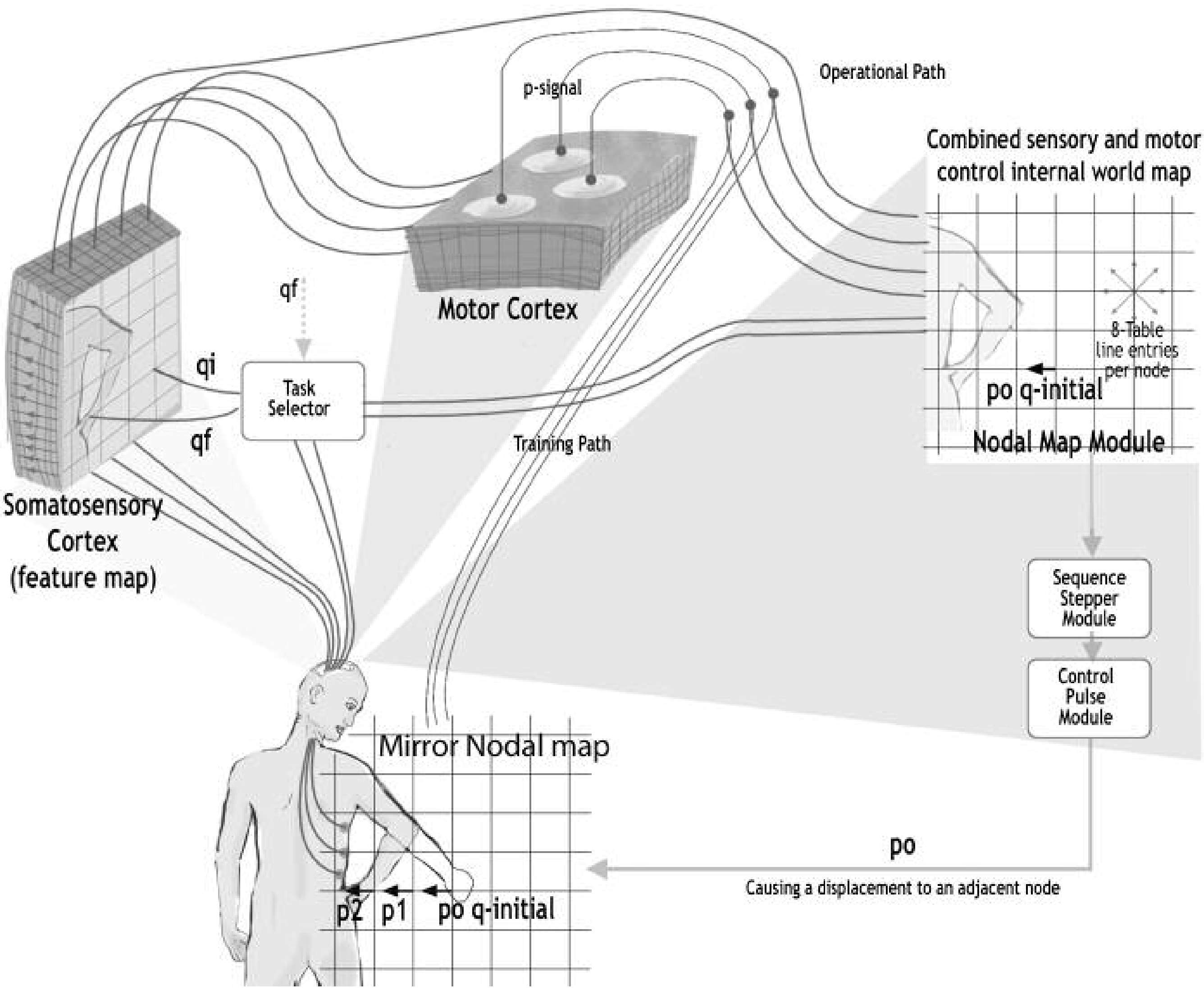

Fig. 5. A flow diagram of the q-vectors and p-vectors through the neural net portion and microprocessor based portion of the RRC. The outputs of all the Nodal Map Modules (associated with all the joints of the robotic body) are applied to the Sequence Stepper Modules, and the Control Pulse Modules, in order to control the motion of the wrist from q-initial to q-final (shown as a sequence of control vectors po, p1, p2, in the figure). (figure courtesy of MCon Inc.)

2. The pressure transducer-sensory system constantly monitors the peripheral surface of the robotic body for tactile activations. Two types of activation are designed into the system, low-pressure and high-pressure thresholds of activation. The low-pressure threshold of activation may be similar to the biological modality of "touch-feel". Whereas the high-pressure activation threshold may be similar to the biological modality of "touch-pain."
3. Similar to the biological brain, the controller has within it a reflection of the external coordinate frame that is the origin of the input signals (mechanoreceptors) and the destination point of the output signals (muscle/motors). The perceived tactile-activation data originating in the external frame are transformed and mapped, by means of direct connections associated with the nervous system, into a coordinate frame located within the RRC-controller.
4. The measure of the internal coordinates is calibrated with the measure of the 3-dimensional space in which the robot is operating.
5. The "robotic self" and the motion of the mechanical limbs of the robot with respect to the center of mass of the "robotic self" are fully defined and controlled in the internal coordinate frame as well as the external coordinate frame.
6. Similar to the biological brain, the controlled trajectories of motion are pre-planned and goal directed with the option of re-planning any planned trajectory. The control of "itch scratch" motion is goal directed and the robot has the option of re-planning (within 1/30-seconds), a pre-planned trajectory of motion in the midst of the action.
7. All the motors of the robot are trained simultaneously by means of neural networks that are initially programmed by inverse kinematics, whenever training is performed on a single end-joint associated with a Nodal Map Module.
8. The robot has the capability to be trained to perform a diverse set of actions guided by the goal directed q-final of the Task Selector Module, and limited only by the design of the sensory system, the sophistication of the neural networks in the controller and the design and the range of motion of all robotic moveable parts. Expansion of the tactile-RRC to other receptor/modalities (e.g. visual and vestibular receptors) is discussed in sections IV-3 and IV-4.

IV. DISCUSSION: COMPARISON OF THE BIOLOGICAL MODALITIES WITH "MECHANICAL MODALITIES." A PROPOSED DEFINITION OF "CONSCIOUSNESS"

Guyton (1991) writes, "Each of the principal types of sensation that we can experience- pain, touch, sight, sound, and so forth- is called a modality of sensation." The biological modality of sensation due to the stimulation of mechanoreceptors may be the subjective experience of "itch-feeling."

1. THE BIOLOGICAL NEURONAL CORRELATE OF A MODALITY (NCM)-CIRCUIT

The biological modalities are correlated with the receptors, afferent axons, and the central pathways that they activate. The central pathways, activated by each modality, may therefore be represented by a “neural-circuit.” That neural-circuit may be defined to be a Neural Correlate of a Modality (NCM)-circuit. Thus, for example, the biological sensations” of “touch feeling,” nociceptic “pain,” and thermal warmth may be correlated with three biological NCM-circuits, each circuit with specific receptors, axons, and central connections. A NCM-circuit is significant for 3-reasons:

1. The circuit has the subjective experience of a biological sensation correlated with it.
2. The circuit has a set of measurable parameters associated with it.
3. The circuit itself is an important psychophysical parameter that is related to the physiological structure of the brain.

2. COMPARISON OF THE BIOLOGICAL NCM-CIRCUIT WITH THE “MECHANICAL MODALITIES” OF THE SENSORS OF THE RRC-ROBOTIC MODEL

The somatotopic coordinate frame of the itch-scratch RRC-robot constantly monitors the state of the pressure transducer/tactile sensors for itch-type activations. The following question is posed to the reader: Is there a mechanical-type of subjective experience, analogous to the biological itch-sensation, correlated with the mechanical “itch-type” activation of the pressure transducers?

The mechanical itch-type activation is similar to the biological itch type activation in that

a) the mechanical central connections emulate the biological central connections. They both are represented by the connectivities of neural-network-based somatotopic coordinate frames.

b) Robotic location, identification and “self knowledge” are similar to biological self knowledge of itch type activations.

c) The itch-scratch motor control response of the robotic system is similar to the response of a biological system.

Based on the similarities enumerated above, it may be proposed a) the connectivity of the reverse engineered NCM-circuit is functionally similar to the biological NCM-circuit; and b) that there exists a “mechanical modality” correlated with the “itch” stimulus falling on the pressure transducer. The stimulus and the central connections of the robotic system form a circuit that is a “mechanical modality” generating mechanism. That mechanical modality integrated with the reverse engineered afferent axons and central connections may be presented to the robot as a subjective experience of the itch-type stimulus that only the robot may “feel”. The RRC-circuit is thus viewed by the authors as an itch-type Sensation-generating Mechanism (SgM).

3. DESIGNING MECHANICAL SGMS: EXPANSION OF THE TACTILE-NCM-CIRCUIT TO OTHER MODALITIES

An RRC circuit that reverse engineers the biological NCM-circuit may also be viewed as a SgM that generates a mechanical “sensation” associated with the mechanical receptors and their central connections. The primary characteristic of a reverse engineered itch-modality is that it gives rise to a sensory form of “robotic self knowledge” in a coordinate frame defined by the sensor and located within the controller. It is proposed that the primary constraints imposed on the reverse engineered design of the modality of any additional sensor (such as the vestibular or visual sensors) is that the added sensor gives rise to a form of “robotic self knowledge” in a coordinate frame defined by the added-sensor and located within the Controller. Furthermore the coordinate frame defined by the added-sensor must be consistent with, and calibrated with the coordinate frame defined by the itch-modalities of the mechanoreceptors.

This generalized reverse engineering procedure may be applied to the modalities of all the somatic as well as autonomic sensors. Thus, the design procedure for the itch-NCM-circuit may be applied to the modalities of the visual, auditory, olfactory and gustatory systems, that are correlated with the subjective experiences of “seeing,” “hearing,” “smelling,” and “tasting,” respectively. Each of the associated NCM-circuits is a SgM that generates the sensation of “seeing,” “hearing,” “smelling,” and “tasting,” respectively. The design of the NCM-circuit for visual perception is presented by Rosen and Rosen (2003c) in a paper titled “The design of the NCM for visual Perception: Solving the inverse optics problem of “seeing.”

4. EMOTIONS: THE MODALITIES OF AUTONOMIC SUBSYSTEMS

In an article titled “What is an Emotion?” (James, 1894), William James, the father of modern psychology, correlates the subjective experience of an “emotion” with the upset of one or more of the involuntary autonomic homeostatic subsystems in the human body. We propose, in accordance with the William James definition, that emotions are the correlates of an upset homeostatic subsystem. That is, the modality of an upset homeostatic subsystem shall be defined to be a subjective experience called an “emotion.” Therefore the problem of finding and designing an emotion-generating mechanism in the brain reduces to the search for an NCM-circuit for the “emotional” modality.

4.1 The emotional NCM-circuit

The generalized reverse engineering procedure of the itch-NCM-circuit may be applied to emotional modalities of upset homeostatic subsystems. The reverse engineered emotional-modality must give rise to a sensory form of “robotic self knowledge” in a coordinate frame defined by the sensor and located within the controller. In this case, the homeostatic subsystem is the receptor, and the upset of the homeostatic system is the activated response of receptor (homeostatic subsystem). Furthermore the coordinate frame defined by the homeostatic subsystems must be consistent with, and calibrated with the coordinate frame defined by the itch-modalities of the mechanoreceptors. In a paper titled “The Design of the Neuronal Correlates of Emotions” present a building path for the design of an emotional-NCM circuit (Rosen and Rosen, 2003d).

4.2 Studies of the psychological experiences associated with sensory modalities and emotional modalities

The itch-NCM-circuit in the brain has a subjective experience (a form of self knowledge) correlated with it. Psychological studies of large number of human subjects may be required in order to find a quantitative correlation between the activated response of the receptor (a measurable set of parameters), and the un-measurable modality experienced by the subject.

The emotional-NCM-circuit in the brain also requires psychological studies of a large number of human subjects in order to find a quantitative correlation between the incident energy and activation response of the upset homeostatic subsystem (a measurable set of parameters), and the un-measurable emotional modality experienced by the subject.

5. A FIRST STEP TOWARDS A DEFINITION OF "CONSCIOUSNESS"

The NCM-circuits and the variety of modalities discussed in the previous sections encompass the subjective experience-sensations of tactile touch, visual seeing, auditory hearing, vestibular balancing, olfactory smelling, gustatory tasting, and a whole gamut of emotions associated with the modalities (upsets) of homeostatic subsystems. If the subjective experience is related to a "conscious" experience (without defining the term "conscious"), then the NCM-circuit may be related to Metzinger's (2000), or Crick and Koch (2000, 2003) long sought after Neural Correlate of Consciousness circuit.

At this time there is no scientific concurrence on a definition of "consciousness", whereas in the field of psychophysics the modalities of receptors are well defined in terms of the subjective experience or sensation that is evoked by the receptors and the physical stimuli associated with them. Thus the authors propose that the whole gamut of subjective experiences of human sensations and emotions are correlated with the modalities of receptors and homeostatic subsystems and the central connections that form NCM-circuits, associated with them. As a first step towards a quantitative definition of "consciousness" the authors propose that:

1. Conscious sensations (including emotional sensations) are the modalities of NCM-circuits.
2. The measure of a modality (subjective experience) may be determined by defining the connectivity of the NCM-circuit and determining the quantitative correlation between the measured incident energy, activation response of the receptor, and the subjective experience as determined by psychological studies of large sampling of subjects.

This definition of "consciousness" expands the study of psychophysics to the connectivity of the NCM-circuit in the brain[7]. This connectivity may shed light on the physiological structure and the functional operation of the human brain. Studies of the connectivity and operational structure of the human brain were undertaken by the authors by reverse engineering the various biological modalities of receptors and their central connections (Rosen & Rosen, 2003a,b,c.d).

ACKNOWLEDGEMENTS

The authors acknowledge the support of machine consciousness inc. (mcon inc.) In the publication of this article. All the data and figures for this article are based on patents and publications relating to the relational robotic controller (RRC)-circuit that have been published in the MCon inc. web site (www.mcon.org). The authors are particularly grateful for the financial support and permission to publish the mcon data and figures, received from Machine Consciousness Inc.

NOTES

1. Psychophysics is often regarded as a sub-discipline of psychology dealing with the relationship between physical stimuli and their subjective correlates.The modern study of sensation began in the 19th century with the pioneering work of E.H. Weber (1846) and G. Fechner (1860) in sensory psychophysics. Despite the diversity of sensations we experience, all sensory systems convey four basic types of information when stimulated; modality, location, intensity and timing. These four attributes of a stimulus yield sensation. An early insight into the neuronal basis of sensation came in 1826 when Johanne Müller advanced his “laws of specific sense energies.” The specificity of response in receptors underlies the “labeled line code,” the most important coding mechanism for stimulus modality (Kandel et al, 2000).
2. Sensorimotor control papers were presented at IEEE-IJCNN WCCI-Vancouver and ICONIP-2006 Hong Kong, and published in the proceedings of the conferences (Rosen & Rosen, 2006a,b). All the data is based on internal MCon publications and research, much of it available for viewing on the MCon website www.mcon.org.
3. The approach of modeling the connectivity of the brain rather than the mind’s symbolic representation of the world was inspired by D. O. Hebb (1949) and Frank Rosenblatt (1958, 1962 p.386). During the past few decades this approach was pursued by many research scientists. Some notable examples are the works of Stephen Grossberg (1988), Gail Carpenter (1991), Teuvo Kohonen (Kohonen, 2001), William Bechtel (Bechtel, Abrahamson, 2002), Paul Churchland (Churchland, Sejnowski, 1996) and Helge Ritter (Ritter et al, 1992). In the past decade the connectionist methodology has blossomed with the development of powerful neural net-based computational techniques that emulate a large variety of brain functions. For example, the work of Teovo Kohonen (2001) and Helge Ritter (1992) applied to self Organizing Maps and micro-structural connectivity in the biological brain, and the work by authors of the Dept. of Cognitive and Neural Systems at Boston University (see note 4).

4. Stephen Grossberg, Boston University director of Adaptive Systems and colleagues and staff at the Department of Cognitive and Neural Systems, are responsible for prolific publications in neural networks applied to cognition, memory, motor control, speech, and pattern recognition. Stephen Grossberg is especially known for his studies of the brain by means of Pattern Recognition by Self Organizing Neural Networks (1982); Studies of Mind and Brain (1980); How Does the Brain Build a Cognitive Code (1980); Adaptive Resonance Theory (ART) models; The Adaptive Self-organization of Serial Order in Behavior Speech Language and Motor Control (1985); The Adaptive Brain vol. I & II (1987a,b) and many other sensorimotor control publications (Grossberg, 1988, 1998; Guenther et al 2001; Pack et al 1988; Cameron et al 1997).
5. In discussing proprioceptive sensations, Kandel, Schwartz & Jessell (1991, p. 337) show that the brain determines precise knee position (in the absence of voluntary muscle contraction). At rest, the angle of the knee can be evaluated to within 0.5-degrees.
6. This is an operational definition of “volition”. The robotic controller is said to be a volitional controller if the controlled trajectory of motion is goal directed and pre-planned, with the option available for re-planning the pre-planned trajectory if an environmental contingency is detected prior to reaching the pre-planned goal. Re-planning is always a function of the contingency that appears in the region of the pre-planned path. In the design of a “volitional” controller, re-planning is never

functionless or random.

7. The field of psychophysics, at its inception in the mid 19th century, was devoted equally to the study of the psychological sensations and to the measurable parameters correlated with them. Over the past 150 years, the study-ratio between psychological sensations and measurable parameters shifted towards the measurable parameters, to the detriment of the psychological sensations. The definition of consciousness, proposed in this paper, expands the field of study of psychophysics into the NCM-circuits, the neural physiology and the operational functions of the brain. Studies of NCM-circuits, in the field of psychophysics, may again bring balance to the study-ratio between the study of psychological sensations and the measurable parameters correlated with them.

REFERENCES

Bechtel, W., & Abramhamson, A. (2002). Connectionism and the Mind. Malden MA: Blackwell.

Brodal, P. (2004). The Central Nervous System: Structure and Function (3rd ed). New York: Oxford Univ. Press

Cameron, S., Grossberg, S., & Guenther, F. (1997). A Self Organizing Neural Network architecture for Navigation Using Optic Flow. J. of Cognitive Neural Science. 9, 313-352.

Carpenter, G. A., Grossberg, S. (Eds) (1991). Pattern Recognition by Self-Organizing Neural networks. Cambridge Mass: MIT Press

Churchland, P. S., & Sejnowski, T. J. (1996). The computational Brain. Cambridge MA: MIT Press

Crick F., & Koch, C. (2000). The Unconscious Homunculus (p.103) in Metzinger, T., Ed. (2000). Neural Correlates of Consciousness. Cambridge Mass: The MIT Press

Crick F., & Koch, C. (2003). A framework for Consciousness. Nat. Neurosci. 6, 119-126.

Dennett, D.C. (1991). Consciousness Explained. Boston: Little Brown and Co.

Dennett, D. C. (1997). Artifact Hermeneutics, or reverse Engineering p. 194 in Evolution edited by Mark Ridley Oxford University Press: New York (1997).

Dennett, D.C. (1995). Darwin’s Dangerous Idea. New York: Simon and Schuster

Fechner, G. (1860) 1966. Elements of Psychophysics, Vol 1. DH Howes, EG Boring (eds), HE Adler (trans) New York: Holt, Rinehart and Winston

Gazzaniga, M. S., Ivry, R. B., & Mangun, G.M. (1998). Cognitive Neuroscience. New York: W.W. Norton and Co. (Chapter 10 Motor Control)

Grossberg, S. (1988). Neural Networks and Natural intelligence. Cambridge Mass:MIT Press

Grossberg, S. (Ed.) (1987a). The adaptive Brain I : Cognition, learning, reinforcement, and Rhythm North Holland: Elsevier science Publishers.

Grossberg, S. (Ed.) (1987b). The adaptive Brain II: Vision, Speech Language, and Motor Control North Holland: Elsevier science Publishers.

Grossberg, S. (1998). A Cortico-Spinal Model of Reaching and Proprioception Under Multiple Task Constraints. Journal of Cognitive Neuroscience. 10, 425-444.

Guenther, F. H., Bullock, D., Greve, D., & Grossberg S. (2001). Neural representations for Sensorimotor Control III. J. of Cognitive Neural Science. 13, 341-358

Guyton, A. C. (1991). Textbook of Medical Physiology. Philadelphia: W.B. Saunders Co.

Haines, D.E. (Ed) (2002) Fundamental Neuroscience 2nd ed. Churchill Livingston: Philadelphia PA

Hebb, D.O. (1949). The Organization of Behavior: A Neurophysiological Theory. New York:Science ed.

James, W. (1884). What is an Emotion? Mind 9:188-205

Kandel, E. R., Schwarts, J. H., & Jessell, T. M. (eds) (1991) Principles of Neural Science. Norwalk Conn: Appleton and Lange.

Kohonen, T. (1982a). Self Organizing Formation. Bio. Cybern, 43:59-69.

Kohonen, T. (1982b). Analysis of a Simple Self-Organizing Process. Bio. Cybern, 44:135-140

Kohonen, T. (1982c). Clustering, Taxonomy and Topological Maps of Patterns. Proc, 6th Int. Conf. On Pattern Recognition, Munich, 114-128.

Kohonen, T. (2001). Self Organizing Maps (3rd ed.) Berlin: Springer-Verlag

Metzinger, T., Ed. (2000). Neural correlates of Consciousness. Cambridge Mass: The MIT Press

Müller, J. (1826) 1833-1840. Handbuch der physiologie des Menchen für Vorlesungen, 2 vols. Coblenz: Holscher.

Pack, C., Grossberg, S., & Mingolla, E. (1988). A Neural Model of Smooth Pursuit Control and Motion Perception by Cortical area MST. Neural Computation. 10:102-120

Penfield, W., Rasmussen, T. (1950) The Cerebral Cortex of Man. Macmillan.

Purves, D., Riddle, D., & LaMantia, A. (1992). Iterated patterns of brain circuitry (or how the cortex gets its spots). Trends Neurosci. 15, 362-368

Purves, D. G., Fitzpatrick, A.D., Katz, L.C., La Mantia, A. S., & McNamara J.O. (eds) (1997). Neuroscience. Sunderland Mass: Sinauer Assoc. Inc.

Ritter, H., Thomas, M., & Schulten, K. (1992). Neural Computation and Self Organizing Maps. New York: Addison Wesley Pub. Co.

Rosen, D. B., & Rosen, A. (2006a). A Neural Network Model of the Connectivity of the Biological Somatic Sensors. IJCNN: Proceedings of the IEEE-WCCI. July 16-21, 2006 Vancouver Canada.

Rosen, D. B., & Rosen, A. (2006b). An Electromechanical Neural Network Robotic Model of the Human Body and Brain: Proceedings of the ICONIP- 2006 Hong Kong; King et al (eds) LNCS Part 1 pp. 105-116, Berlin Heidelberg: Springer-Verlag.

Rosen, D.B., & Rosen A. (2003a) The Design of a Volitional, Obstacle Avoiding Multi-tasking Robot. Machine Consciousness Technical Journal. 1, 41-56 doi:10.2962/mctj.0003

Rosen A., & Rosen D. B. (2003b). The Engineering Design of an NCC circuit for the Sensory-motor Control of a Robotic Arm. Machine Consciousness Technical Journal. 1, 57-69 doi:10.2962/mctj.0004

Rosen A., & Rosen D. B. (2003c). The Design of an NCC circuit for Visual Perception. Machine Consciousness Technical Journal. 1, 19-40doi:10.2962/mctj.0002

Rosen A., & Rosen D. B. (2003d). The Design of the Neuronal Correlate of Emotions. Machine Consciousness Technical Journal. 1, 74-111doi:10.2962/mctj.0006

Rosenblatt, F. (1958). The Perceptron. Psychological Review. 65, 368-408

Rosenblatt, F. (1962). The Principles of Neurodynamics. New York:Spartan

Rumelhart, D. E., McClelland, J. L., & PDP research group (1986). Parallel Distributed Processing: Explorations in the Microstructure of Cognition, Vol 1: Foundations. Cambridge,MA: MIT Press.

Weber, E. H. (1846). Der Tastsinn und das Gemeingefühl. In: R Wagner (ed) Handwörterbuch der Physiologie, Vol 3, Part 2 pp 481-588, 709-728 Braunschweig: Vieweg