Brain Activity and Conscious Experience

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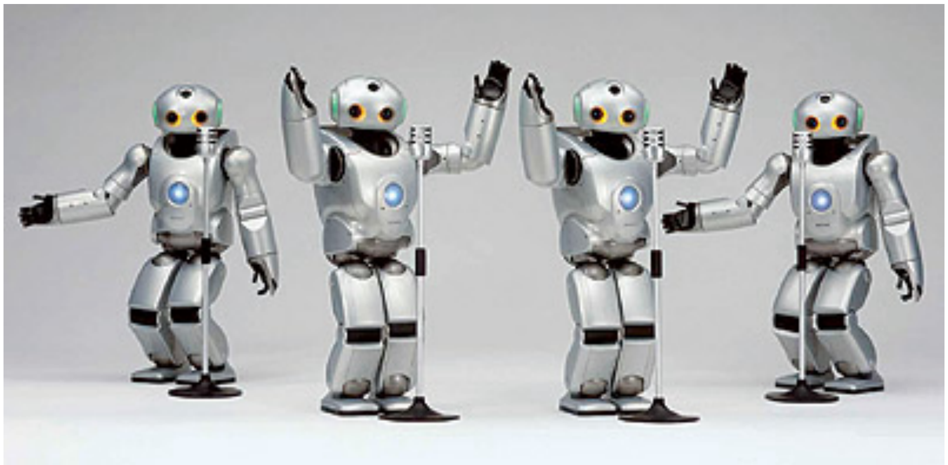

Figure 1. The Sony SDR-4X is a bipedal humanoid robot. According to Sony, the 2-foot-tall, 13-pound offspring of Sony's Digital Creatures Laboratory can recognize faces, learn new vocabulary, fetch things, and hold "nearly conversations." It sings and dances, too.

In 1780, Galvani simultaneously discovered electrical currents and laid the foundations of modern neurophysiology (Galvani 1791, p. 363). He found that frog muscles twitch when they come in contact with two different metals, and believed he had discovered the essence of life energy in electricity.

Since Galvani's day we have learned to use electrical technology to study brain function. We also construct robots, which are capable of sensing and recognizing their environment (as in voice recognition), and performing meaningful acts such as greeting guests or cleaning the kitchen (Figure 1). The question has arisen for many: is the human brain a sophisticated computer, and are we really robots? What would be the moral consequences for society if we thought of ourselves in this way?

Electricity and Physiology

If we connect a loudspeaker, a voltmeter or a monitor to the human body by means of several wires and skin electrodes, and use a good amplifier connected to an electric power source, we will detect some activity. Most obvious and easily recordable at almost any point on the body will be the electrical activity of the human heart. This activity is commonly shown in an electrocardiogram (EKG), and we can recognize its rhythmical activity as synchronous with our heartbeat and pulse.

In a similar fashion, we can record electrical activity from all muscles by proper placement of our electrodes. In contrast to the heart, which tends toward an even rhythm, the rhythmical electrical activity of our muscles, expressed in "action potentials," increases dramatically in frequency when we exert our muscle strength. For many patients, who have an electromyogram (EMG) performed for diagnostic purposes, it is quite an experience to see how their intentional effort is reflected immediately and accurately in the output of the loudspeaker or the EMG monitor second by second.

With more effort — for example, by placing needle electrodes properly — we can also record electrical activity directly from the peripheral nerves or the posterior part of the spinal cord. Again we find rhythmical activity, now at even higher frequencies than in the muscles, but in this case it is no longer synchronous with any outer movement. This recording can be quite painful due to the irritation of the nerves; however, the pain can give us further insight into the activity of the nerves. When we pinch the skin area around the nerve, we may find that the frequency of the electrical activity in the nerve increases according to the intensity of the pinch. Of course, the stronger the pinch, the more pain we feel. Thus, it seems that the intensity of our pain is reflected in the frequency of the electrical activity in the nerve or spinal cord. Feeling the pain is really a personal and internal experience, which cannot be observed from outside like a muscle movement. Similar observations can be made just from touching the skin. Maybe the pain or the experience of touch can be understood as an inner movement in the arena of our consciousness.

When another skin area is pinched or touched, unconnected to the nerve or the portion of the spinal cord from which we are recording, we observe no response. In this way, we find that the spatial organization of the nervous system closely reflects the functional organization of our body. Specific skin areas correspond to specific peripheral nerves, to specific portions of the spinal cord and brain stem, and finally even to specific portions of the thalamus and cortex (Figure 2). This phenomenon is referred to as the "somatotopic organization" of the nervous system. More sensitive skin areas are associated with a denser distribution of nerves and larger corresponding brain regions. Thus we can picture the ever-changing electrical activity along all these pathways in the nervous system as continuously reflecting both in frequency and in location what is going on on our skin.

With even more sophisticated recording techniques, it is possible to record electrical activity from our sense organs and the corresponding nerves — for example, the ears, cochlear nerve, and brain stem; and the eyes, optical nerves, thalamus, and optical cortex. We then discover how the properties of an observed external object (a flower, an animal, or another person) and of our inner sensory experience (a color or shape, a tone, a melody, or words) become immediately and accurately reflected in the frequency and distribution of electrical activity in the sensory system. In analogy to the somatotopic organization, we can speak of the "tonotopic" organization of the auditory nerve, medial geniculate region of the thalamus, and auditory cortex in the temporal lobe (Pantev and Lütkenhöner 2000), and likewise of the "retinotopic" organization of the optical nerve, lateral geniculate region of the thalamus, and optical cortex.

We can also record the overall electrical activity of the brain by placing electrodes evenly spaced over the entire skull. This recording is referred to as an electroencephalogram (EEG). We find a mixture of frequencies, ranging from about 1 wave per second (1 Hz) up to 16 Hz, and with more sophisticated analysis we may find activities up to more than 500 Hz. The most striking aspect of EEG patterns is their dependence on our state of consciousness. By far the easiest distinction to make from EEG recordings is whether the subject is awake, drowsy, or asleep. If he or she is falling asleep, we can tell exactly when he or she is becoming drowsy, possibly more accurately than by external observation. Again we find how the electrical activity of the brain accurately reflects our inner experience, in this case the state of our consciousness.

The Necessity of Nervous Activity

Taking together all these striking phenomena of nervous system physiology, we may arrive at a picture of nervous system function. In contrast to all other organs, which develop their own function in the body — for example, the lungs take in the air to refresh the blood, the liver builds up and secretes proteins for the blood, the kidneys filter the blood and secrete urine, the heart stops the blood flow and creates blood pressure — the nervous system does not have a separate function of its own. Instead, like a mirror it reflects in its activity everything else that is going on around it. In neurophysiological terms this is referred to as "representation." The electrical activity of the nervous system — more precisely its time structure in many frequencies — reflects how and where we touch something with our skin; it reflects what we see and hear around us; it reflects the activity of our inner organs via the autonomic nerves; and it even reflects our intentions to move and what we feel and think. All these sensory experiences, reflected in the time-structure of brain electrical activity, are internal. We might call them "mental images".

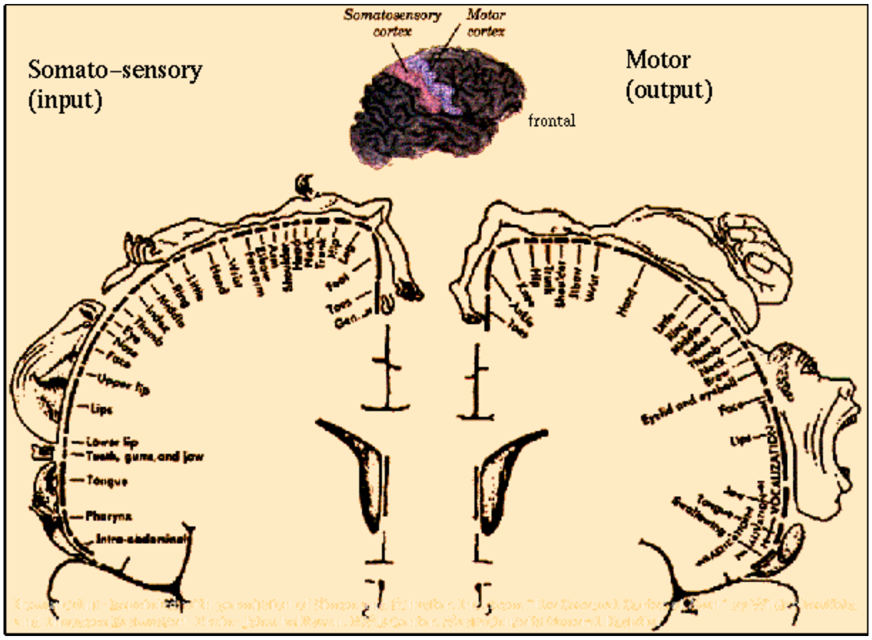

Figure 2. Somatotopic organization of somatosensory cortex (left) and motor cortex (right).

So we might be tempted to think that the electrical activity of the nervous system actually does have a separate function of its own, namely, to produce our inner experiences, or mental images, as well as our outer movements. This would be similar to how the liver produces proteins for the blood and excretes bile.

I will briefly examine this hypothesis. If it were true, then electrical activity of the nervous system would be both necessary and sufficient for our inner experiences and bodily movements to occur. First, then, we will look at the question of necessity. We need to eliminate all or part of the nervous system's electrical activity and see what functions are left. If the functions always disappear along with the electrical activity, then we can conclude that the electrical activity is necessary to the functions.

The body's electrical activity is based on the relative concentration of salts, specifically the difference between concentrations in the blood and concentrations inside the nerves and muscles. If this balance is disturbed by loss or increase of salts, or by a change in properties of the dividing membranes, global dysfunction of the nervous system results. It is similar to our experience of excessive deep breathing (hyperventilation): we may feel tingling of the skin, especially on the most sensitive areas such as hands, feet and around the lips; our muscles may involuntarily contract or be limp and cease to follow our will; and we may develop colored visual hallucinations or slowly drift into drowsiness and eventually into unconsciousness. In extreme cases, effects similar to those in our muscles may result in disturbances of heart rhythm and could cause death.

Local damage to nerves or brain tissue through injury or a stroke results only in the local loss of electrical activity in the nervous system. In each case, there is a specific loss of function related to the affected part of the nervous system. If a peripheral nerve is injured, we may lose sensation and muscle strength in the affected part of the limb. If the brainstem or cortex becomes damaged on one side, sensation and muscle strength may be partially or completely impaired on the other half of our body. Other specific cortical brain lesions may cause loss of vision, the ability to speak or to understand, or even the ability to recognize specific objects in the presence of good vision.

The loss of language comprehension in the presence of good hearing, or the loss of object recognition in the presence of good vision, could be described as an inability to form an appropriate mental image of the perceived sensory experience. The sensory experience remains raw, we are unable to connect a known concept to our percept. Apparently, the normal function of specific brain regions is necessary for the formation of specific mental images. In this regard, nerves and brain tissue appear similar to sense organs: when we lose an organ, we can no longer perceive objects via the particular sense quality or sensory area in question. In the case of the nervous system, we lose the ability to form mental images, and with it we lose the conscious awareness of specific aspects or sometimes the whole of an object.

A stroke in the primary motor cortex area (located in the precentral gyrus, or fold, of the brain) results in weakness or paralysis of the contralateral limbs; damage anterior to it in the supplementary motor area results in apraxia, the inability to perform learned complex movements such as brushing one's hair or teeth, using a hammer, or writing with a pen. Difficulty or inability to speak while still being able to use mouth and tongue, called aphasia, is a special example of apraxia from this viewpoint. One might say that in these situations we have lost the capacity to form a mental image of the intended movement. The situation is similar to what we have seen with the sensory regions of the brain: it appears that intact function of specific brain regions is necessary to form a mental image of the intended movement. Understood in this way, the motor regions of the brain are rather like sense organs for movement, since we need them in order to form the associated mental images. Without mental images, meaningful and conscious movements are impossible.

Taking this evidence together, we may safely conclude that electrical activity of the nervous system is indeed necessary for the occurrence of our inner experiences, body movements, and even conscious object-awareness.

The Sufficiency of Nervous Activity

We will now inquire whether in the presence of otherwise general health, electrical activity of the nervous system is sufficient to produce our inner experiences and body movements. To test this experimentally, we need to induce electrical activity in the muscles or the nervous system, and to do so in a manner as close as possible to physiological conditions.

When in a medical emergency someone's heart has "stopped beating," it may have stopped completely (asystole), or it may be caught in very small and fast contractions (fibrillations). The difference is apparent in the EKG. In the second condition, a strong electric shock by a defibrillator may stop the fibrillations and allow the heart to return to rhythmic contractions. In the first condition (asystole), the electric shock has no effect at all. So the electric shock cannot produce rhythmical contractions of the heart, but can only stop unrhythmical activity. A cardiac pacemaker, used for irregularities of the heartbeat (arrhythmias), has an effect only when the heart is already beating. Apparently, in the case of the heart, externally induced electrical activity can only modulate movement that is already present, but cannot initiate it.

Direct electrical stimulation of limb muscles will cause muscle twitches or sustained contractions, depending on the duration of stimulation, but no meaningful limb movements. Electrical stimulation of the peripheral nerves — for example, during diagnostic nerve conduction studies — is quite painful and will cause similar muscle twitches or contractions. In both cases, the individual who is stimulated experiences the induced movements as involuntary and as forced from outside.

Similar to the somatotopic representation of touch sensations in electrical activities of the postcentral gyrus of the brain, conscious movement is reflected in the precentral gyrus of the brain (primary motor cortex) in somatotopic fashion (Figure 2). When this region is directly stimulated by a small electrical current (a few milliamperes) — for example, during brain tumor surgery, or by transcranial magnetic stimulation (TMS) through the skull — muscle twitches or contractions similar to direct muscle or nerve stimulation can be induced. At the same time, voluntary movements are impossible during stimulation. Stimulation just anterior to this area in the "supplementary motor area" can induce somewhat more complex movements or even the sensation of an urge to move. However, such induced movements or sensations are always perceived as involuntary and as imposed by the experimenter.

Can induced electrical activity in the brain produce mental images and conscious experience? Most electrical stimulations of the awake brain have been and still are being carried out in the context of surgery in epilepsy patients to remove an epileptic focus in their brain. Stimulations of primary sensory areas can induce elementary hallucinations of being touched, buzzing sounds, light flashes, and so on. In contrast, stimulation of secondary and tertiary sensory areas, such as Wernicke's area, which is needed for the comprehension of speech, does not usually result in hallucinatory phenomena but mainly in a temporary loss of function. Stimulation of certain regions of the temporal lobe, including hippocampus and the entorhinal cortex, can induce complex feelings such as the sensation, "I have experienced this situation before" (déjà vu), fear, or complex visual memories. However, in each case the patient is aware that the sensation is not a spontaneous feeling or memory, but is artificially induced by the experimenter, and normal awareness of the surroundings continues. In many aspects, such induced experiences are quite similar to the "auras" that epilepsy patients experience at the beginning of a seizure. Epileptic auras tend to have stereotypical sensory or emotional content that does not match the sensory surroundings and that is outside the control of the patient.

Even in nonepileptic individuals, cortical stimulations can induce brief focal epileptic electrical discharges. Spontaneous epileptic auras are usually accompanied by electrical discharges in the epileptic focus in the brain. Thus, cortical stimulation and epileptic auras have in common that electrical brain activity occurs out of context. As we have seen above, electrical brain activity normally reflects or represents sensory or other internal experience. That is, it correlates with conscious or subconscious mental images. In the abnormal situations involving cortical stimulation or epileptic auras, internal experiences are elicited. However, in both cases the individuals experiencing the elicited mental images clearly recognize that the events or spontaneous memories or feelings are not real, but occur out of context, similarly to hallucinations.

The Brain's Role in Conscious Experience

Let us take together the considered evidence for the question whether electrical activity in the nervous system is sufficient to produce inner experiences and body movements. While induced electrical activity can indeed elicit movements and inner experiences, such induced movements or inner experiences remain fragmentary, and always have the character of involuntary or hallucinatory events. One might argue that this finding is only the result of technically imperfect stimulation. But another view, consistent with the picture of nervous system function developed above, would lead us to conclude that electrical brain activity in itself is not sufficient to produce meaningful movements or inner experiences. In this view, meaningful movements or inner experiences would require that external realities (such as objects or changes in our body) or internal realities (such as mental images or intentions) become reflected or represented in electrical brain activity.

Such a view would also be consistent with our own natural inner experience of our thoughts, feelings and intentions. We experience them as inner realities and not as hallucinatory byproducts of our brain. After all, we know very well that the content and direction of our thoughts are independent of our bodily organization. In thinking, we are able to arrive at truths such as 3 x 4 =12, independently of who has the thought, and of our physical and emotional state. In situations where our body does have an influence, such as when we are tired, drunk, obsessive-compulsive, or schizophrenic, our thinking becomes impaired. Usually we (or others) are then aware that our reasoning cannot fully be trusted.

Similarly, we experience our intentions as truly our own, and not as involuntary reactions of our brain. Again, in situations where our body does have an influence, such as when we are intoxicated or suffer from mental illness — in short, when we are “out of control” — we or others know that such actions are not in line with our well-considered intentions.

Thus, while we experience the process of thinking and our intentions as independent from our bodily organization, we know from electrophysiological (Rodriquez et al. 1999; Kornhuber and Deecke 1965) and functional imaging studies that our thoughts or mental images always are correlated with specific neuronal electrical activity and a corresponding local increase in blood flow in the brain. Thus it appears that the thinking process, just as all the sensory processes studied above, leaves an imprint or reflection in the brain. If the corresponding part of the brain becomes damaged or lost, we become incapable of forming the particular kind of mental image which is associated with that part of the brain — just as we lose the capacity to see when we lose an eye.

It seems, then, that the general rule of brain function holds: the brain does not produce thoughts or mental images, just as it does not produce the light of vision or the strength of our movement. Instead the brain serves to bring the thought or mental image to consciousness by allowing it to be imprinted. The brain in this sense might be compared to the sand that provides enough resistance to receive the form of a footprint:

> He who walks over a soft ground will imprint his footprints into the soil. One will not be tempted to say the forms of the footprints were pushed up from below by forces in the soil …. Similarly, he who observes the essential being of thinking in an unbiased manner, will not ascribe any part in this being to the traces in the body organization, which arise from the preparation of thinking for its appearance by means of the body. (Steiner 1967, author’s translation)

That is, the resistance the brain presents to thought images may allow them to become conscious. In this way, the brain may serve as a kind of sense organ for thoughts and concepts that have an independent existence.

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For more about Siegward, see the article, “A New Affiliate Researcher” on p. 6 of this issue.

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