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PHYSIOLOGY OF FREE WILL

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The Problem

As a motor physiologist, one of the central issues that I must grapple with every day is voluntary movement. Issues such as the anatomy of the motor system, the physiology of the motor cortical regions, the spinal cord, and the motor units, the kinematics and kinetics of movement, and reflexes are the day to day activities. We also have made strides in understanding the pathophysiology of movement: ataxia, bradykinesia, tremor, myoclonus and dyskinesias. We generally skirt around the issue of voluntariness itself. It is a common perception that we have free will, that we choose to make our (voluntary) movements. There has been no understanding of this, however, on the physiological level. What does free will mean, and how can it be studied?

As C. M. Fisher has said, “The neurologist with his special knowledge should have an opinion, or at least should be interested.”(Fisher 1993)

A Brief Aside about Consciousness

Unfortunately, we cannot even begin to discuss free will without dealing with the more general problem of consciousness. Neurologists do talk about states of consciousness, waking, sleep, coma, so we do understand that lesions in certain parts of the brain will impair or modify consciousness. But there is nothing really intelligent to say about consciousness itself. This has been the subject of philosophy, and generally speaking there have been two general views. Dualism is the view that the brain and the mind are separate; that we study the brain, but that consciousness is a feature of the mind. The problem with this view is that there is not a shred of evidence to support it. Monism is the view that mind is a product of brain. Most neurologists likely accept this view, but the chief problem is our lack of understanding about how this is possible. I will accept monism, which will allow our discussion to go forward.

The best definition of consciousness is “awareness.” When there is no awareness of anything, there is no consciousness. Consciousness is composed of awareness of different elements, a rose, warmth, a Beethoven symphony, love, fear, a thought, the view that I have chosen to make a movement. “I think, therefore I am.” Each element is called a “qualia.”(Searle 1998) How does the brain appreciate a qualia? Is there a little man sitting somewhere in the brain, appreciating these different sensations and deciding when to move? This solution is often called the Cartesian theater.(Kinsbourne 1993;

Baars 1998) This seems nonsensical, of course, since we would have the same physiological problems for the little man as we have for the whole person. We have no understanding of the physiology of awareness and must leave it at that. It must be noted, however, that awareness is a construction of the brain, and there is no assurance that its constructions always are true reflections of reality.

Is the “Will” In Charge?

Recognizing that consciousness is awareness does change the way we can look at the fundamental problem of free will. Free will is more correctly defined as “the perception that we choose to make movements.” Looking at it in this way produces at least two possibilities. The first is that there is a process of free will, an aspect of consciousness, that does choose to make a specific movement. The second is that the brain’s motor system produces a movement as a product of its different inputs, consciousness is informed of this movement, and it is perceived as being freely chosen. It is not certain which of these is correct, but there are some good arguments in favor of the latter.

Three Arguments in Favor of Free Will as a Perception

The Brain Initiates a Movement Before Awareness of Volition

The clever experiment that showed this was reported by Libet et al. in 1983.(Libet et al. 1983) Subjects sat in front of a clock with a rapidly moving spot and were told to move at will. Subsequently, they were asked to say what time it was (where the spot was) when they had the first subjective experience of intending to act (this time was called W). They also were asked to specify the time of awareness of actually moving (this time was called M). There were two types of voluntary movements, one type was thoughtfully initiated and a second type was “spontaneous and capricious.” As a control for the ability to successfully subjectively time events, subjects were also stimulated at random times with a skin stimulus and they were asked to time this event (called S). At the same time, EEG was being recorded and movement-related cortical potentials (MRCPs) were assessed to determine timing of activity of the brain.

The MRCP has a number of components. An early negativity preceding movement has two phases, an initial, slowly rising phase lasting from about 1500 ms to about 400 ms before movement, the Bereitschaftspotential or BP (also called the readiness potential in translation of the German), and a later, more rapidly rising phase lasting from about 400 ms to approximately the time of movement onset, the negative slope or NS'. (These two components could also be called the BP1 and the BP2.) The NS' peaks about 90 ms before the onset of EMG activity and is followed often by a brief decline in the negativity, called the premotor positivity. The next component is the motor potential or MP which begins before movement, peaks after movement onset and produces the highest negativity in the recording. The topography of the BP is generalized with a vertex maximum. With NS' the negativity begins to shift to the central region contralateral to the hand that is moving. The main contributors to the BP are the primary sensorimotor cortex and premotor cortex and the supplementary motor area, both

bilaterally. With the appearance of NS' the activity of the contralateral motor cortical regions predominate. With thoughtful, preplanned movements, the BP begins about 1050 ms prior to EMG onset (the type I of Libet), and with spontaneous movements, the BP begins about 575 ms prior to movement (the type II of Libet).(Libet et al. 1982) The type II may consist mainly of the NS' component.

Subjects were reasonably accurate in determining the time of S indicating that this method of timing of subjective experience was acceptable. W occurred about 300 ms prior to EMG onset and M occurred about 90 ms prior to EMG onset. The onset of the BP type I occurred about 800 ms prior to W, and the onset of the BP type II occurred about 350 ms prior to W. The authors concluded "that cerebral initiation of a spontaneous, freely voluntary act can begin unconsciously, that is, before there is any (at least recallable) subjective awareness that a 'decision' to act has already been initiated cerebrally."(Libet et al. 1983)

These results have been reproduced by others. Recently Haggard and Eimer looked carefully at the timing of W compared with BP onset and the onset of another measure, the lateralized readiness potential (LRP, the difference in the voltage of right and left central regions).(Haggard and Eimer 1999) The LRP timing is similar to the NS' component indicating the onset of asymmetry of the cortical activity. The onset of the LRP always preceded W. Across subjects they found a better relationship between the timing of the onset of the LRP and W than between the onset of the BP and W, and suggested that the "processes underlying the LRP may cause our awareness of movement initiation."

Voluntary Movements Can Be Triggered with Stimuli that are Not Perceived

To understand the experiments here, the phenomenon of backward masking is a prerequisite. By itself, a small stimulus would be easily recognized. If the small stimulus is followed quickly by a large stimulus, then only the large stimulus is appreciated; the small one has been masked. This phenomenon is robust and has been demonstrated in the visual and tactile modes. Its physiology is not completely understood, although there is some speculation.(Macknik and Livingstone 1998)

Taylor and McCloskey looked to see if voluntary movements could be triggered by backwardly masked stimuli.(Taylor and McCloskey 1990) Large and small visual stimuli were presented to normal human subjects in two different experiments. In some trials, the small stimulus was followed 50 ms later by the large stimulus. In perception experiments, they demonstrated in this circumstance that the small stimulus was not perceived even with forced-choice testing showing the phenomenon of "backward masking." In reaction time (RT) experiments, the RTs for responses to the masked stimulus were the same as those for responses to the easily perceived, nonmasked stimulus. Hence, subjects were reacting to stimuli not perceived. In this circumstance, the order of events was stimulus-response-perception, and not stimulus-perception-response that would seem necessary for the ordinary view of free will.

Subsequently these authors extended this work by using large and small stimuli in two visual locations that signaled two different types of movement.(Taylor and McCloskey 1996) Large and small stimuli were presented in either location, and in some trials, the small stimulus was followed 50 ms later by the large stimulus. In this circumstance, the small stimulus was "masked" by the large stimulus and could not be perceived on forced-choice testing. Despite not perceiving the test stimulus, subjects were able to select and execute the motor response appropriate for each location. The RTs for responses to the masked stimulus and to the same stimulus presented without masking were the same. The authors concluded that “this result implies that appropriate programs for two separate movements can be simultaneously held ready for use, and that either one can be executed when triggered by specific stimuli without subjective awareness of such stimuli and so without further voluntary elaboration in response to such awareness.” In this situation, the order of events would have to be stimulus-response selection-response-perception.

Similar results have been obtained in experiments using weak and strong electric shock stimuli to the palm.(MacIntyre and McComas 1996)

Freely Chosen Movements Can Be Externally Biased Without Perception of Influence

The phenomenon that transcranial magnetic stimulation (TMS) can bias motor choice was first reported by Ammon and Gandevia.(Ammon and Gandevia 1990) Subjects were asked to movement right or left hand randomly upon hearing the click of the magnetic coil. There was a bias to right hand movement with left hemisphere stimulation and to left hand movement with right hemisphere stimulation. We pursued this phenomenon to learn more of its physiology.(Brasil-Neto et al. 1992) The task consisted of extension of an index finger in response to the click produced by the discharge of the magnetic coil (go-signal). The subjects were asked to choose the right or left finger randomly, and only after the go-signal was delivered. Single, focal magnetic stimuli were delivered to the prefrontal or motor area, and in the control situation, away from the head. This was not a reaction time experiment and subjects could choose their time to respond as well as which finger to move. TMS affected hand preference only when it was delivered to the motor area. With stimulation of this area, subjects more often chose the hand contralateral to the site stimulated with response times that were mainly less than 200 ms. With longer response times (between 200 and 1100 ms), TMS had no effect on hand preference regardless of the site stimulated. Stimulation of prefrontal areas and control stimulation had no effect. These results suggest that response bias in this paradigm is caused by an effect of TMS on neural structures within, or closely related to, the motor areas of the brain. For the purposes here, it is critical to note that although the response bias was clear and predictable, the subjects were unaware of its existence. Each movement was believed to be freely chosen. It is therefore possible to influence endogenous processes of movement preparation externally without disrupting the conscious perception of volition.

Since this effect occurred only with short reaction times, the TMS has influenced only those movements very close to the pulse itself. We know that TMS delivered to the

motor cortex can produce the shortest reaction times possible and can shorten reaction times to other stimuli.(Pascual-Leone et al. 1992a; Pascual-Leone et al. 1992b) It is possible to consider that TMS may have, in fact, played a role in triggering the movement, which was then subsequently interpreted as being freely chosen.

A Few Other Issues

Once the possibility of free will being a perception is considered, some other aspects of behavior might be more easily understood. One such situation, I refer to as the “salted peanut problem.” Imagine yourself sitting in front of a bowl of salted peanuts. After having eating a moderate number, you say, at least to yourself, that you have had enough and you will not eat any more. Shortly afterwards, you find your hand going toward the bowl. Who’s in charge?

Fisher has described this same issue more harshly, “If there is a will, it must be flimsy judging from the commonplace of deceit and dishonesty in principled persons.” (Fisher 1993)

Observe your own behavior with respect to this other phenomenon. If asked a question that you do not immediately know the answer, you think about it. Then, you say the answer. In this situation when you have reacted quickly, which comes first, saying the answer or recognizing that you know the answer? (For me, it is often saying the answer.)

Then, there is the problem of some classes of involuntary movements. Patients with chorea often do not recognize that there are any involuntary movements early in the course of their illness. Why not? Is their brain interpreting everything that is done as voluntarily chosen? Patients with tics often cannot say whether their movements are voluntary or involuntary. This is not really a relevant distinction in their minds. It is perhaps a better description to say that they can suppress their movements or they just let them happen. Tics look like voluntary movements in all respects from the point of view of EMG and kinesiology. They are often not preceded by a BP or only a brief BP, and hence the brain mechanisms for their production clearly differs from ordinary voluntary movement.(Karp et al. 1996) If forced to choose, however, patients will usually say that the movements were voluntarily performed.

How Can There Be Voluntary Movement Without Free Will?

Humans do not appear to be purely reflexive organisms, simple automatons. A vast array of different movements are generated in a variety of settings. Is there an alternative to free will? Movement, in the final analysis, comes only from muscle contraction. Muscle contraction is under the complete control of the alpha motoneurons in the spinal cord. When the alpha motoneurons are active, there will be movement. Activity of the alpha motoneurons is a product of the different synaptic events on their dendrites and cell bodies. There is a complex summation of EPSPs and IPSPs, and when the threshold for an action potential is crossed, the cell fires. There are a large number of important inputs,

and one of the most important is from the corticospinal tract which conveys a large part of the cortical control. Such a situation likely holds also for the motor cortex and the cells of origin of the corticospinal tract. Their firing depends on their synaptic inputs. And, a similar situation must hold for all the principal regions giving input to the motor cortex. For any cortical region, its activity will depend on its synaptic inputs. Some motor cortical inputs come via only a few synapses from sensory cortices, and such influences on motor output are clear. Some inputs will come from regions, such as the limbic areas, many synapses away from both primary sensory and motor cortices. At any one time, the activity of the motor cortex, and its commands to the spinal cord, will reflect virtually all the activity in the entire brain. Is it necessary that there be anything else? This can be a complete description of the process of movement selection, and even if there is something more -- like free will -- it would have to operate through such neuronal mechanisms.

The view that there is no such thing as free will as an inner causal agent has been advocated by a number of philosophers, scientists, and neurologists including Ryle, Adrian, Skinner and Fisher.(Fisher 1993)

Where is Movement Selection Located in the Brain?

Can we use the tools of Neurology and Neuroscience to locate movement selection? Lesion studies can reveal situations where voluntary movements are lacking or diminished. Functional imaging studies can reveal what regions are active with movement selection.

The symptom of loss of voluntary movement is often called abulia or, in the extreme, akinetic mutism.(Fisher 1983) The classic lesion is in the midline frontal region affecting areas including the supplementary motor area (SMA) and cingulate motor areas (CMA). Recent studies have further detailed these regions to the SMA, the pre-SMA, and rostral and caudal cingulate motor areas (CMAr, CMAc), with perhaps further division of the caudal cingulate area into the dorsal and ventral (caudal) cingulate areas (CMA_d, CMA_v). Which of these regions is the most critical is not yet clear. Lesions in other areas may give rise to similar symptoms including particularly the basal ganglia. The bradykinesia and akinesia of Parkinson's disease is a symptom complex of the same type.

Using blood flow PET, Deiber et al. have investigated the issue of movement selection in a series of studies. In the first study, normal subjects performed five different motor tasks consisting of moving a joystick on hearing a tone.(Deiber et al. 1991) In the control task they always pushed it forwards (fixed condition), and in four other experimental tasks the subjects had to select between four possible directions of movement depending on instructions, including one task where the choice of movement direction was to be freely chosen and random. The greatest activation was seen in this latter task with significant increases in regional cerebral blood flow most prominently in the SMA. In a second study, normal subjects were asked to make 1 of four types of finger movements depending on instructions.(Deiber et al. 1996) The details here were

better controlled and included a rest condition. Of the numerous comparisons, the critical one for the discussion here is between the fully specified condition and the freely chosen, random movement. The anterior part of the SMA was the main area preferentially involved. Both of these studies addressed specifically the issue of the choice of WHAT to do at a designated time.

The other side of the coin in movement selection is the choice of WHEN to move. This was approached by Jahanshahi et al. using PET.(Jahanshahi et al. 1995) Normal subjects, in a first task, were asked to make self-initiated right index finger extensions on average once every 3 s. A second task was externally triggered finger extension with the rate yoked to that of the self-initiated task. Greater activation of the right dorsolateral prefrontal cortex (DLPFC) was the only area that significantly differentiated the self-initiated movements from the externally triggered movements. A similar experiment was conducted by Deiber et al. using fMRI focussing on the frontal mesial cortex.(Deiber et al. 1999) There were two types of movements, repetitive or sequential, performed at two different rates, slow or fast. Four regions of interest (pre-SMA, SMA, CMAr, CMAc) were identified anatomically on a high-resolution MRI of each subject's brain. Descriptive analysis, consisting of individual assessment of significant activation, revealed a bilateral activation in the four mesial structures for all movement conditions, but SI movements were more efficient than VT movements. The more complex and more rapid the movements, the smaller the difference in activation efficiency between the self-initiated and the visually triggered tasks, which indicated an additional processing role of the mesial motor areas involving both the type and rate of movements. Quantitatively, activation was more for self-initiated than for visually triggered movements in pre-SMA, CMAr and CMAc.

Movement selection likely involves a network of structures, but the mesial frontal regions clearly play a major role.

Temporary Interruption of Volition

A strong, single pulse TMS over the motor cortex during the reaction period of a reaction time movement can delay the execution of the movement without affecting its form.(Day et al. 1989) Delivered in the middle of a movement sequence, it will produce a temporary pause.(Berardelli et al. 1994) It is interesting that in a situation like this, the intended movement must in some way be held in a buffer until it can be implemented. With repetitive TMS over the motor cortex or SMA, the motor program for movement sequences can be disrupted indicating their central role in implementation of a motor program.(Gerloff et al. 1997; Gerloff et al. 1998)

As noted earlier from the experiments of Libet et al., the subjective sense of having moved precedes the actual onset of movement.(Libet et al. 1983) This interesting, inaccurate judgement of consciousness suggests that, to some extent, the brain assumes that if it issues a motor command, the movement will be generated. In experiments where the RT is delayed with TMS over the motor cortex, the judgement of when movement occurred is delayed less than the movement itself.(Haggard and Magno 1999)

This suggests that the motor cortex may be downstream from the site of movement awareness.

Matters of Morality

If there is no free will, are persons responsible for their behavior? This is a difficult question, but I think we must still believe at some level that this is true. Behavior, like all other elements of a person, are a product of that person's genetics and environmental exposure. A person's behavior should be able to be influenced by specific environmental interventions, such as reward and punishment.

What has been Demonstrated

What has been the providence of philosophy, from the time of Plato and Aristotle, has now become, in the new Millennium, legitimate discourse for Neuroscience.

NOTE

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REFERENCES

- Ammon, K. and Gandevia, S.C. (1990) Transcranial magnetic stimulation can influence the selection of motor programmes. *Journal of Neurology, Neurosurgery and Psychiatry* **53**: 705-707.
- Baars, B.J. (1998) Metaphors of consciousness and attention in the brain. *Trends Neurosci* **21**: 58-62.
- Berardelli, A., Inghilleri, M., Polidori, L., Priori, A., Mercuri, B. and Manfredi, M. (1994) Effects of transcranial magnetic stimulation on single and sequential arm movements. *Exp Brain Res* **98**: 501-6.
- Brasil-Neto, J.P., Pascual-Leone, A., Valls-Solé, J., Cohen, L.G. and Hallett, M. (1992) Focal transcranial magnetic stimulation and response bias in a forced-choice task. *Journal of Neurology, Neurosurgery and Psychiatry* **55**: 964-966.
- Day, B.L., Rothwell, J.C., Thompson, P.D., Maertens de Noorhout, A., Nakashima, K., Shannon, K. et al. (1989) Delay in the execution of voluntary movement by electrical or magnetic brain stimulation in intact man. *Brain* **112**: 649-663.
- Deiber, M.-P., Ibañez, V., Sadato, N. and Hallett, M. (1996) Cerebral structures participating in motor preparation in humans: a positron emission tomography study. *Journal of Neurophysiology* **75**: 233-247.

- Deiber, M.-P., Passingham, R.E., Colebatch, J.G., Friston, K.J., Nixon, P.D. and Frackowiak, R.S.J. (1991) Cortical areas and the selection of movement: a study with positron emission tomography. *Experimental Brain Research* **84**: 393-402.
- Deiber, M.P., Honda, M., Ibanez, V., Sadato, N. and Hallett, M. (1999) Mesial motor areas in self-initiated versus externally triggered movements examined with fMRI: effect of movement type and rate. *J Neurophysiol* **81**: 3065-77.
- Fisher, C.M. (1983) Honored guest presentation: abulia minor vs. agitated behavior. *Clin Neurosurg* **31**: 9-31.
- Fisher, C.M. (1993) Concerning mind. *Can J Neurol Sci* **20**: 247-53.
- Gerloff, C., Corwell, B., Chen, R., Hallett, M. and Cohen, L.G. (1997) Stimulation over the human supplementary motor area interferes with the organization of future elements in complex motor sequences. *Brain* **120**: 1587-602.
- Gerloff, C., Corwell, B., Chen, R., Hallett, M. and Cohen, L.G. (1998) The role of the human motor cortex in the control of complex and simple finger movement sequences. *Brain* **121**: 1695-709.
- Haggard, P. and Eimer, M. (1999) On the relation between brain potentials and the awareness of voluntary movements. *Exp Brain Res* **126**: 128-33.
- Haggard, P. and Magno, E. (1999) Localising awareness of action with transcranial magnetic stimulation. *Exp Brain Res* **127**: 102-7.
- Jahanshahi, M., Jenkins, I.H., Brown, R.G., Marsden, C.D., Passingham, R.E. and Brooks, D.J. (1995) Self-initiated versus externally triggered movements. I. An investigation using measurement of regional cerebral blood flow with PET and movement-related potentials in normal and Parkinson's disease subjects. *Brain* **118**: 913-33.
- Karp, B.I., Porter, S., Toro, C. and Hallett, M. (1996) Simple motor tics may be preceded by a premotor potential. *Journal of Neurology, Neurosurgery and Psychiatry* **61**: 103-106.
- Kinsbourne, M. (1993) Integrated cortical field model of consciousness. *Ciba Found Symp* **174**: 43-50.
- Libet, B., Gleason, C.A., Wright, E.W. and Pearl, D.K. (1983) Time of conscious intention to act in relation to onset of cerebral activity (readiness-potential). The unconscious initiation of a freely voluntary act. *Brain* **106**: 623-42.

- Libet, B., Wright, E.W., Jr. and Gleason, C.A. (1982) Readiness-potentials preceding unrestricted 'spontaneous' vs. pre-planned voluntary acts. *Electroencephalogr Clin Neurophysiol* **54**: 322-35.
- MacIntyre, N.J. and McComas, A.J. (1996) Non-conscious choice in cutaneous backward masking. *NeuroReport* **7**: 1513-6.
- Macknik, S.L. and Livingstone, M.S. (1998) Neuronal correlates of visibility and invisibility in the primate visual system. *Nat Neurosci* **1**: 144-9.
- Pascual-Leone, A., Brasil-Neto, J.P., Valls-Solé, J., Cohen, L.G. and Hallett, M. (1992a) Simple reaction time to focal transcranial magnetic stimulation: Comparison with reaction time to acoustic, visual and somatosensory stimuli. *Brain* **115**: 109-122.
- Pascual-Leone, A., Valls-Solé, J., Wassermann, E.M., Brasil-Neto, J., Cohen, L.G. and Hallett, M. (1992b) Effects of focal transcranial magnetic stimulation on simple reaction time to acoustic, visual and somatosensory stimuli. *Brain* **115**: 1045-1059.
- Searle, J.R. (1998) How to study consciousness scientifically. *Philos Trans R Soc Lond B Biol Sci* **353**: 1935-42.
- Taylor, J.L. and McCloskey, D.I. (1990) Triggering of preprogrammed movements as reactions to masked stimuli. *J Neurophysiol* **63**: 439-46.
- Taylor, J.L. and McCloskey, D.I. (1996) Selection of motor responses on the basis of unperceived stimuli. *Exp Brain Res* **110**: 62-6.