Article

A Brain Charge Mechanism Modeled in Synchronistic Dyadic Interpersonal Interaction

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ABSTRACT

A simple model of charged brain states in coupled synchronous interpersonal interaction is presented. Active states are treated as electromagnetically positive and passive and receptive states are negative. Cognitive and behavioral action is modeled during simultaneous charge-paired dyadic conversational exchange as well as in longer-term social decision-making processes. Theoretical principles are derived from electrochemical and neurobiological foundations that can be tested using imaging and electrophysiological techniques.

Key Words: brain charge, synchrony, interpersonal coupling, mirror neuron, interpersonal coordination, coordination dynamics, brain electrodynamics

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Introduction

Interest in the features of synchronously 'coupled' interpersonal interaction has grown in recent years. It is now well-understood that there are often simultaneous activations of matched brain regions between interrelated individuals and that there are special physical mechanisms of interdependently linked processes in social coordination dynamics (Haken *et al.,* 1985; Tognoli *et al.,* 2007; Kelso, 2008). New theories of interpersonal synchronization and entrainment have appeared (Semin and Cacioppo, 2008) as well as empirical studies of the simultaneous social exchange between individuals (Rotondo and Boker, 2002; Stephens *et al.,* 2010). Much of the interest in this topic followed from the discovery of the mirror neuron system and an increasing recognition of the importance of functionally aligned behavior between individuals that enhances productive cooperative interaction (Gallese *et al.,* 2007). Recent brain imaging demonstrations leave little doubt that socially paired individuals will often exhibit a simultaneous activation in similar brain regions during interaction and that dyads may be understood to be coupled with each other in a unique way (Stephens *et al.,* 2010).

At the same time, there has also been a dramatic increase in the use of electrically based technologies such as EEG and EMG to measure a variety of cognitive and behavioral processes (Lagopoulos *et al.,* 2009; Naeem *et al.,* 2012). For example, it is now possible to routinely measure the electrical difference between two states of mind using inexpensive devices available to the general public (e.g. the Emotiv EPOC headset). The technology has advanced to the level of being able to control computers and devices merely by thinking a specific thought. Surprisingly, however, a complete theoretical biophysical description of some of the basic aspects of the biological

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physics behind quantitative measurement of variable states of mind and matched states in coupled interpersonal systems remains lacking.

For example, in comparing one state of mind to another or when contrasted with a baseline level of activity, there will be a quantitative difference between two distinct states of mind that is more than a matter of identifying the characteristic waveform or location of the two measured states. The same will apply when there is a complementary matching and pairing of simultaneous states between two individuals, where the difference between them can be measured in both a chemical and electrical way. In these cases, it is implied that there must be an electrochemical ("electrical") potential and charge difference between two such related states. For example, it may be considered that an individual will reside in what would be considered a "default mode" state of lower baseline activity level (Raichle *et al.,* 2001) but when thinking a specific thought or engaging in a particular matched social activity there will be an increase in the "task positive network" relative to the baseline or complementary state. There will be a net difference in the biochemical activity between two related states when they are treated as a pair of relatively active and passive or receptive states in an individual or coupled interpersonal interaction.

Currently, however, there is little or no research literature describing the possibility of such an explicit electrochemically based (*i.e.,* "electromagnetic") model of charged individual cognition and coupled interpersonal behavior, and of genuine biophysical "positive" and "negative" states of mind (see discussion in Haas, 2011a; 2011b; 2011c; 2011d). Yet it has long been known that neurobiological processes involve a large number of electrochemical phenomena, including action potentials, ion channel gating, etc. These have traditionally been measured with electrophysiological biophysical techniques at the single cell level such as with the patch clamp method or through the result of bulk statistical cellular activities using EEG and MRI that measure larger collections of group neural activity. But there remains no extant model that would describe the actual functional units of cognitive and behavioral action using explicit physical terminology correlated directly to the physical chemical origin and nature of these neural events, although electrophysiological methods are capable of measuring an impressive amount of fundamental bioenergetic activity.

For example, while certain EEG brainwaves (alpha, beta, delta, etc.) represent oscillations in potential at the surface of the skull indicative of general classes of cognitive processes (*e.g.,* alert or resting states), they have not been described in a way that would define the specific state of mind using a physical concept that is correlated precisely to the cognitive neurochemical action of the brain and body. Similarly, models of complex interpersonal coordination dynamics that use physical concepts to explain synchrony or entrainment as self-organizing (Haken *et al.,* 1985) and emergent processes have not detailed how these would arise from the actual physical chemistry of the brain and body. The signals are typically treated as byproducts or fingerprints of cognition and behavior rather than physical cognition itself, though useful EEG signatures of general states of interpersonal synchrony have been identified (Tognolli *et al.,* 2007; Naeem *et al.,* 2012).

It is important to recognize that the brain and body are likely to be driven by biochemical and electrochemical charged states at specific moments and episodes of cognitive and behavioral action. These may represent very specific active or passive and receptive states that can be considered inherently "charged" in a direct psychological and physical conceptual way. This may become particularly important in optimally coupled interactions where individuals are matched in complementary ways during resonant synchronistic interpersonal interaction and in relation to other objects in the environment (Kelso and Engstrom, 2006; Stephens *et al.,* 2010). The physical principle of brain charges would correlate directly with specific cognitions and would not be unlike the concept of electromagnetic attraction or repulsion, except that it is different in its biological mechanisms and manifestation (Haas, 2011c).

It can be proposed that there are indeed net electromagnetically "positive" and "negative" mental states during alternate states of greater and lesser mental activity in individuals and matched interpersonal behavior. Such charged states may occur both in an individual's personal changing states as well as in coupled interpersonal active and receptive interactions that utilize specific cognitive and behavioral functions. For example, affective states that are commonly described by psychologists as being of a positive or negative valence could be more accurately described by how the cognitive and emotional states arise from the actual chemistry and physics of the brain and body. Anger or fear, typically considered to be "negative" emotions, may often require a higher level of effort and action than relatively passive states of bliss or happiness that are typically considered to be positive states or emotions. Using a fully physical scientific model of psychology, however, such ostensibly "negative" active states like anger would perhaps be more accurately treated as physically positive. The physical reality of psychology will depend on how the reaction is generated from within the body and its interactive coupling with the environment. For example, directing one's own positive angry "electromagnetic" energy productively toward beating a competitor or wisely actively running in fear from danger could certainly be considered psychologically positive in some ways, especially in regard to the increase in energy expenditure by the brain and body relative to a passive or defeated state.

There are a number of pieces of biophysical evidence and simple chemical principles that can be used to convincingly inductively reason toward a charge-like model of the brain during cognition and behavior. First, on the whole, active brain regions are known to use a greater amount of oxygen than resting or inactive regions (Lin *et al.,* 2011). This is the basis for BOLD measurements that are generally correlated to the region of the brain responsible for a given cognitive event. Wherever there is greater neural activity, there is likely to be greater oxygen required for energy generation within mitochondria because those areas consume more oxygen during a given brain process. What may be less appreciated, however, is the fact that this chemical "combustion" of oxygen with electrons derived from the late products of metabolism, is likely to yield a net positive result. For example, the reduction of oxygen by the fourth mitochondrial complex, cytochrome *c* oxidase, uses electrons originally derived from food and the subsequent low potential metabolic substrate NADH. This ultimately liberates energy by taking advantage of the higher electrochemical redox potential or chemical "electronegativity" of oxygen (Haas *et al.,* 2001), and is likely to be net positive as shown in Figure 1.

From a physical chemical perspective, the end products of the first part of the metabolic reaction must be considered to result in a net positive conversion with respect to the entire system and environment. However, much of the energy generation will be conserved through subsequent negative results during the following production of ATP in the brain (Abrahams *et al.,* 1994). But the ATP is likely to be utilized in subsequent reactions in the cell until the point at which an approximation of the original equilibrium constant value (or "homeostasis") of the brain system is restored. Even under the assumption of a very high efficiency in the total work done in the latter part of the reaction by the neural system, which could not be perfectly efficient, it is not likely that the system would be driven into an equal or greater negative state when compared to the initial amount of net positive transformation in the first part of the sequence. So the net result of the chemical "burning" of organic material in such a way will yield a net electrically positive result while being a part of the entire surroundings that includes the biological system, due to the net movement of electrons toward relativity positive (electronegative) oxygen nuclei and a less than perfectly efficient second half of the bioenergetic process.

The oxygen consuming part of the metabolic process may therefore be treated as net positive within the context of the entire system and environment, and the second part will, at best, be equally negative or slightly less so. Regardless of precise knowledge of all the later cellular processes involved in the neurobiology, the net result on the entire system during cognitive *activity* will consequently be the transformation of an initial quantity of electrochemical potential driving force (ΔG) to a new and increasingly positive form. From a bioenergetic perspective, the entire system must move up or down an electrochemical charge gradient and potential, and in this case the result will always be at least slightly positive when compared to times of lower neurological activity, though some cellular components and parts of the brain are possibly driven to an increased negative state. For the purposes of creating an operational physical definition useful to psychology, however, higher levels of cognitive and bodily action and activity can be simplified as being positive, and periods of lower activity may be defined as negative. The positive nature of neurochemical activity itself can be inferred from the metabolism up to the point of oxygen reduction or from the result of all activity. Indeed, each step of the bioenergetic metabolic process can be described in terms of potential and kinetic energy as in Figure 1, and the final step of ATP consumption itself is likely to be a positive kinetic action.

There are also other ways in which neural components may exist in comparatively charged ensembles of states. For instance, enzymatic modifications such as phosphorylation may control action in neurons, and there are of course many ways in which learning and memory creation take place, such as through the creation of stronger synaptic connections (Kandel, 2006). These modifications may be treated as net positive or negative in themselves, as collections of cells comprising functionally devoted regions of the brain that attain states of slightly higher or lower potential, analogously to dynamic active or less active oxygen consuming regions. In these cases, direct chemical and genetic modification may lead collections of cells to reside in a higher or lower electrochemical state. Modifications could create small changes in potential in the state of a cell itself as well as by regulating functional activity. For instance, the addition of formally negative inorganic phosphate to an enzyme or the switching on of a voltage gated ion channel through a conformational change may create a slightly increased positive or negative electrostatic state of an enzyme or cell. Thus, in addition to the relatively dramatic transient kinetic mechanism during greater oxygen consumption, there are likely to be other modes by which cognitive and behavioral states become net positively or negatively charged. These cases of stronger biochemical modification could control longer-term cognitive processes as effected through longer lasting chemical bonds and biological structures, while kinetically active cognition and behavior utilize larger bursts of metabolic oxygen consumption for short-term activities.

These fundamental biochemical principles can be used to support the hypothesis that cognitive and behavioral states are in fact truly electromagnetically "positive" and "negative" (Haas, 2011a; 2011b; 2011c). Positive and negative cognition and social interaction can be considered to be pairs of such charged physical states. For instance, social receptivity may involve a relative decrease in activity in some areas of the brain, and this may require a relatively negative basal level of activity in these areas. A receptive listener might also create stronger impressions and longer-term bonds in the brain that are negative, although the act of creating such impressions may be positive due to the neural activity required to do so. Conversely, an active speaker, who is likely to be using a greater number of motor skills, would be more positive in relevant active brain regions, and this would also include the electrophysiological properties and energy consumption of other parts of the body.

Both scientific and colloquial descriptions of "negative" behavior might be considered with a less pejorative connotation. For example, actively listening would be relatively negative in the areas involved in speaking but positive in areas of the brain required for paying active attention or involved in actively creating a memory (although the memory itself may be stored in negative form). Listening may often be equally positive to speaking in many ways, although it is sometimes considered an inferior activity. Both positive and negative activities are required for coupled interpersonal coordination: for every active positive speaker there must be an equally negative receptive listener(s) in some specific attributes, and vice versa in others. The two may be paired and use similar amounts of energy in many of the same parts of their brain and contrasting amounts in others. But the speaker on the whole may generally be considered more positive due to his or her greater energy consumption. Figure 2A offers a simple model of how the active state of mind of one individual would be received in a negative receptive part of another person's brain during a synchronously coupled interpersonal interaction such as during ordinary conversation.

Comprehensive quantitative analysis of whole brain signals will help to clarify precisely how and in which parts of the brain/body these events occur (Naeem *et al.*, 2012). It is likely to be the case that a person will be both positive and negative in different parts of their neural networks at the same time, and that is why two charges per brain are shown in Figure 2. There will probably be many more pairs that are equilibrated within the brain itself (Haas, 2011a). For the purposes of introducing of the simplest physics of this model, it is important to emphasize the electromagnetic nature of the states and their higher or lower relative activity. The details of precisely where these processes occur in the brain and body (whose activities must be evaluated together as whole) and how they are complementarily balanced intra- and inter-individually will need to be elucidated. There are likely to be differences between two individual's perceptual, motor, short and longer-term memory areas that are complementary in their activity levels, and it is already known that the mirror neuron system activates many of the same regions.

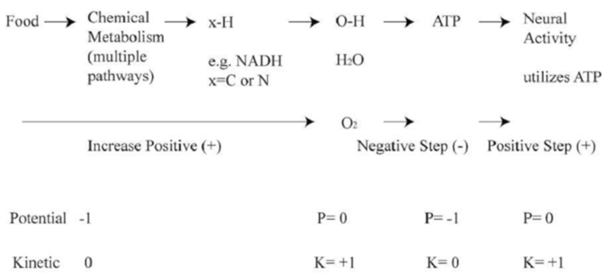

Figure 1. Simplified description of net electrochemical charge changes during cellular combustion of organic substrates in the brain and body. Food is broken down through metabolic cycles in mitochondria to the relatively negative product of NADH that is converted to a positive electrochemical proton gradient and then into relatively negative energy rich ATP. In a final step the ATP is used for neural activities and the release of its negative potential energy is treated as a positive kinetic step. For purposes of simplification, the changes in charge of potential and kinetic energy are normalized in each step to be a sum total of 1, a key principle of psychobiophysics (Haas, 2011a).

The state of an individual's brain may also change as a function of a longer period of time, especially following interpersonal interactions. This would be mediated primarily through the suggested second class and mode of charge transformation involving neural modifications in longer-term memory processes. The case of longer-term processes is depicted in Figure 2B&C. For instance, after or during a social interaction, each individual will cognitively process their prior experience and ultimately make decisions. They will "recharge" and redistribute the potential energy of their instinctual drives and motivations before responding or choosing to meet with the other person again. Ideally, perhaps, as regards synchronistic behavior, a subsequent meeting would take place at a later time optimized for additional productive cooperative interpersonal exchange, taking advantage of the maximal efficiency of complementarily charged states (Haas, 2011a; 2011d). In these instances, synchronistic events may occur at times of effective mutually aligned interests in a unique simultaneous and specially matched way. They may emerge from subconscious processes after a period of time (Cambray 2002; Hogenson, 2009; Haas 2011d).

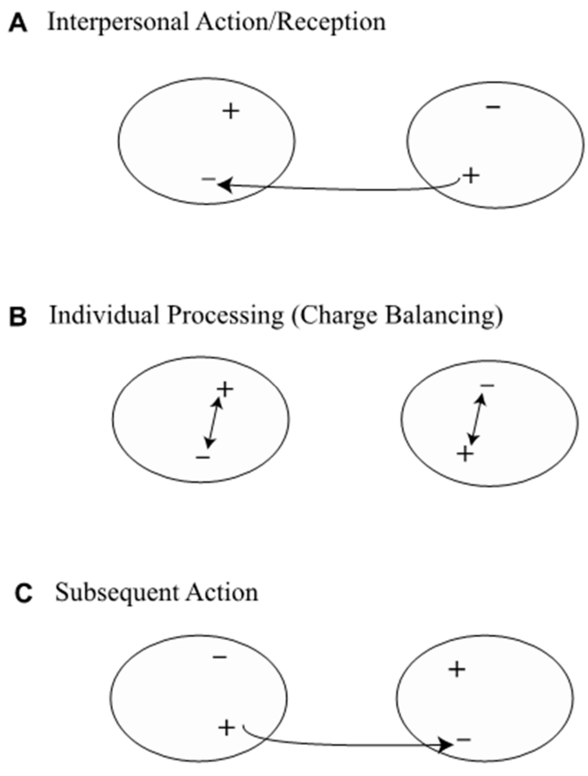

Figure 2. (**A**) Coupled individuals are simultaneously activated in matched regions of the brain (+) and overlap in oppositely charged regions, e.g. expressive(+)/receptive(-) areas. This may occur in a speaker-listener exchange while the speaker is using a larger number of active motor skills and the listener creates an impression of the speaker in their memory. (**B**) After the two individuals engage in a mutual synchronously aligned behavior, they may reverse roles or separate to process their experiences, regenerate productive interactive desires, and make decisions. After an interval of time passes they become optimally "recharged" or redistributed and their neural networks are rebalanced. (**C**) They may exchange roles

and return to meet again to repeat the exchange with the opposite person being more positive.

The effect is suggested to resemble the classic Jungian synchronicity phenomenon (Jung, 1955). In this case, a plausible physical synchronistic mechanism is provided through a model involving the concomitant occurrence of a physically matched and aligned set of electrochemical events and circumstances (Haas, 2011a). Much of this synchronous alignment and charge-driven behavior may take place beneath ordinary conscious awareness in the biochemistry of the brain and body, and to that extent it can be considered unconscious or non-conscious. There may often be a lack of awareness or understanding of the strength and mechanisms of this kind of overlapping of physical interpersonal chemical "bonding" (Haas, 2011a; 2011c). Recent studies have begun to show that individuals in dyads and groups will exhibit a sense of coordinated timing even after entraining cues cease to provide the *zeitgeber* (Hove, 2008; Oullier *et al.,* 2008; Valdesolo, 2010), but the effects have not been described in an electrodynamical way.

To confirm the central features of this model, it remains to clarify which parts of the brain are paired in opposite complementary ways during simultaneously timed interaction, that whole brain and body states are differentially charged, and that the effects can persist through longer periods of time. This may be achieved using a global brain analysis of net differences in cognitive activities from EEG and MRI measurements; *e.g.,* using sums from the entire brain, or body. If such effects can be proven, it may have substantial implications regarding the physical description of mental and behavior states, as well as in understanding the general timing and organization of thought and behavior in social structures. From this perspective, it may eventually become possible to construct a practical physical scientific theory of mind and social behavior. The approach would be similar to that which already exists for sensory psychophysics, and would have a much broader social application if used in conjunction with the traditional thermodynamically derived principles of psychoanalysis (Haas, 2011a).

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