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Review

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From Brain to Mind: A Plain Route from Neurobiology to Psychology

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SUMMARY

Mind sciences have not yet provided a definitive answer to the dual nature of self and to the existence of Free-will (FW), so the mechanisms operating in cognitive processes such as action decision-making remain partially elusive. In this review, we address the question of a so-called "voluntary" action from the agent's and the scientist's points of view (respectively from 1st and 3rd person perspectives) and conclude that the "Bignetti Model" (TBM) may offer a solution to reconcile both; i.e. FW is an illusion in line with the agent's belief in the soul-embodied self and, along with this belief, it may play a functional role in cognition. With TBM, we explain cognition in a bottom-up track from a molecular to a psychological level without the need of soul-body duality.

KEYWORDS: Bignetti model; Self; Free-will; Probabilism; Determinism; Cognition; Inner speech; Bayes' theory.

ABBREVIATIONS: FW: Free-will; TBM: Bignetti Model; fMRI: functional Magnetic Resonance Imaging; EEG: Electroencephalograph; BCI: Brain-Computer Interface; CEMI: Consciousness electromagnetic field theory; MM: Michaelis and Menten; SoO: Sense of ownership; SoA: Sense of agency; CM: Conscious Mind; UM: Unconscious Mind; IS: Inner Speech; BDT: Bayesian Decision Theory; AI: Artificial Intelligence.

INTRODUCTION

Advances in technology have proved invaluable in lending support to neuroscientists in revealing the complex architecture of the brain and its neurophysiology. In cognitive sciences, non-invasive methods are certainly preferred when assessing intimate brain activity. One of the most common technique to study the information flow state in brain areas is functional Magnetic Resonance Imaging (fMRI).[1,2] Attempts to achieve integrated signals of the loop between muscles and brain decisions have been carried out also by using Electroencephalography (EEG); to this regard, a Brain-Computer Interface (BCI) was developed to allow direct communication between humans and computers by analyzing electrical brain activity, recorded at the surface of the scalp with EEG.[3-6] These two techniques seem the most promising research and presents challenges for the study of neuroscience, signal processing, machine learning, neurorehabilitation, user interface etc.

Although the mind, consciousness, and cognitive processes remain open to different hypotheses, we trust that a model of mind and consciousness compatible with biophysics and the brain's architecture, will sooner or later be discovered. In order to better understand the mechanisms underlying cognitive processes, we will assume that the relationship between brain and mind is the same as for any other organ of our body: structure and function. In this regard, the recent proposal of the "Consciousness electromagnetic field theory" (CEMI) made by McFadden is intriguing.[7] The basis for his theory is that the brain's electrical activity and magnetic fields have a reciprocal inductive effect, so that neurons behave like electrical cables. Due

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to the brain's highly dense and compact wiring, the magnetic field associated with a firing neuron can modulate or even trigger electrical firing in its neighbours and *vice versa*. In summary, the sense of self, the conscious computational and representational experience and the associated "*qualia*"[8-10] are far from being understood *via* the CEMI theory, yet it is a straightforward physical approach to a plausible solution of brain-mind duality.

Now the question is, can we understand cognitive processes by simply assuming as true the biophysical properties of CNS? Considering ever more complex functions, we may reach a point where we have to admit defeat, i.e. it may be that the higher cognitive functions can only be controlled by a soul or an immaterial agent. Thanks to considerable progress in neurosciences, one aspect in particular, has been brought to the forefront of the discussion: "Can the capacity to make decisions, perform voluntary actions and consequently believe in the existence of a self having FW, be sustained solely by brain biophysics?"

THE PARADOX OF BURIDAN'S ASS

The issue of action decision and performance can be illustrated using the "paradox of Buridan's ass". The paradox is incorrectly attributed to Buridan since it was formulated by others in a logical extrapolation of his thinking. A freely adapted version of this paradox says that before a hungry donkey there are two identical meadows or two identical hay sacks, but the donkey cannot decide which one to eat first and starves to death. This absurdity-even considering the dumbest of donkeys is used to support the thesis that if the mind is strictly "deterministic" or "mechanistic", it will be unable to decide between two perfectly identical situations, where there is no preference indication. In reality, the donkey would eat first from one sack and then from the other, apparently at random. The point is then, that the mind is not "strictly deterministic" yet is determined to reach its goal. In other words, the donkey is determined to satisfy its hunger and the probability of a successful outcome is no different whichever sack it choses to eat from, and in whatever order. We may comment on this taking a reductionist view: it is the lack of food that leads to a drop of sugar levels in the donkey's brain; when the brain is off balance due to an external stimulus like this, it adopts a purpose-built strategy which is made initially by many aleatory attempts to search for food. In conclusion, hunger satisfaction is a statistical-deterministic goal that can be met by a stochastic search for food everywhere (like throwing a dice many times until we get the right number).

Is this behaviour of the mind so natural? The answer is yes! In nature there are many of these examples. Let's start with the brain.

Analyzing the different structural and organizational levels of the brain from the lower molecular level to the anatomical level, we can imagine a model of cognitive functioning which is complex but acceptable. Taking the single molecular component or sub-microscopic fragment of the nervous system such as an ion channel, a membrane receptor or a synaptic bouton, we see that its functioning is unpredictable,[11] i.e. it is aleatory as if we were throwing dice. If the mind worked in a similar way to this, we would have serious difficulty satisfying our desires, e.g. hunger! Primarily, we would be unable to understand the meaning of hunger; moreover, it would be hard to decide how to eat etc. The switching of a single voltage-gated Na+ channel from a closed to an open state upon membrane depolarization seems to be an unpredictable-stochastic event, i.e. it occurs at random, is unconditioned by any desire or motivation and does not depend on the prior physical state of the channel. In other words, random behaviours of single CNS molecules would not explain decision-making and action coherence of the mind. If we now extend our angle of observation to supra-molecular organization, things change noticeably. First of all, we note that by stimulating a sufficiently large membrane patch, i.e. averaging over about 2000 Na+ channels per squared micrometer, we observe a stereotypical, predictable Na+ signal which is conditioned by a membrane depolarization upstream. Therefore, a collection of stochastic elements exhibits probabilistic-deterministic behaviour thus conforming to the cause-effect paradigm. The complex and coherent actions which derive from these events are the basis of common cognitive functions in large areas of the brain. Due to the complex structure of the brain, "collective" events can be synchronized by physiological stimuli evoked by the external or internal environment, so that a thinking mind may emerge from the brain without recourse to a soul-inhabited self.[12,13] We should not forget, too, that the possibility of dialogue with the world is not a new characteristic of the brain; signal processing and the complex integration of different random systems in CNS was acquired thanks to genetic and epigenetic pressure.

In summary, we are able to successfully apply the Hodgkin-Huxley formalism[14] to neuronal activity to describe the dynamics in terms of a deterministic theory and graded ionic currents; yet, we must admit that its success is due to a collective response of pores, synaptic boutons and receptors and not to any one of these elements taken singly.[11] Averaging microscopic currents by so many stochastic neuronal components working in parallel and serially, make macroscopic currents in brain areas highly predictable. Then, coherent and functional stream of thought is "deterministically" ruled by the laws of probability.[15]

Again, we would like to stress that probabilistic-deterministic systems are quite common in biology at all levels of organization. Some other examples taken from natural systems are shown below:

1. Let's consider a physical system determined by a fluid dynamic (or by molecules in a fluid) in a closed space (for instance a cell). The fluid molecules move by virtue of thermal perturbation, in every direction, at random. However, if they find a hole they spill over into the empty space in a spontaneous and irreversible way. An outside observer might think that the net flow of fluid in a specific direction depends on the "will" of the fluid, but for the fluid the mo-

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tion is unconscious, it is the result of the fortuitous cooperation of two factors: the random motion of each molecule of the fluid and the probabilistic (thermodynamically-driven) direction of the molecules into newly-formed empty spaces. Similarly, thoughts are like fluid, ready to expand in every direction when stimuli come. Hunger, for example, and the sight of hay activates preferential pathways and thought becomes apparently coherent with a clear goal to pursue. Thought, thanks to its intrinsic "desire" to think, will continually take the pathways (open partitions) most likely to quell the stimulus.[12,13]

2. In this example we refer to a scientific paper published few years ago in a reputable journal about a simple physical-chemical system displaying "intelligent" behaviour.[16] The authors demonstrated that a drop of oil in a water maze at the first attempt finds the shortest way to reach the exit, similar to laboratory mice after lengthy training. Briefly, the "trick" of this "brainless intelligence" is that the drop and the maze's exit have been treated with substances with a notoriously high reciprocal affinity and the drop moves in the maze in a probabilistic-deterministic way. The results of this experiment suggest that only two things are necessary to efficiently carry out a purpose-built strategy: there must be a certain "pre-existing" attraction between the subject and its goal and the movement toward the attraction entity must be carried out through a probabilistic-deterministic system.

3. The third example is biochemical. Enzyme mechanisms and the famous kinetics study of enzyme reactions in catalytic enzyme concentrations ($[E_o] << [S_o]$), carried out by Michaelis and Menten (MM).[17,18] Initial velocities of enzyme catalysis obtained in the presence of varying experimental substrate concentrations, are plotted, thus obtaining the famous hyperbolic MM function, a sort of enzyme fingerprint whose maximal catalytic velocity (V_{max}) and Michaeli's constant (K_M) are macroscopic parameters characteristic of each kind of enzyme. The MM study is a classic in biochemistry texts, since it demonstrates that each kind of enzyme exhibits specific kinetic behaviour. However, these texts rarely highlight the fact that each point on the MM curve is, in reality, the mean macroscopic observation of as many microscopic catalytic rates as the enzyme molecules working in the test tube. Certainly, the collisions between enzymes and substrates are random in water but MM experimental conditions are such that: a) in any experiment all enzyme molecules in the bulk have the same probability of colliding with a substrate molecule; b) this probability increases with substrate concentrations. So the statistical approximation of many stochastic rates calculated at different substrate concentrations concur to give rise to a predictable function.

Many other examples could be given of the statistical-deterministic behaviour of natural events, e.g. the allosteric mechanisms regulating enzyme catalysis or the cooperative flagellar activity for efficient microorganism movement etc.[19,20] However, our concluding remark on the Buridan's ass paradox is that not a single ass would starve to death in such a ludicrous situation. To tackle the question of "action-decision making" and of "who is in charge?", ambiguity rises from the idea that "deciding" an action and "being in charge" of it are synonymous with "self-awareness".[21] Rather, our opinion is that "decision" means (brain) elaboration of a response which may be considered statistically the most adequate reaction to a stimulus, in the natural interrelationship between the individual and his surroundings. This point of view is quite close to Autopoiesis, a theory introduced by Maturana and Varela.[22] Initially, they introduced it to describe the chemical mechanism by which living cells self-maintain and reproduce. Then, the main characteristic of Autopoiesis and the focus on a continuous dynamic implicated in any rudimentary form of knowledge or cognition, lead researchers to apply it to many forms of self-organisation in human society.

In summary, the kind of "action decision and performance" we are dealing with, can be carried out by an unconscious brain without the simultaneous awareness of any form of agency. Only later on, the outcomes of an individual action might appear to self-consciousness like a pre-recorded broadcast. The process of an action (reaching one of the hay sacks to eat) can neither be based on a single stochastic model nor on a pure deterministic response, but rather is a sophisticated blend of the two. One stochastic "decision" at a time (like throwing dice only once) wouldn't lead to a coherent and adequate solution of the problem. Conversely, a strictly deterministic brain would not have the means to choose between the two hay sacks as discussed above. Our final hypothesis is that of a (brain) model responding to a mix of probabilistic trial-and-error behaviour that leads to a successful deterministic conclusion. First of all, the perception of hunger would certainly open some nervous pathways leading to a final target: the meaning of eating. Moreover, the mind is unlikely to spend its life deciding what to do if the sacks of hay are identical; it would be more likely to stuff itself with the first available sack.

A deterministic brain would stop in front of a choice, while a probabilistic-deterministic brain would swing from one solution to another, allowing its thoughts to consider a range of possible situations until it finds a coherent answer to the initial stimuli. Obviously "trial and error" is an efficient experiential method provided it is accompanied by a specific memory store. The ass's response refers both to stimuli such as hunger, i.e. physiological stimuli, as well as stimuli coming from our memory and our personal experience (e.g., the emotional world of the limbic system). Since each individual has his or her own personal history, it follows that each individual's actions are unique.

Imagine the Buridan paradox where instead of one hungry donkey, there are two donkeys standing in front of two hay

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sacks. The probability that the donkeys will fight over the same sack must be very low.

THE SELF AND THE FREE WILL

Self-awareness and the Senses of Agency and of Ownership

The specific mechanisms operating to achieve human self-recognition have recently been elucidated.[23] Very early on, in the uterus and then after birth by physical contact and social communication, we develop the conviction that our body belongs to us and that it has distinctive psycho-physical characteristics which distinguish it from the rest of the world. However, the Sense of ownership (SoO) is only one of the constituents leading to self-recognition; concomitant with the sense of ownership we realize our self is always in motion. All the feed-back sensations associated with our movements generate a growing Sense of agency (SoA) internally. A conscious agent refers to SoA when he feels causally involved in an action.[24] Moreover, by moving or trying to move our body in any direction (to perform either a mechanical or a logical task), we not only explore the limits of our body but we also realize the limits of our own effective power. Mainly dependent on this prerequisite an individual can develop the critical distinction between self-generated actions and actions generated by others, from which, in turn, leads to the sense of responsibility, a key function for mature self-recognition. In this respect, some years ago it was demonstrated that a lesion impairing spatial recognition in the brain, does in fact impair self-recognition of movement.[25] Later on, specific brain areas which can finely discriminate between a first-person and a third-person action, were discovered using neuroimaging techniques.[26,27]

Long ago, Tolman demonstrated that voluntary action performance is determined by the incentive value of the outcome of the action itself.[28,29] So that, each appetitive behaviour triggered by a motivational system stands on specific incentive value.

The "Bignetti Model" (TBM)

In humans, pure appetitive motivational states are rare. Moreover, hedonic incentives to possess an object are often secondary. The need to reinforce egocentric attributes, however, such as self-recognition, self-responsibility and self-esteem appears to be the necessary and sufficient incentive, regardless of what the material target to be reached may be. We unconsciously consider the voluntary action as a type of egocentric challenge to raise our level of skill or knowledge. Every time we act, we have the opportunity to test the relative efficacy of our incentives; thus, we may not only infer new information about the stimuli, but we can also evaluate the adequacy of our motivational system. In other words, the cognitive processes and motivational systems appear to be linked because depending on the outcome of an action, we learn how to finely tune our motivational system for the future.[12]

The 5 stages of TBM[30] are:

1. The so called "voluntary" action is decided and performed by the agent's Unconscious Mind (UM) by means of probabilistic responses to inner and outer stimuli.

2. After a slight delay, the agent becomes aware of the ongoing action through feedback signals (somatosensory, etc.) that are conveyed to the brain as a consequence of its performance. Thus, the agent's Conscious Mind (CM) always lags behind unconscious activity.

3. Owing to this delay, the CM cannot know the unconscious work that precedes awareness; thus the CM erroneously believes it has freely decided the action. Though objectively false, this belief is subjectively perceived as true (FW illusion). It is so persistent and deep-rooted in the mind that the CM is unwilling to abandon it.

4. The FW illusion satisfies a psychological need to secure the arousal of the sense of agency (SoA) and of responsibility (SoR) of the action. Both SoA and SoR inevitably lead the CM to self-attribute reward or blame depending on action performance and outcome.

5. Both reward and blame are motivational incentives that foster learning and memory in the CM; the updating of knowledge will provide new information and the skill required for further action (restart from point 1).

An overview of TBM suggests that human knowledge evolves in a circular sequence of intervention from the UM to the CM and back to the UM. A scheme of the flow of these events is reported in figure 1. CM has a distinct though complementary role with UM. CM resides in the ego (with the Freudian significance). Not all the operations of the ego are conscious; however, in this context, we assume the ego acts according the "reality principle" (i.e. the ability of the mind to assess the reality of the external world, and to act upon it accordingly). In our context the ego is a virtual representation of our personal identity that emerges as a conscious thinking entity. The ego believes itself to be independent when interacting with the environment; so, premeditation to obtain a goal can be psychologically attributed to the ego as a free causal agent.

According to TBM we might infer that the so-called "voluntary" action is just a reaction of UM to an external stimulus in order to attain a new equilibrium with the environment.[12,13,30-35] The action protocol at best follows unconscious memory skills. At the very moment we do something we have no time to intellectualise about our action or consider the purpose of acting as premeditated so we cannot be fully conscious of the nature of action agency. However, a second later, the back

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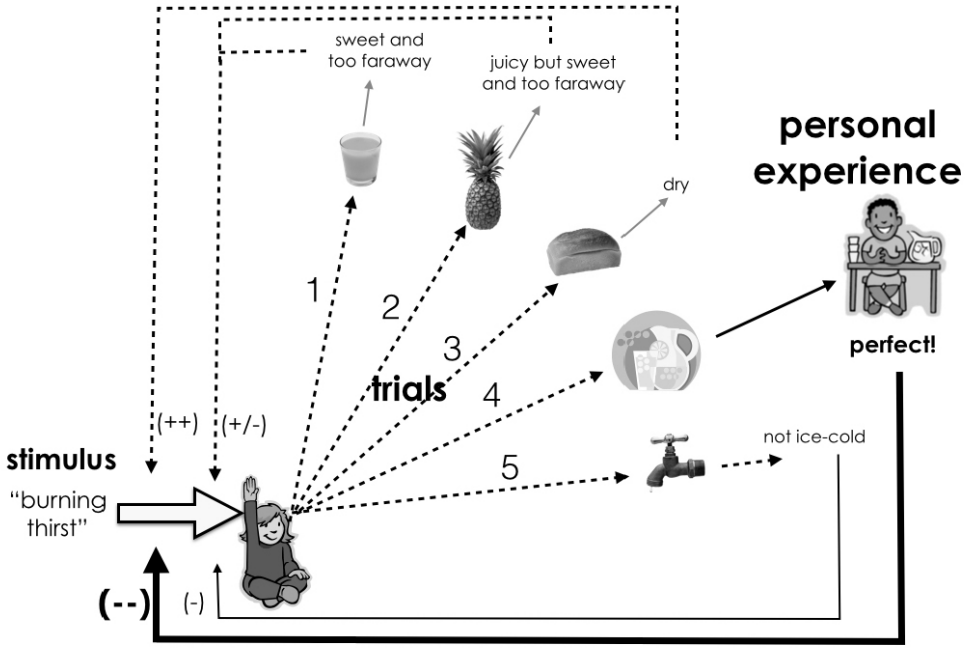

Figure 1: The course of a voluntary action according to TBM. Assume that's the first time that a burning thirst (external stimulus) is perceived by the boy; so, the past experience archived in memory stores cannot facilitate the unconscious mind (UM) in finding the correct trial that would extinguish it. Initially, the first choice is aleatory since the 5 hypotheses are equally probable. However, trial after trial, conscious mind (CM) can update memory stores on the basis of motivational incentives like reward and blame. Then, the trial and error paradigm of UM evolves towards a conditional probability, i.e. towards the choice 4 (perfect!) which CM has memorised as the most efficient one. Obviously, the less hypotheses remain, the faster and the more instinctive would be UM decision and the least will be CM intervention.

signals of the performing action draw the attention of the ego. Then, giving the ego the possibility to recall the overall timing of the event and analyse the action outcomes, it is beset with the sensation of having "wanted" and caused the action. Thus, the ego jumps to the false conclusion that it has freely decided that specific action among a number of options. The belief in FW has no rational basis, rather it looks like a self-referential appreciation of the ego exalting its power, i.e. a sort of psychological motivation to put itself in the forefront. Moreover, the false belief in FW which is the consequence of a subjective 1st person perspective, is not a mere psychological illusion. As a consequence of this illusion, the senses of agency (SoA) and of responsibility (SoR) arise in the ego leading it to self-attribute either a reward or blame, depending on the action outcomes. In cognitive sciences, reward and blame are generally considered the motivational incentives leading to action-decision making; in TBM, however, it appears in the ego ex-post. Therefore, every piece of experience leads to the updating of memory stores thus preparing the unconscious mind for further actions (restart from point 1). After a series of trials and errors, the ego has the opportunity to learn and memorise the correct protocol in response to the stimulus. In conclusion, the ego cannot decide an action, but can update its memory stores, thus providing the unconscious mind with the most accurate information possible with which to perform a similar action in the future.

According to the reductionist view of TBM, we might claim that the individual keeps believing in the ego as a spiritual body-independent entity (with all the philosophical and psychological implications of the ambiguous nature of the individual self). In other words, the ego is the primary illusion of the mind, i.e. a virtual agent self-instantiated in mind *ad-hoc* to assume the responsibility of intentional actions. FW, which is a by-product of the ego, is also an illusion which, however, plays a functional role in cognition.[30,32]

1st person and 3rd person perspectives

A further insight into understanding whether our FW is an illusion of the mind is based on perspective, i.e. the 1st person or the 3rd person perspective. My personal experience of self-consciousness sometimes alternating with an inner witness of the self, might shed some light on this aspect:

1. Self-consciousness: I have two personalities one of which belongs to the private sphere where I search for a pencil or eat quietly with my family; the other one belongs to the public sphere where I am engaged in scholarly discussion (for instance, when I'm publicly claiming that FW is an illusion!). In both situations I instinctively feel able to control my reactions with my innermost perceptions of SoA and SoR and am bewitched by the fascinating belief in FW. Both personality traits, public and private, coexist and alternate distinctly in the mind; even the transition from one to the other belongs to me, in accordance with Dennett's phrase "My brain made me do it".[36] These mental states do not enter into any psychological conflict with each

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other. They alternate and never overlap either in time or in space but they are not so far apart as they might appear at first sight, originating from the same self.

According to the scientific literature, these personalities reflect "private self-consciousness" and "public self-consciousness", respectively. The first is the introspection of the inner self and one's feelings; the second, instead, is the awareness of the self as it might appear to others. These personality traits may co-exist without cross-influencing each other.[37] To these definitions I might add that the transition from one personality into the other, is perceived as an explicit fruit of my will, so that my belief in FW is reinforced. Moreover, both traits of Self-consciousness are conditioned by a unique subjective view (1st person perspective).

2. Inner witness: Sometimes during the day, I feel the awakening of an inner witness which, independent of psychological needs, desires and affects, begins observe my private and public personalities; likewise in a 3rd person perspective, it can analyse me, i.e. the 1st person, in a cold and detached way. It happens in certain self-inspired situations like in Hindu Transcendental Meditation where the first step in Sadhana (the ego-transcending spiritual practice pointing to the final target Moksha) is the awakening of the inner witness.

In summary, Psychology, then, seems to be the most suitable discipline for delving into the labyrinth of self-consciousness and is nearly able to give a reasoned answer to the question of whether decision-making is really free and whether FW is somehow a bias based on the 1st person or the 3rd person perspective.

The next question is: "how do the different kinds of self-consciousness and the inner witness become explicit in the mind? The most convincing theory in my opinion is the mechanism of "Inner Speech" (IS), also known as "intrapersonal communication". IS is a sort of silent dialogue conducted with oneself at a fully- or semi- conscious level, in the mother tongue.

The Russian Vigotsky was the first to observe IS in children and suggested that it was a mental faculty fostering the development of higher cognitive functions. The mother tongue is learnt at an early stage and is spoken aloud for the purpose of social interaction; later it is internalized, first in a sub-vocal modality then in an inner modality. Inner speech constitutes a formidable tool not only to self-narrate and interpret the actions going on around us but also to guide personal behaviour by means of intimate reasoning. In contrast to the three major scientific theories (see: *constructivism*, *gestaltism and behaviourism*), Vigotsky proposed that learning always precedes maturation in children provided that they are accompanied in their early years by an external tutor.[38]

We may suppose, then, that at the beginning of an individual's life the environment may be interpreted and memorized through very basic though vital language. Later on, individual thinking develops a higher level of sophistication until intrapersonal communication coincides with the mother tongue to enable communication with others. It is interesting to note that IS vanishes in automatic gestures, i.e. in a skill we have already acquired such as when crossing a street in a hurry at the green light or when we play a back-hand at tennis. It seems that in many repetitive actions, we no longer need to evoke the instructions to make them.

When I am aware of myself, I can constantly perceive IS: I am the one silently describing in Italian the thoughts going through my mind at this very moment. IS is not only a tool to describe the events around me but also a tool for reasoning about past actions, present desires, or future decisions (such as the wish to take the car, call someone by phone or have a drink instead of bread, etc.). Making this explicit reinforces SoA and SoR in my mind.[31]

This discussion typically provokes an epistemological debate in cognitive sciences about the meaning of "voluntary" action and the *ex-ante* or *ex-post* role of IS in action decision-making. The proposals of the scientific community may be divided into at least three main models:

a. If one agrees with soul/mind-body duality and believes in FW, it is conceivable to think that action decision may be taken by a free or partially conditioned agent. Consequently, IS should play a significant role in decision making thus preceding the action.

b. On the other hand, if one assumes a deterministic, non-dual position, the "voluntary" action, though made by a conscious agent, is a "conditioned" response dominated by cause-effect rules. Then, FW is a mere illusion and IS cannot mediate "proactive" thinking; at most, IS might be reduced to a chronicle of the action, i.e. a sort of void chattering.

c. The third theory is TBM, another "non-dual", reductionist position reconciling both 1st- and 3rd-person perspectives. Action-decision-making is carried out by the unconscious part of the mind (UM) on the basis of a statistical-probabilistic modality (see above for details). This is the first thought that is elaborated along the agency path, so it necessarily precedes the action itself. Slightly later, the agent becomes aware of what is occurring by means of feed-back sensory signals of the action performance and its outcomes. With the exception of very fast "gut" reactions (see below), these afferent signals are also translated by IS into a language comprehensible to the mind, so that SoA and its relative SoR can emerge in self-consciousness. The agent (the psychological Self) perceives that the action has been decided completely autonomously

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and freely (FW illusion). SoA and SoR are a prerequisite for cognitive processes; even though they are false, they promptly foster IS to evaluate the action outcomes in order to self-attribute either the prize or the punishment, a necessary step for cognition.

There are several points to note: a) The belief in FW is a psychological need either of private and public self-consciousness to foster cognition. In other words, Self-consciousness and FW illusion represent a virtual binomial apt for cognition; b) the agent's affective conviction that he or she makes his or her own choices in daily life is a typical subjective 1st person perspective, while, the rational, detached approach of the functional role of FW illusion in cognition, leading the subject to perceive false SoA and SoR, is a 3rd person perspective. So 1st person perspective is necessary for the development of the individual knowledge while both 1st person and 3rd person perspectives are necessary for the development of scientific knowledge; c) IS is the tool by which the ego can converse with itself. The ego starts its dialogue too late to manifest a proactive effect in action decision-making but explicitly chronicles the events, then it can evaluate the action outcomes and reason with itself about the correctness and efficacy of the action. So, by means of IS, the agent can learn and memorize the correct protocol from the experience, thus making an action better and faster. Specific skills are ingrained in our memory so that a protocol based on trial and error is replaced by a single, instinctive and automatic gesture. Obviously, when this occurs, IS is no longer needed and the reaction time is so fast that IS vanishes (see above).

Jones and Fernyhough[39] claim in their "Forward Model" (FM) of motor control that IS is a form of action which precedes the action in order to create an emotional expectation of what is about to happen. If this expectation is promptly followed (milliseconds later) by the actual action, the perception of self-authorship will then increase. These authors admit that their FM borrows its ideas from Wegner's model of "apparent mental causation".[40,41] However, Wegner's model does not clarify the ambiguity of the dual/non-dual position.[32] Our objections to FM are as follows:

a. The authors claim that IS is a "sort" of action; if this is the case then why this action is not preceded by a previous prediction state, or previous motor control of an intelligent agent? In a similar situation, Akins and Dennett's objection was that if IS is intelligently planned by a specific discourse plan, then there should be an intelligent entity planning IS and so we regress to infinity.[42] We concur, and are unconvinced by Jones and Fernyhough's defence of FM in not assigning to IS a vital role in action planning. They circumvent this criticism claiming that the important thing is the mismatch between the predicted and the actual action; the mismatch is the crucial step that might lead to the neurological activity associated with passivity experiences, which may indeed lead to IS being experienced as "unintended". However, assuming that instead of a mismatch there is a match between predicted and actual action, this event might unleash enormous affective implications on the growing the ego, i.e. on self-esteem and personal identity. In conclusion, with a matching situation the agent feels self-authorship, whereas, with a mismatch, the agent might ascribe his action to a stranger/an alien, lying to himself as if he were schizophrenic.

b. Second, the authors seem to position the "motor command" timing of both IS and action milliseconds earlier than they actually occur. This is necessary to allow the final matching of the predicted and the actual action. IS should derive from the "desire state" which also programs action performance. Our question therefore is: "Who is really in charge of the motor command and IS? Moreover, IS is not used for action decision-making but only to check the final matching between expectations and the action itself. So, where does the awareness of a desire state (or action goal) come from?

c. FM theory claims that a matching mechanism occurs at the end of an action but nothing is said about the degree of matching for cognitive purposes. Since we cannot modify our trial and error in advance, it is more plausible that IS may be effective only when receiving information on what has already been done. Then, it would be plausible that cognition proceeds by means of a post-adaptive mechanism (through a sort of Darwinian cognitive mechanism); to this end, the real action is fragmented into tiny components to redirect the action by means of a "point-to-point protocol" (a similar hypothesis was proposed by Bodovitz)[43] in which IS though *ex post*, could really become useful along the action path to reach its goal.

d. In FM, the main focus of interest is on the mismatch which determines the perception of other-authorship; nothing is said about events which may underlie further cognitive processes. In TBM, however, IS is an instrument of self-consciousness for the generation of intelligible experience with which to enrich the memory. A psychological reward for an achievement or punishment for failure in action performance is thought to have intrinsically the same epistemological value in TBM. In FM, the focus is more on the mismatch (and the other-authorship possibly deriving from it) rather than on the match (and self-authorship), and so there is a didactic asymmetry between prize and punishment taught by experience. In our opinion, the authors' intent was driven more by a concern for solving psychiatric problems than for proposing a model of human cognition.

TBM and Bayes' Decision Theory

The conditional probability calculated on the basis of

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Bayes' theory (BT) is a widely used tool of information processing. Bayesian Decision Theory (BDT) and Artificial Intelligence (AI) share common roots and strive for similar goals by adopting the same probabilistic-computational approach of BT.[44-46] Recently, it has been proposed that also the post-adaptive learning mechanism exhibited by TBM is compatible with BT.[30]

Consider any two events A and E (with P(E)>0); Bayes' equation:

$$P(A|E) = P(A) \times P(E|A)/P(E)$$

tells us how to update our degree of belief about A on the basis of the occurrence of E.[47] Some vocabulary:

- P(A|E) stands for the "final" or also, less properly "posterior" probability of success of A, i.e. the hypothetical probability of A inferred on the basis of given E. In other terms it indicates the compatibility of experience E with the action A.
- P(A) is the "initial" estimate of probability or also, less properly, "prior" probability.
- P(E) is sometimes called the "marginal likelihood". This factor must be always positive. It is the same for all possible hypotheses being considered, since the term A does not enter it.
- P(E|A) is the "likelihood function". It indicates the probability of observing E given action A or, in other terms, the compatibility of the final experience with a given hypothesis.
- P(E|A)/P(E) is the "updating" factor, i.e. the term that multiplied by P(A) can update the degree of belief of A.

Bayes' theorem can be applied to TBM with some specific caveats. We must consider that the conditional probability of success of action decision making may be calculated on the basis of this formula, given that:

- A crucial notion is the correlation between the events (see figure 1). On the one end, UM cannot know *a-priori* the effect of A; so, UM decides on A due to the close resemblance of the present situation with past experience (note this decision is the consequence of a conditioned will, not of free-will). On the other end, CM may evaluate the degree of success of A only after the occurrence of E. Therefore, the "updating" factor P(E|A)/P(E) and, as a consequence, the degree of belief about A, will be revised by CM too late with respect to UM decision. This revision, however, will help UM in future (see point 5 of TBM).
- The agent's reaction A in response of a change E of the environment, has the aim to remove the stimulus and re-establish a new equilibrium. The resemblance between the interacting agent-environment system and the chemical equilibria according to Le Châtelier's principle is striking.[48] This principle states that when a system near equilibrium is subjected to change in concentration, temperature, volume, or pressure, it readjusts itself to counteract the effect.
- In iterative actions, the "posterior" probability tends to match the "prior probability since the "updating" factor tends to 1; so, the interventions of CM and of IS are no longer needed (see "d" above). A further striking evidence is that the higher is the matching between results and expectations, the faster will be the action (see figure 1).
- P(A|E) ranges between the limiting values 0 and 1 which correspond to two paradoxical situations, respectively: a virgin mind like a Lockean *tabula rasa* and a deterministic mind, like the "Laplace's Daemon". On the one hand, a decision made in the absence of any prior experience would be stochastic, with practically no chance of success; on the other hand, an intellect that would know all forces and the vast net of information set by nature would unequivocally be able to predict the future. As Laplace says: "... *Rien ne serait incertain pour elle, et l'avenir comme le passé, serait présent à ses yeux*".[49] This inference sounds like a deterministic prediction of the probabilism death.

Based on these principles, we are carrying out psychophysical experiments to monitor the time needed by a subject during voluntary actions in response to a series of known stimuli. Preliminary results seem to indicate that conscious "response" time reduces with trials, getting closer to the classic, instinctive "reaction" time. These data seem to corroborate the hypothesis of a post-adaptive cognitive mechanism and comply with the old Tolman's "cathexis" theory.[28-30]

CONCLUSIONS

The basic idea in TBM is that the brain is a probabilistic-deterministic machine using the trial and error paradigm in cognition. In particular, decisions are made by the agent's unconscious mind, while learning and memory processes fostered by personal experience are exclusively driven by the agent's conscious mind which is awaken by feed-back signals of action performance. So, what we learn and memorise from the outcome of a so-called "voluntary" action is a too-late experience for that specific action but it might be useful knowledge for the next one. The more repetitive a stimulus is the higher the likelihood of reacting faster and more efficiently to it.

Thus, TBM stands on a sort of "radical empiricism": it denies soul-body duality but admits the existence of a dual soul-body perspective in the mind as an inescapable "trick" which looks like a "teleological" design of evolution to increase cognition and respond optimally to environmental changes. This trick does not require a soul but simply a psychological mechanism giving rise to the virtual binomial Ego-FW.

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In summary, the 1st and the 3rd person perspective can be reconciled in the name of human cognition: TBM (the 3rd person perspective of a voluntary action) claims that the conscious mind (the 1st person perspective of the agent) does not decide an action but can perform a psychological trick to make action experience comprehensible and fruitful. By assuming the ego and FW are real and by using inner speech to make the reasoning explicit and worthwhile, the agent is convinced he is fully responsible for the chain of events leading from a decision making to a fruitful experience.

In the preceding paper, we have discussed the potential impact of TBM in social life.[30] A great concern was given to the accountability of TBM in ethics. Moral rules enable social relationships to be organized on the basis of stable, predictable behaviour. Then, one might fear that, without FW, the conscious agent would not have sense of morality; however, he/she thinks to possess FW and this belief, though illusionary, is still real. As he/she perceives SoA and SoR as real these feeling make him/her responsible for determining their moral rules and their compliance with the law. It is evident that FW is an illusion but it is also evident that the FW illusion is the basis for human cognitive processes. So the solution of the moral question kicks the problem to how moral values can be imprinted by formal education together with familial and social environments.

Issues regarding the possible role of mirror neurons in TBM were also raised; they might play a primary role in agency and self-awareness, by facilitating the awakening of the agent's CM. According to TBM, the implication of mirror neurons in cognitive processes would come even prior than mimicking other's action.[30] In everyday life, the successful monitoring of behaviour requires continuous updating of the effectiveness of motor acts; one crucial step is becoming aware of the movements one is performing. To this regard, we should mention *anosognosia*, an interesting pathology which is viewed as a deficit of self-awareness. Sometimes, hemiplegic patients suffer from *anosognosia* and obstinately deny their motor impairment, claiming that they could move their paralyzed limbs. Denial was associated with lesions in several brain areas deputed to programming motor acts and the somatosensory cortex.[50] A review on the possible causes of *anosognosia* has been recently published;[51] however, it is clear that further research is needed. Then, it might be interesting to investigate this disorder according to TBM perspective and see whether CM defect due to the lack of feed-back signals, might be the principal cause of self-awareness impairment.

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