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Info-Relational Cognitive Operability of the Posterior Cingulate Cortex According to the Informational Model of Consciousness

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Abstract: Based on the analysis of the accumulated experimental data and on the informational concepts of the Informational Model of Consciousness (IMC), in this article is presented an informational modeling of the operability of the posterior cingulate cortex (PCC). Examination of the experimental results obtained with the modern non-destructive, high spatial resolution investigation tools to study the functional characteristics of the PCC and associate metabolic processes, shows mainly that this is involved in the large scale default mode network (DMN), composed primarily by PCC, medial prefrontal cortex (MPFC), and the inferior parietal lobe (IPL), displaying an increased activity under passive task conditions (i.e. negative mode). This operability mode is in an opposing balance with attention and task performances mode, acting thus as a disruption process. One of the main conclusions is that the PCC cognitive orientation is primarily focused on the self person or on the "self" (I) projected from others, in "daydreaming" or "mind-wandering" wakeful rest, involved in present or future virtual projects. In spite of these advances, the particular role and specific functions of PCC are not yet fully understood, PCC remaining an enigmatic/contradictory structure of the brain, not included up to date in any brain model, so the PCC informational modeling presented here in terms of IMC covers this lack. IMC assigns to the brain the fundamental role of informational processor, composed by various operating structures according to specific objectives synthetically expressed by seven main cognitive centers of "self" (I) as: Iknow (memory), Iwant (decision), Ilove (emotions), Iam (self-status), Icreate (genetic transmission), Icreated (genetic inheritance), Ibelive (info-selection), assuring the info-connectivity with the body and external/internal world, the adaptability (learning process) and survival. It is deduced in this way that the specific behavior of PCC according to its intermediary architectural position between the vital central region of the brain, connecting the mind with the external/internal reality, is that of a moderator/integrator hub/informational YES/NO switcher from the external/awake captured focusing information to the internal accumulated experience of life, used as a valid reference. Therefore, the specific operability of PCC in terms of cognitive centers is that of an informational switcher, mainly operating with Iknow/Iwant to explore the self-status reflected in Iam, within day-dreaming/imaginary virtual sceneries.

Keywords: Posterior Cingulate Cortex (PCC), Informational Model of Consciousness (IMC), Default Mode Network (DMN), Cognitive centers, PCC Operability

1. Introduction

The brain and the cognition behavior is a topic of intensive researches and discussion, from the perspective of various scientific branches, starting from philosophy [1] to the modern neuroscience, including not only the neurology, psychiatry, psychology [2] and biomedical specialized fields [3], but also physics [4] and more recently the information science [5]. One of the fundamental factors impelling/boosting the new results in the brain understanding was the intensive development of microelectronics and micro-physics systems, which allowed a dynamic development of the non-invasive and non-destructive tools of investigations, specifically applied in this case to the investigation of the posterior cingulate cortex (PCC) operability [6]. On the other hand, the

advances on the theoretical concepts involved in this field, particularly the concept of information, are adding a special, particular key value for the understanding of the brain functions and operability [5]. That is because, although when the brain and its functions are discussed, it is generally admitted that information is the fundamental means of the brain operability, no deep meaning of this concept is taken into account, neither at the molecular level (assuring the internal connectivity [7]), nor at the macro level structure [8]. On the philosophic/informational line concerning the information role discussed earlier for non-living and living systems [9, 10], later continued, developed and applied for the analysis and modeling of consciousness and of the informational system of the human body [5], it has been opened new perspectives to understand consciousness and the informational operability modes of the brain [11].

From the perspectives presented above, PCC continues to be one of the mysterious zone of the brain, mainly because, although it is neuro-connected to vital areas of the brain (thalamus, hypothalamus, amygdala) and the prefrontal cortex, its activity is increased especially during the rest of the brain, acting as a disruption process from the attention focused on some external tasks to a “day-dreaming" internal exploration, justifying the reference to such a behavior as a negative mode [6]. A modeling of PCC behavior is lacking actually. Starting from the present accumulation of experimental data on PCC and their particular interpretation as a function of the specificity of the experimental used techniques, in this paper it is presented an analysis and a modeling of the PCC behavior in informational terms, according to the Informational Model of Consciousness (IMC), allowing to describe from a global and coherent inter-relational perspective the functions and operability mode of PCC, still considered up to date an enigmatic and contradictory issue [6].

2. Data Analysis of the PCC Cognitive Behavior

The PCC is an anatomic area of the brain situated in the posterior zone of the brain, in an antipodal position with respect to the anterior cingulate cortex (ACC), as a posteromedial cortex and upper part of the limbic system [12], indicated schematically in the upper right side of Figure 1.

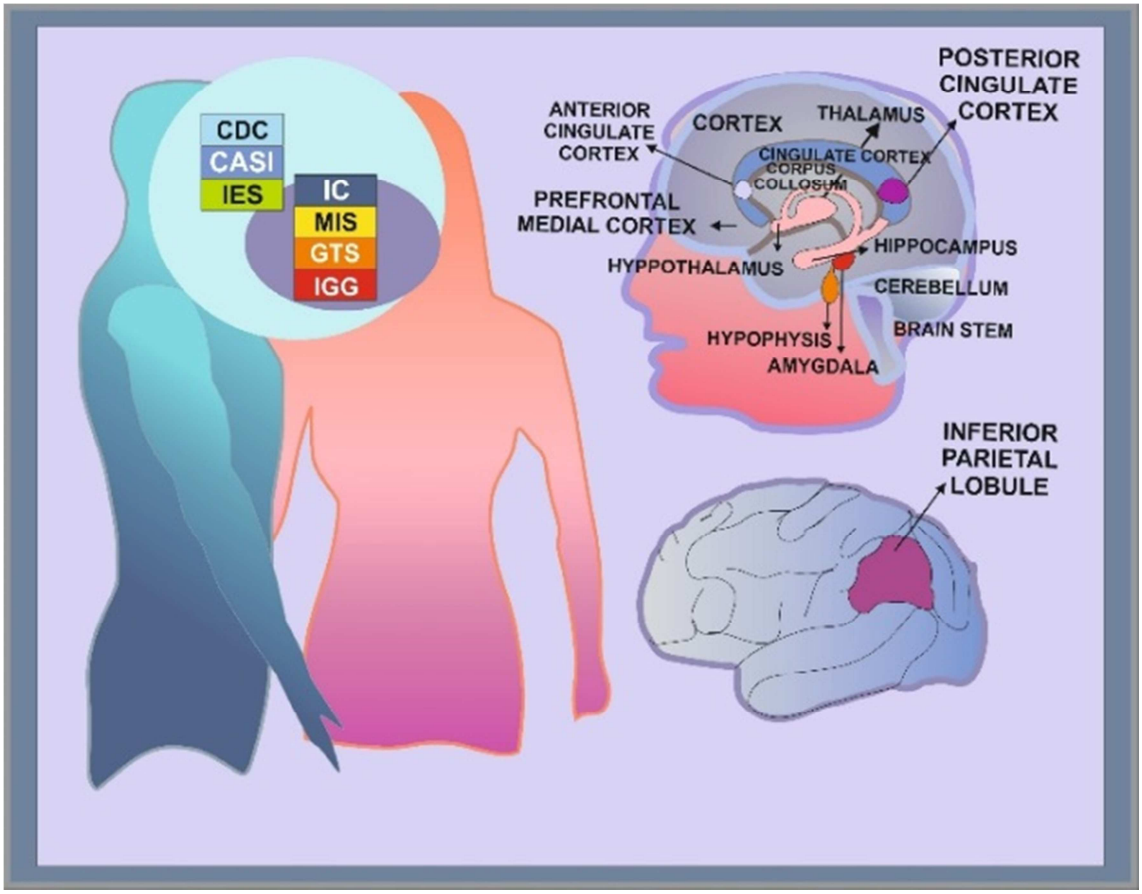

Figure 1. *Schematic representation of the main components of the brain (right side) and of the main corresponding components of the informational system of the human body, defined as CDC, CASI, IES and IC, MIS, GTS, IGG (left side of the figure).*

While the activity of ACC is quite well studied and known, this operating in the awake state especially as an automatic administrator/moderator YES/NO informational hub between the amygdala alarm/emotional input impulses and decisional prefrontal cortex, as pain moderator and stimulator of the empathy relations, involved also in the religious states [4 2],

the role and the functions of PCC are not yet well understood [6]. On the basis of the recent development of the high spatial resolution, non-invasive and non-destructive investigation tools, like functional magneto-resonance imaging (fMRI), fluoro-deoxy-glucose (FDG)-positron emission tomography (PET), electroencephalography (EEG) [6], the real-time fMRI neuro-feedback [13], there were obtained important experimental data in the investigation of PCC.

Starting with the reported results in a study published in 2001 [14], and taking into account the observed specific inter-relational behavior, PCC was included into the so called Default Mode Network (DMN), primarily together with the medial prefrontal cortex (MPFC), and the inferior parietal lobule (IPL) [15], as shown in Figure 1. Specifically, the IPL is involved, among other cognitive processes like language and mathematical operations, in emotional perceptions/interpretation of sensory information and in the self body image [18], so it is focused also on the self state perception like PCC, as detailed below.

It seems that PCC could interact with ACC in task decisions (connected also with prefrontal cortex), especially concerning the self-related processes, like choice justifications [17, 18], including autobiographic information on self, remembrances, emotions (involving also IPL), the self person projected in relation with others, with the past and the planning of present and future objectives [16, 19].

During the external task performing, the increasing of the PCC activity was related to “lapses" in attention, or “caught up in" experiences, both of them manifested by the mind shifting from the external world to the mentation focused on self. Such phenomena contribute to poor mental performances; however, the increasing of the level of the task difficulty, induces the PCC deactivation, like for instance during a meditation/implication process on a certain important objective. The so called “caught up in" experience consists in the “capture" of attention in a self monologue, which decreases or interrupts the connection with the reality and with the initial starting point of attention. Some experimental investigations using direct intracranial EEG recording, highlighted that the PCC activity is situated in the gamma frequency range [20]. Resisting craving of smoking and drug addiction are also related with the PCC activity [21].

Although PCC is important either for health and diseases, its role and functions are actually absent from the reported brain models [18]. For instance, Alzheimer’s disease was associated with reduced metabolism in PCC area, and a series of abnormalities in PCC functions were associated with psychiatric disorders like schizophrenia, autism, depression, ~~and~~ attention deficit hyperactivity disorder~~,~~ and even with ageing [18].

High-density EEG experiments, interpreted here from the informational (bipolar YES/NO) perspective, have shown recently that in the YES/NO type operating mode (like eyes open/closed or extroversion/introversion state), the PCC activity is significantly increased in a closed eyes/introversion (NO – negative) state with respect to the open eyes/extroversion (YES – positive) state [22]. One of the findings of the above related experiments was that PCC acts as a regulatory hub in the closed eyes (NO) state, triggering and increasing the modulator activity of the information flow to other alpha rhythm (pre-sleeping) brain regions, while MPFC was found to be a modulator/regulator zone for the output flow to the delta rhythm brain regions during the open eyes (YES) stage.

Concerning the above presented data, we have to note that the positive task mode describes typically the attention-involving tasks, while the negative mode is typically associated to PCC/DMN, as a contrary~~,~~ disrupting mechanism. So, from the informational perspective, we have to note that the positive task mode could be associated with YES and negative task mode with NO like a Bit YES/NO informational unit, as pointed out above, and as it will be discussed in more details below, according to IMC.

One of the main characteristics of the PCC region is the higher (40%) metabolic rate with respect to the average consumption of any other region of the brain [14]. Although does little probability to occur and thus there are little data on ischemic lesions of PCC allowing to observe the cognitive consequences, it was observed that PCC is involved in various dysfunctions and disorders like Alzheimer’s disease (lower metabolic level), ageing (impairment, lower speed of the information processing/operability of memory and motor function), schizophrenia (structure abnormalities, problems to maintain the balance between internal/external thought, confusions), depression (functional abnormalities in connectivity), autism (specific symptoms), attention deficit hyperactivity disorder (related with attentional lapses) [23]. The activity of PCC is also involved in the transitional phase between awareness and sleep, consisting in the stepwise reduction of the connectivity between PCC and prefrontal zone of the brain during the sleep and anesthesia processes, showing the regulation role of PCC in consciousness [24, 6].

A dynamic description of PCC activity was recently proposed [23, 6], taking into account the main aspects revealed by the experimental results, centered on three main coordinates, i.e. the state of arousal (sleep/awareness, attention degree), the balance between externally and internally focused attention (vigilance on the changes), the breadth of attention. The dominant and prominent theory indicates that the fundamental PCC function is the implication in the internal mind/thought control, including long-term memory and general spatial and temporal orientation, with large inter-connecting relations with the limbic and paralimbic structures, with hippocampus, prefrontal cortex, medial-temporal structures, demonstrating the hub role of PCC in administration of information in the brain, although one of the intrigue aspects [6] is the appearance of non direct connection with sensorial and motor systems.

Concluding, the main results from the analysis of the available experimental data concerning the cognitive operability implication of PC consist in the appearance of a paradoxical contradiction first of all between the high metabolic consumption of PCC and negative task activity. A second important conclusive observation is the balance

behavior between the external (reality) and internal/self connection, manifested by lapses, “catch up in”, “daydreaming” or “mind-wandering", wakeful rest phenomena, implication in self-personality, including the memory experience and planning of future perspectives, vigilance awake/sleep balance, without a direct connection with the sensory motor systems.

3. Informational Modeling of the PCC Operability

In order to understand the operability mechanisms of PCC from the informational perspective, we have to understand first of all the main related concepts and description of the Informational Model of Consciousness (IMC). This model stipulates that information plays the fundamental role in the operability of the brain, defined both as perceptual (virtual) information or matter-related information, included/incorporated in the genetic or epigenetic structures and processes, or manifested by means of informational flows carried by electronic or chemical informational agents. Part of this information is incorporated/”embodied"/encoded [5] into genetic/epigenetic structures which contains all the instructions of living operations, manifested when it is necessary (cellular division, growth, gene expression), and other type consists in information involved into the current tasks of the organism, i.e. in intra and intercellular chemical communication and in the operability of the brain and of the nervous system by mixt electric/chemical carriers.

Taking into account the specific, distinct informational categories of brain functions, the Informational System of the Human body (ISHB) is composed by (Figure 1 left side): Programmed Informational System (PIS), including the Maintenance Informational System (MIS – involved in the body current automatic metabolic tasks), Genetic Transmission System (GTS – responsible for the info-genetic transmission), Info-Genetic Generator (IGG – managing the body growth and evolution according to the age) and by the Operative Informational System (OIS – engaged in the prompt reactive/adaptive response to the input external and internal information received from sensors), composed by the Center of Acquiring and Storing of Information (CASI – memory and info-sensors network), Center of Decision and Command (CDC – operational info-processing/decisional center connected to the motor and execution elements) and Info-Emotional System (IES – managing the body emotional reactive response to the input information). The Info-Connection (IC) pole of the organism was defined as an informational connection involved in extreme consciousness states like Near-Death Experience (NDEs) [25], Religious and Mystic Experiences (RMEs) [26, 27] and paranormal phenomena [8], with a current info-administration operability shown mainly by ACC activity, directly involved in the dynamic selection between YES (acceptance) or NO (rejection) of a tasks or reaction. YES/NO balance is actually the info-Bit unit and the info-selection is referred to that suitable/convenient information corresponding to the survival or others acquired info-decision criteria, received from the hierarchically-inferior brain structures (limbic, brain stem), in order to be transmitted to the hierarchically-superior cortex structures (prefrontal cortex) for adequate control and decision [~~5~~ 28].

The schematic representation of these informational systems are shown in Figure 1 left side, corresponding ~~with~~ to the anatomical related support structures of the brain [~~8~~, 5] shown in the right side of Figure 1: CASI is defined as the sum of the specific areas of the brain associated with the memory and sensitive/sensorial processing, represented mainly by prefrontal cortex (short-term memory), hippocampus (long-term memory), cerebellum (memory of learned automatic skills and abilities), cerebral cortex interpreting sensorial signals; CDC (decision maker) is connected especially with cerebral hemispheres, frontal and prefrontal lobes of the cortex and with cerebellum for motor commands; IES is related especially to the limbic system – thalamus, hypothalamus, hippocampus, midbrain and amygdala, while MIS is composed mainly by the brain stem, medulla and hypothalamus, managing the vital/metabolic functions of the organism; GTS and IGG are especially represented by hypophysis and hypothalamus, managing the sexual activity and ageing.

According to IMC, the projection/detection in awareness of each component activity of ISHB composes actually consciousness, expressed/defined by the activity of cognitive centers, with specific associated informational functions, as follows: CASI is reflected in consciousness by the cognitive center suggestively defined as Iknow (CASI => Iknow (memory)~~)~~, CDC => Iwant (decision [29, 30]), IES => Ilove (emotions), MIS => Iam (self-status), GTS => Icreate (genetic info-transmission), IGG => Icreated (genetic info-reception [31]) and IC => Ibelieve (selection/maintenance between certainty and uncertainty) [32].

As a subcortical structure, neuro-communicating with cortex (CASI/CDC) and limbic (IES)/sub-limbic (MIS) systems of the brain, the cingulate cortex fulfils various functions both in cognition (attention/associated eyes motor, anticipation, decision-making, ethics/morality, emotions, error detection and autonomic activities) and in automatic body maintenance (blood pressure/heart rate) as an info-administrator in double senses, from the inferior to the superior direction of the brain and in a reverse order [28]. Analyzing now comparatively the operability of ACC and PCC in terms of ISHB/IMC, we have to observe that the two brain regions show an opposite, but synchronized activity: when ACC is active, the PCC is inactive and inversely. They act therefore as intermediary and correlated modules/hubs administrators of information from (or to) the inferior structures (IES, MIS), to (or from) the hierarchically-superior (cortical) structures (CASI, CDC) of the brain. These special functions of relational info-administration are a result of the intermediary position of the cingulate cortex between automatic/programmed structures specific to PIS, situated in the down part of the anatomic architecture of the brain, and the

superior cortex, involved specifically in the OIS conscious/decisional processes. ACC and PCC play therefore a fundamental/key role in the inter-change of informational flow between the inferior and superior brain structures in both senses. ACC is involved in the automatic/autonomic error detection and conflict monitoring of the contradictory data during the current tasks, activating automatically the subsequent prefrontal cortex for ulterior regulation, within an error comparator process in which representation of the intended correct response is compared with a representation of the actual response [32]. PCC is involved in similar activities, but switching the brain attention from external to an internal intro-prospection on the existing accumulated experience serving as a reference, with which the external reality should be fitted. This commutation is initiated by a contradictory balance between the task purposes and internal judgment criteria, PCC connecting attention to a new task derived from the initial one, to deeply and longer-time enter in own self world to find the real response, suitable for own self-reality and to transmit it to the prefrontal cortex for regulation.

Specifically, the main task of PCC is therefore to commutate from the external positive (YES) connection tasks (involving attention to a certain objective), to the internal (negative – NO) world connection, to explore it as a comparative reference. This is actually a specific mechanism to conciliate/integrate the external information with the accumulated experience and informational criteria, accepting (or not) the new information and its consequences for the present or future planned projects.

However, the operability of PCC cannot be reduced only to this function, taking into account specifically (but not limited to) the high metabolic consumption of this region of the brain. Therefore, additional detailed functions should be taken into account for PCC to explain such a high consumption. For this, we have to observe that the PCC/DMN regions are involved in the internal connection/exploration, with special PCC contribution, as an intermediary surveyor of the internal activity and activator of the memory informational area and associated selection/integration mechanisms. Therefore, the connection of consciousness to the personal world, which consists in the stored information in CASI recalled/reproduced from Iknow under the form of integrated "video-clips" plus associated emotional remembrances represented as a global self image, needs obviously a notable metabolic consumption.

The process of integration of the external environmental information is well demonstrated, understood and explained within IMC: the external virtual information captured by sensors is firstly perceived and stored as a short-term (about 1 min.) information and then is accumulated in the long-term memory in CASI and processed by CDC, if this information is important, intensively signaled or repetitively received. IES brings also a significant contribution to the integration process, a sensitive/emotional intensive reaction consolidating the info-integration in a stabilized form. A subsequent superior step is referred to a process of info-integration, which involves additional brain structures like cerebellum, where are stored the acquired new information as automatically manifested abilities, typical for MIS system. The chain of the epigenetic reactions integrates finally the acquired information managed by GTS under epigenetic form, ready to be transmitted by IGG to the next offspring [7]. The info-integration is therefore a progressive process starting from the reception by the external sensors connected to CASI and processed by CDC, following an internal processing pathway of reactions in various specific areas of brain via IES and MIS to GTS, which transfers to IGG the new acquired information. The info-connection center expressed by Ibelieve consolidates this integration, by maintaining firm the internal decision. The epigenetic info-integration is therefore a progressive process in which all the informational centers of ISHB are involved.

From this perspective, the main revealed activity of PCC, seems to be directly involved in the integration process described above, at least in the first phases, by a spontaneous decoupling process from the external task and switching to the internal world, in order to analyze/observe under the own experience auspices if this new information can be fitted with a new composed scenery. The primary role of PCC is therefore to adjust the received information with the internal world within an info-integration process, avoiding the internal conflicts and therefore possible internal dysfunctions, which can become chronic disorders. PCC acts therefore as an automatic guardian to offer to CASI/CDC the necessary opportunity to analyze/select the suitable information, puzzling it comparatively in various configuring ("dreaming") sceneries of present and future, and to observe if this is well fitted. PCC acts therefore in correlation but in antiphase with ACC, the last one contributing to an automatic spontaneous relay-type selection of information sent to the prefrontal cortex, while the first one submitting the information to MPFC (CASI/CDC), for an internal process of intimate analysis/decision with the possibility of info-integration. The PCC intervention could be also dedicated to explore (by a disruptive "dreaming" process) the internal experience to find a suitable non-conflictive responsive solution to an external situation, communicated finally by CDC as attitude. In terms of cognition, the PCC role is to switch the brain to Iknow and Iwant centers for analysis and decision, with consequences on self-status situation reflected in Iam.; A "lapse" is a disruptive process, but not finalized by a complete internal analysis.

The high energy consumption can be justified on the basis of the conclusive observations presented above concerning the PCC specific behavior and could be explained from the perspective of IMC as following:

(1) the closing of eyes is an automatic reflex initiating/triggering the self-introspection, so the PCC activation; the closing of eyes implies a deep signification, i.e. the disconnection from the external world and the connection with the internal informational and emotional experience, by using for exploration the internal "eye of the mind", which is an energy consuming process;

(2) the connection under awake/vigilance conditions to discriminate the low signal level of the internal world, supposes a highly focused attention, needing a notable energy

consumption, probably the highest, to explore and maintain in a semi-active stand-by status the life informational/emotional experience, with a very high quantity of information;

(3) the search of the appropriate information in the informational field of consciousness (accumulated "library" data in CASI) as defined by IMC [5], taking into account that an information is registered and recalled by association with other previous existing consolidated information, is an energy consuming process;

(4) the selection of the suitable searched information, its activation, integration in a global form on the self and displaying it on the mental "screen", which also should be activated and maintained, is a process of energy consumption;

(5) during the visual perception from the external sources, a large (near half) region of the brain is engaged in the visual perception and information processing, the visual information is at human the main mean of external connection and exploration of the reality [33]; as during the imagery process, like in the internal exploration and planning, some image circuits are relatively the same [34, 35], two main consequences are to be expected: (i) the recall processes of internal stored information cannot be activated in the same time with the reception process of the external information, so a balance YES/NO system (performed by PCC) is necessary to operate the suitable change; (ii) the energy consumption on the smaller area (associated with PCC) necessary to activate and maintain the recall process, should be higher than the energy consumption reported to the quasi half area of the brain during the external signal perception, even taking into account the smaller resolution of the recalled memorized image;

(6) in daydreaming and mind-wandering processes, the specific role of PCC is that of a switcher to a "semi-automatic pilot" of mind "navigation" on the life experiential trajectories stored in Iknow, a special exploration between rationality and rather irrationality virtual states; this intrinsic passive (non-motor engaging) exploration managed by PCC supposes a notable consumption of energy, firstly because the info-travel virtual navigating control is assured specifically by this region, and secondly, because the mission to bring up at the conscious level the deep sub-consciousness information including the info-emotional states of earlier life experiences (no sensory neuro-connection), is also a difficult energetic task, consisting in the re-composition of some stored "life clips" and their integration in a "daydreaming" story; in this context, the full engagement of attention in difficult tasks makes of course more difficult a spontaneous commutation to the internal world exploration, as experimentally observed and discussed in the previous section;

(7) the implication of PCC in same mental disorders like depression, Alzheimer's disease, ageing, schizophrenia can be easily understood, taking into account their relations with distortions and confusions which could occurs by a dysfunctional operability of PCC, acting as a regulator/adjuster/integrator switcher between the reality and the internal perception and interpretation, between rationality and irrationality states;

(8) in terms of cognitive centers of IMC, the specific characteristics of the PCC activity recommend it as a disruptive switcher from an external task for connection with Iknow/Iwant and other contributing centers (Iam, Ilove) for exploration of the life experience, sustaining a fitting conciliatory/integrative process of information obtained from two (external/internal) sources during a comparative "dreaming" analysis, expressed in terms of "self" (status) by Iam. The created new information (from this "daydream/dreaming" process) is stored in CASI (Iknow), with additional consumption of energy [4].

During NDEs, PCC could be also involved, surveying actually the self informational status of body, which starts to enter into a disembodiment process by the separation from the material body [36].

4. Conclusions

The analysis of the recent informational data obtained by non-invasive and non-destructive modern methods like fMRI, RDG-PET and EEG reveals some apparently mysterious and contradictory properties of PCC, which concern: (i) the PCC engagement typically in disruptive (negative – NO) tasks, but actually with a high metabolic consumption with respect to any other active region of the brain; (ii) the PCC operability dedicated mainly to the connection with information on self personality, including the past, present and even the future projects, but not connected to the sensory-motor system.

The conclusions of the data analysis were discussed in terms of IMC, allowing the informational modeling of PCC operability, explaining the apparent observed contradictions by: PCC implication in stand-by maintenance of the internal connection to the life experience (including the emotional one) under awake/vigilance conditions, the info-searching and selection, the passive (non motor) navigation as an independent semi-automatic "pilot" within the informational field of data, elaboration of virtual sceneries concerning the planning of present and/or future during the internal introspection to fit the received information with the own judgment criteria. PCC operates as a YES/NO switching balance between external and internal world, in anti-phase but synchronously with ACC, and is related especially with the self personality, so PCC operates with Iknow/Iwant centers, for a global comparative analysis and info-selection or info-integration expressed in "self" (status) terms by Iam cognitive center, with possible role in NDEs experiences, as a supervisor of the body/informational status during the disembody of the informational life experience from the body itself.

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