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The Variant and Invariant in Perception

Fumihiko TAYA[1,2] and Ken MOGI[2]*

[1]*Graduate School of Medicine, Osaka University, 2-2, Yamadagaoka, Suita, Osaka 565-0871, Japan*
[2]*Sony Computer Science Laboratories,*
Takanawa Muse Bldg. 3-14-13, Higashigotanda, Shinagawa-ku, Tokyo 144-0022, Japan
**E-mail address: kenmogi@csl.sony.co.jp*

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Abstract. The recent advances in cognitive neuroscience have made it possible to study the neural correlates of conscious experience in a systematic way. The first principles how and why we have phenomenal experience at all, however, is at present not known. Here, citing some recent advances in cognitive neuroscience, we argue that the phenomenal qualities (qualia) of subjective experience and the origin of subjectivity are tightly coupled. We propose that in order to find the first principles behind subjective experience, we need to tackle the yet-unknown principle in information representation in general, and in particular, the interplay between the variant and invariant in information representation. The relevance of quantum mechanical formalism in this respect is discussed.

1. Introduction

Recent advances in neuroscience have opened several experimental and conceptual tools in order to study the problem of consciousness in a scientific way. Most researchers have attempted to find the neural correlates of consciousness (NCC), which is the minimal set of neuronal events that give rise to a specific aspect of conscious percept.

The idea of the neural correlates of conscious percept is originally due to Francis Crick and Christ of Koch (CRICK and KOCH, 1995). They argued that an explicit representation in terms of neural activities is necessary for the subject to be aware of an object or event. Here, an “explicit representation” refers to the multilevel, symbolic interpretation of some aspects of the visual scene that is represented by a smallish group of neurons (CRICK and KOCH, 1998). Taking the psychological and neurophysiological data into consideration, they hypothesized that only the visual features represented by neurons with direct projections to the prefrontal or premotor cortical areas are “explicit”. Those areas were assumed to be necessary for the planning and execution of voluntary actions, and were therefore considered to correlate with awareness. They concluded that the neural activity in the primary visual cortex (V1) did not enter the visual awareness because it had no direct projection to the frontal area.

CRICK and KOCH (2003) then went on to stress the importance of elucidating the neural correlates of consciousness at least in one instance. They assumed that there was a basic common mechanism under all different aspects of consciousness, so that if one could understand the mechanism for one aspect of consciousness, we could understand all others. Based on this assumption, they chose visual consciousness as the initial object to attempt a scientific attack, because it appeared to be the most tractable. With the advent of the modern imaging techniques such as fMRI, MEG, optical recording, on top of the traditional single unit recording, investigating the neural correlates of conscious percepts has become one obvious and admittedly promising way of attacking the problem of consciousness.

However, as CHALMERS (1995) pointed out, the enigma of qualia is likely to remain even if we have solved the mapping between neural activities and conscious percept as CRICK and KOCH (1995, 1998, 2003) suggested. Here, the term "qualia" is used to refer to the phenomenal aspect of consciousness. The problem of qualia has been regarded as the "hard problem", which seems insusceptible to the standard methods of cognitive science (CHALMERS, 1996), and is central to the problem of subjectivity.

In this paper, we suggest that there are two distinct categories of qualia, i.e. the sensory and intentional qualia. Based on neurophysiological evidences, we argue that these two different categories of qualia correlate with different subsets of neural activities in the brain. The distinction between sensory and intentional qualia leads to a useful streamlining of various neurophysiological data concerning the nature of the neural correlates of conscious experience.

In order to tackle the relevance of qualia in considering the functional set-up of the neural network in the brain, we need to question the very framework of information representation. Any system of information representation is composed of variant and invariant elements. Investigations into the neural information representation have traditionally focused on the variant in information representation, by investigating the change of neuronal activities that correlate with a specific feature of the stimulus or a particular aspect of the functionality of the brain. In order for such variations of neural activity to be functionally relevant, however, an invariant "framework" of representation must exist, in which the variations count as coding of information, and thus become neural correlates in the Crick and Koch paradigm. We argue that the origin of subjectivity is closely related to this invariant framework in cortical information representation, providing the prerequisite basis for neural correlates. We discuss how the phenomenally distinct categories of qualia (i.e., the sensory and intentional qualia) originate from the cortical network of subjectivity which functions as a framework of invariance in cortical information representation. Finally, we discuss the possible relevance of the quantum formalism to the question of the variant and invariant in cortical information processing.

2. The Role of the Primary Visual Cortex in Visual Awareness

As Crick and Koch pointed out, at present the most robust experimental approach for studying the nature of consciousness is to search for its neural correlate by means of measurements of brain activities accompanied by a comparison with subjective reporting (both in humans and monkeys). For example, electrophysiological single unit recordings in the behaving monkey's brain observing perceptually ambiguous figures have been a valuable source of information. In particular, binocular rivalry, where incongruent stimuli from two eyes compete to emerge in the visual awareness, has been regarded as the most effective platform for studying the neural mechanism underlying visual awareness. Data on the neural correlates of perceptual change in binocular rivalry provide a valuable source of information on the neural correlates of conscious experience, where the percept changes without a corresponding change in the physical stimuli.

We review now the experimental evidence of the neural correlates of visual awareness as has been indicated by studies on binocular rivalry.

Signals from the right and left eye retina are conveyed through the LGN of the thalamus and then integrated in the primary visual cortex (V1). The activities of neurons in area V1 are therefore the obvious candidate for the neural correlates of perceptual change in binocular rivalry. However, there are apparently conflicting reports on the role of V1 in binocular rivalry. Early studies on binocular rivalry have suggested that V1 is crucial in inducing rivalry (BLAKE, 1989). POLONSKY and his colleagues (2000) measured BOLD signals in early visual cortex while the subjects viewed rivalrous images with two different contrasts presented dichoptically to each eye. They found that the activities in V1 changed during binocular rivalry. These variations were about 55% as large as those induced by the alternating presentation of two monocular images without rivalry and roughly equal to those observed in other visual areas (V2, V3, V3(a) and V4v). There are other evidences that support the view that area V1 plays a crucial role in the perceptual alternation in binocular rivalry (TONONI *et al*., 1998; TONG and ENGEL, 2001; LEE and BLAKE, 2002). WILSON *et al*. (2001) reported that the speed of ocular dominance propagation as it is mapped onto the visual cortex depended on the eccentricity of the annual gratings, indicating that the site of dominance wave propagation is retinotopically organized and has a cortical magnification similar to V1.

On the other hand, there are reports which suggest that higher visual areas, rather than V1, are the crucial correlates of perceptual change in binocular rivalry. Logothetis and his colleagues have suggested that the best correlation with the percept in the macaque visual system was found to be in the activities in the extrastriate cortex. They trained monkeys to report which of the rivaling stimuli, i.e. gratings drifting in different directions (LOGOTHETIS and SCHALL, 1989) or grating of different orientations (LEOPOLD and LOGOTHETIS, 1996) was perceived. They found that ~35% of the recorded neural activity in area V5/MT and 38% of that in area V4, and about ~90% of that in STS and IT correlated with the monkeys' reported percepts. On the other hand, only 20% of neurons in area V1 correlated with the reported percepts.

Other studies have also suggested that the extrastriate cortex was the site of rivalry. TONG *et al*. (1998) showed by fMRI measurement of human brain that BOLD signals from the parahippocampal "place" area (PPA) and the fusiform "face" area (FFA) varied reciprocally in magnitude during binocular rivalry. KOVACS *et al*. (1996) used complementary patchworks of intermingled rivalrous images and found that perceptual alternation occurs between coherent images rather than patchy images. This result suggested that the competition among images in binocular rivalry is independent of the eye of origin, pushing the likely site of rivalry to higher stages of visual processing than V1. LOGOTHETIS *et al*. (1996) also showed that the competition between two percepts was independent of the eyes. The subjects were presented with rivalrous stimuli which interchanged every 333 ms with each other and flickered at 18 Hz. The mean dominance time was 2,350 ms, corresponding roughly to seven stimulus exchanges. This result, on the face of it, seems to suggest that activities in V1 do not correlate with the perceptual change in binocular rivalry.

3. The Sensory and Intentional in Perception

As summarized above, there are apparently conflicting reports on the involvement of V1 in perceptual shifts in binocular rivalry. The question whether neural activities in V1 are crucial in the perceptual alternations in binocular rivalry, or the makeup of the neural correlates of visual awareness in general, is interesting in terms of the argument by CRICK and KOCH (1995).

Crick and Koch's argument about the importance of direct connection to the prefrontal areas and the exclusion of V1 from neural correlates of conscious perception carries some weight when one considers that visual information only makes sense when it is eventually reflected in the motor response.

However, neurophysiological evidences indicate that activities in V1 are necessary for conscious visual perception, in a differential manner from the higher visual areas. In a condition called blindsight, patients with V1 lesions retain residual visual functions while reporting that they cannot see anything at the corresponding region of the visual field (WEISKRANTZ, 1997). When instructed to report under a two-alternative-forced-choice condition, blindsight patients can discriminate the presence, location, orientation, wavelength, and direction of motion of a visual stimulus well above the chance level. These observations suggest that there are two distinct elements of visual perception, one tightly coupled with our subjective sense of "seeing" something and the other coupled with the ability to make appropriate motor responses. Blindsight conditions seem to suggest that one is able to have the latter in the absence of the former.

By contrast, damages to any other cortical visual areas causes more restricted impairments in visual perception, without a loss of the sense of being able to see. Lesions in area V5/MT lead to the loss of motion perception (NEWSOME and PARE, 1988), while lesions in the inferotemporal cortex (IT) lead to the impairment in face or object recognition (KOLB and WISHAW, 1985), without a loss in the sense of being able to see.

Considering these neurophysiological evidences, we suggest that the differential contributions of V1 and higher visual areas to our conscious visual experience can be streamlined by taking note of the fact that our visual percepts are composed of two phenomenologically distinct elements, namely the sensory and intentional qualia. Here, sensory qualia refer to elements of visual percepts that correspond to color, shine, transparency, texture etc. that represent the stable qualities of object surfaces. On the other hand, intentional qualia refer to the active interpretation of the visual scene, matched with the representation of the outside world in terms of sensory qualia.

Kanizsa's triangle (KANIZSA, 1976) consists of three black pacmans in a white background (Fig. 1(a)). The completion of the edges of the illusory triangle is perceived in terms of intentional qualia, not in terms of sensory qualia. You have a vague sense (intentional qualia) of the edges being completed, but not the sense of seeing an actual line composed of distinct color (sensory qualia). In psychology, this particular nature of the

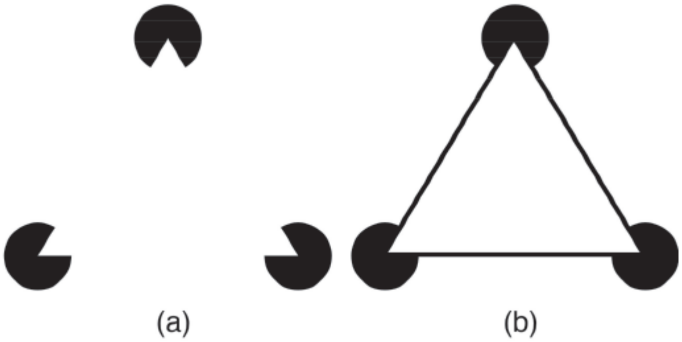

Fig. 1. Illusory triangle and real triangle. (a) The illusory edges in Kanizsa's triangle are experienced as intentional qualia in an amodal completion. (b) The real edges in an actual triangle are experienced as sensory qualia, i.e. lines composed of color distinct from the background.

triangle illusion is referred to as an "amodal" completion, as opposed to a "modal" completion involving a change in the perceived color and/or luminance. Illusory perception in general can be thought of as an instance where there is a discrepancy between sensory and intentional qualia. In the case of a "real" triangle (Fig. 1(b)), there is no such discrepancy.

Another instance where the distinction between the sensory and intentional qualia is useful is the so-called "biological motion" stimulus, which is composed of a set of appropriately coordinated moving point lights. When presented with a biological motion captured from a walking person, subjects can perceive the stimulus as such, often finding it possible to tell the sex, age, and other details of the walker (NERI *et al*., 1998). In terms of sensory qualia, only the point lights moving in the black background are experienced. The "interpretation" of the point lights as a walking person is experienced as intentional qualia, matched with the sensory qualia of lights on black.

Neurophysiological and lesion studies suggest that the sensory and intentional qualia correlate with differential brain areas. Here, the word "correlate" is used in the sense that when there is a change of neural activity in a particular brain area, there is a corresponding change in the subjective percept. This statement does not necessarily mean that the neural correlate of a particular conscious percept (qualia) is the sufficient condition for the particular percept to occur.

We can almost certainly say that a particular neural correlate is a necessary condition for a particular element of conscious perception. There is the theoretical possibility that activities in other cortical areas can induce the same conscious percept. However, given the economy of cortical information representation, such a duplicative correlation is unlikely. On the other hand, it is in general difficult to establish a sufficient condition for a particular element of conscious perception to occur. We will come back to this point later.

With the above disclaimer in mind, evidences such as blindsight suggest that sensory qualia correlate with neural activities in the early stages of visual processing, with the activities of neurons in V1 required as a necessary element. Thus, activities in V1 count as neural correlates of sensory qualia. The absence of neural activities in V1 results in the lack of sensory qualia, and the loss of the subjective experience of seeing something. On the other hand, the intentional qualia are likely to arise from the cluster of neuronal activities within the extrastriate cortex (i.e. V5/MT, MST and IT). The absence of sensory qualia in blindsight results in the loss of the subjective feeling of seeing something, while the residual intentional qualia support the ability to make a correct guess of the nature of visual stimuli presented. Thus, the phenomenal distinction between sensory and intentional qualia can resolve the apparent discrepancy between the neuropsychological evidences regarding blindsight and the Crick and Koch's model of the neural correlate of visual awareness (CRICK and KOCH, 1995).

The distinction between sensory and intentional qualia can also remove the apparent discrepancy among the studies on binocular rivalry. Variations in the neural activities within the extrastriate cortex can be interpreted to correlate with the change in intentional qualia (such as motion perception, object recognition etc.) occurring as a result of the ocular dominance change. Ocular dominance itself is defined in terms of sensory qualia. The variations in the neural activities in V1, on the other hand, can be interpreted to correlate with the corresponding change with sensory qualia, resulting in a change in ocular dominance.

These arguments demonstrate that taking the phenomenology of visual perception seriously can lead to a useful methodology of sorting out the implications of physiological data.

4. Contextual Modulation and Perceptual Stability

The distinction between the sensory and intentional qualia is also useful in describing how the stable and changeable elements of perception match to build an active and adaptive perception.

In the perception of ambiguous figures (e.g., the Necker cube (Fig. 2(a)) or Rubin's vase (Fig. 2(b)), where more than one interpretation is possible, there is a transition between the possible interpretations following a gamma distribution (FOX and HERRMANN, 1967; LEVELT, 1967; WALKER, 1975; MURATA *et al.*, 2003). Phenomenologically, such a perceptual shift is experienced as a change in the intentional qualia. The sensory qualia representation of the figures, i.e. in terms of color, remains stable during the perceptual change. Thus, the perception of ambiguous figures can be thought of as a matching process between sensory and intentional qualia, representing the basic characteristics of the visual scene and its dynamically constructed interpretation, respectively.

The importance of the matching between the sensory and intentional qualia in perception suggests a close interaction between the cortical areas that correlate with these elements of perception. From this viewpoint, it is interesting to note that the activities in V1 exhibit a high degree of contextual modulation.

Neurons in the primary visual cortex are activated by presentation of a stimulus to their classical receptive field (CRF). Stimulus presented outside the CRF does not induce an activity. However, provided that there is a stimulus presented within the CRF, stimuli presented in the surrounding non-CRF can modulate the activity of the target neuron (ALLMAN *et al.*, 1985). This phenomenon is called a context-dependent modulation.

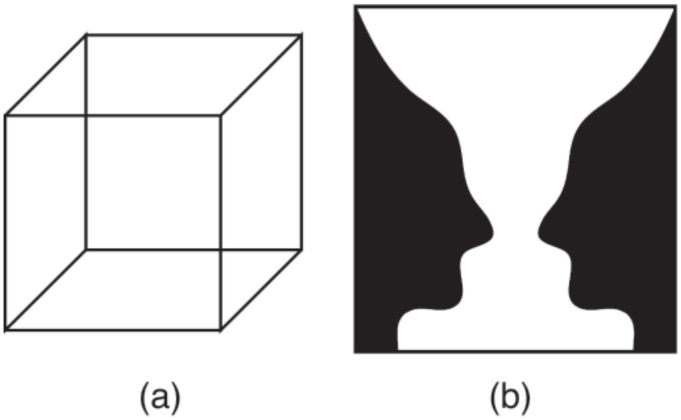

Fig. 2. Ambiguous figures with more than one plausible interpretations. (a) Necker cube. There are two alternative interpretations of this line drawing, with different edges assigned as the forefront. The alternations in interpretation are experienced as a change in intentional qualia, while the sensory qualia of color remain constant. (b) Rubin's base. This figure can be interpreted either as a vase or two human faces. The alternations are experienced as a change in intentional qualia, and the sensory qualia of color do not change.

The modulation by stimuli presented to areas surrounding the CRF tends to work in a suppressive manner. WALKER *et al*. (2000) examined the context-dependent modulation in the cat's striate cortex. They found that for over half of the cells, the effect of stimulation in the surround of the CRF is to suppress activity by at least 10%.

It is known that the effect of the surround suppression is strongest when the property of stimulus presented to the surround of the CRF is similar to that of stimulus inside the CRF. When a vertical grating is presented within the CRF, the presentation of a vertical grating in the surrounds (Fig. 3(b)) induces a strong suppression, sometimes eliminating the target neuron's activity altogether. On the other hand, presentation of a horizontal grating in the surrounds (Fig. 3(a)) results in a weak suppression effect.

Context-dependent modulation of neural activities may play significant roles in object perception. LAMME (1995) suggested that the figure-ground segregation was the key functionality of the context-dependent modulation. In this experiment, recordings were made from awake, behaving macaque monkeys while the animals were viewing texture stimuli. Neural responses in V1 were significantly larger for the figure part of stimulus than for the ground part, consistent with the idea that the one of the functions of contextual modulation in V1 is to separate the figure from ground.

The contextual modulations in the primary visual cortex pose an interesting question regarding the neural correlates of sensory and intentional qualia, and the interaction between these areas underlying the dynamical matching in perception. The contextual modulation is likely to reflect some aspects of the dynamic interpretation of the scene by the visual cortex. While such a dynamical change is expected for a neural correlate of intentional qualia, there is an apparent discrepancy between the fact that neurons in V1

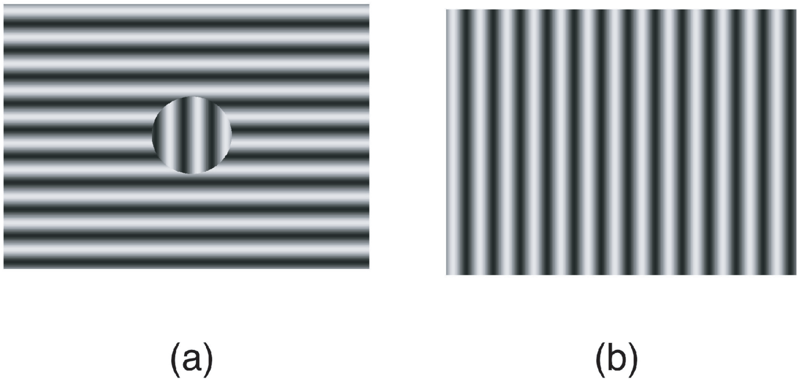

Fig. 3. Stimuli inducing differential contextual modulation in the neural activities in the primary visual cortex. (a) Vertical grating in horizontal grating background. (b) Vertical grating in vertical grating background.

exhibit contextual modulation and the idea that activities in V1 are neural correlates of sensory qualia.

As is obvious when looking at Figs. 3(a) and (b), our perception of the vertical grating in the center is remarkably stable in terms of sensory qualia (i.e. color). The major perceptual difference between Fig. 3(a) and Fig. 3(b) is to be found in the intentional qualia accompanying the subjective feeling whether the central circular region “pops out” or not.

These observations suggest the need to build a more sophisticated model of the neural correlates of conscious visual percepts, beyond that of simple one to one mapping. While intentional qualia mainly correlate with the activities of neurons in higher visual areas, secondary correlates might be found in the contextually modulated neural activities in V1. Neural correlates of sensory qualia, which definitely include activities of neurons in V1 as evidenced by blindsight data, need to be defined in terms of some invariant properties of neural activities which remain stable despite the extensive contextual modulation found in V1. The interplay between the neural correlates of sensory and intentional qualia encompassing both V1 and higher visual areas in this respect is likely to be central to the process in which the brain actively represents and constructs an interpretation of the outside world.

5. The Variant and Invariant in Information Representation

Based on the neurophyiological review above, we now attempt to consider the essential requirements for a model of neural information representation and subjectivity, centered around, but not limited to, the neural correlates of conscious perception.

In CRICK and KOCH (1995), the basic idea behind the formulation of neural correlate of conscious experience is that certain aspects of cortical neural activity co-varies with that of the phenomenal elements in conscious experience. There are some possible complications in the concept of co-variance due to nature of correspondence between physical time (in which neural activities are embedded) and the psychological time (MOGI, 1999). However, within the specious moment of ~100 ms, it is not unreasonable to assume that we can empirically establish a correspondence between neural activities and elements of conscious perception in the conventionally accepted sense of a "neural correlate".

As discussed previously, a neural correlate in the conventional sense only means that a certain neural activity is a necessary condition so that the subject experiences a certain aspect of conscious perception. In considering the sufficient condition, one of the essential factors is the neural origin of subjectivity. At the core of the subjectivity enigma, there is a general and even functionally conceptualizable question regarding information representation in a system, conscious or otherwise.

The idea of the covariance of physical activity and information contents is an implicit assumption behind any conventional model of information representation. For example, when some bits in computer are said to represent numbers, what is implied is that the system is configured in such a way that the bits change in a way consistent with the semantics of the number. Information representation in this sense is primarily concerned with what is explicitly variant in the physical system. The neural correlate idea has inherited the essential framework from this conventional assumption behind information representation. Empirical evidences based on single unit recording, fMRI, MEG etc. are all concerned with this explicit covariance.

In any system configured to represent and handle certain information, the explicitly variant parameters need to be complimented with an implicit, invariant structure that makes it possible to encode, store, and read the information in such a system. In other words, in order for certain parameters that co-vary with the information to continue to represent the same information, certain aspects of the system structure need to remain invariant.

Let us assume that a system in question is composed of N variables. Out of N, E variables would explicitly co-vary with the information represented within the system, while I variables remain stable, to make it possible that the E variables explicitly represent the relevant information, where $E + I = N$. In conventional theories of information representation, upon which the neural correlate idea is based, attention is directed only towards the explicitly variant part. It is the usually unquestioned implicit part, however, upon which the framework of information representation in general and the origin of subjectivity in the case of the conscious brain depends.

An interesting empirical question to ask is how much of a population of neurons in the brain actually sustains stable activity no matter what the brain is explicitly processing in terms of sensory, motor, emotional or other types of information. This population of stably firing neurons is conjectured to function as the neural correlates of the frame-of-reference/subjectivity structure in the context of which the explicitly varying populations of neurons are given their specific functionality and become neural correlates of conscious experience in the phenomenological context.

The conventional idea of the neural correlates of conscious experience has centered on the variant elements, effectively assuming that $I = 0$ or otherwise ignoring these elements. The invariant variables sustaining the frame-of-reference/subjectivity structure can be thought of invariant neural correlates, as opposed to the conventional variant neural correlates of conscious perception.

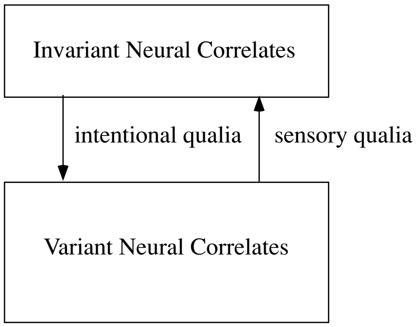

Fig. 4. The variant and invariant in the neural correlates of subjective experience. In order for the degrees of freedom that co-vary with information represented in the brain to be functional, we need a set of variables that remains stable during the processing of information. These invariant degrees of freedom are expected to form a second class of neural correlates, namely the invariant neural correlates of conscious experience, which gives rise to the subjectivity structure. The phenomenally distinct sensory and intentional qualia are likely to arise from the interface between the variant and invariant neural correlates. The known locus of the neural activities that generate sensory and intentional qualia, along with other neurophysiological evidences, suggest that the invariant neural correlates are centered in the prefrontal region, whereas the variant neural correlates are distributed over the sensory cortex.

Figure 4 shows a scheme for the interaction between the variant and invariant neural correlates. The sensory and intentional qualia are conjectured to correspond to the projection from the variant to invariant elements, and from the invariant to variant elements, respectively. Evidence which show that sensory and intentional qualia in vision correlate mainly with neural activities in V1 and higher visual areas, respectively, along with other neurophysiological evidences, suggest that the invariant neural correlates are centered around the prefrontal cortex, while the variant neural correlates are distributed over the entire sensory cortex. These interpretations are consistent with the idea that the invariant neural correlates are central to the neural mechanism of subjectivity, usually considered to be seated in the prefrontal cortex.

6. Possible Relevance of Quantum Formalism

Now we consider the broader implications of the necessity of the invariant neural correlates of conscious experience.

There is an apparent non-locality in the correspondence between neural activities in the brain and the elements of conscious perception. In visual awareness (CRICK and KOCH, 1995, 1998, 2003), the "self" is able to access and integrate the massively parallel distribution of visual sensory qualia in the visual field. Even in the absence of specific and explicit interpretation in terms of objects, the self is able to hold an awareness of the visual scene. For this, the brain must somehow conduct property binding (TREISMAN, 1996), binding features whose neural correlates are distributed over spatially distributed areas in the physical brain. Although the explicit interpretation of the visual scene by the putting together of various parts that constitute an object exhibits serial (one at a time) nature (part binding, TREISMAN, 1996), the massively parallel nature of visual awareness in terms of sensory qualia in particular indicates that the brain must somehow integrate information represented by neurons non-locally.

The apparent non-locality of the mapping between the activities in the physical brain and the elements of conscious perception has led some authors to suggest the involvement of quantum dynamics (JIBU and YASUE, 1995; BERNROIDER, 1998). The EPR type entanglement (EINSTEIN *et al.*, 1935), if it exists in the brain, could be a physical correlate of such a non-locality. Some authors have suggested that quantum processes in the microtubules could provide the basis for conscious perception (HAMEROFF, 1994; HAMEROFF and PENROSE, 1995).

Some authors have pointed out that conditions in the brain, such as a high temperature and the involvement of many degrees of freedom, make it unlikely that a quantum mechanical effect is involved in the physical correlates of consciousness (GRUSH and CHURCHLAND, 1995; TEGMARK, 2000).

The juries are still out. Although the opponents to quantum involvement in conscious processes appear to have a more solid reasoning at present, the remarkably integrated parallelism exhibited in visual awareness alone seems to justify a search for a radically new way of thinking, quantum or non-quantum, to come to the gist of the physical (neural or otherwise) correlates of conscious experience.

Here, we suggest that quantum processes might be involved in the implicit, invariant nature of information processing in the brain, supporting in some essential manner the computations conducted by the explicitly varying neural activities.

Given the reality of biological neural networks, it is reasonable to assume that the relevant degrees of freedom involved in the information processing in the brain, as reflected in our conscious experience, is that of neural firings (BARLOW, 1972). Quantum processes in the brain, if they are relevant, are unlikely to correlate in a direct and explicit manner with the change in elements of conscious perception.

However, there is a possibility that quantum mechanical processes contribute to the nature of conscious experience by providing a basis for frame-of-reference/subjectivity as the invariant neural correlates discussed above. An intriguing possibility is that quantum processes influence the subjectively unique nature of each sensory quale, so that the redness of red has this particular feeling, while the transition between a particular quale to another correlates with the neural activities in the brain, which are macroscopic phenomena well above the quantum limit.

In this respect, it is interesting to note that a solution for the still enigmatic quantum measurement problem (PENROSE, 1989) likely involves a fundamental relation between the invariant and variant in the description of a physical process, where the macroscopic functions as a invariant frame-of-reference for the microscopic quantum wave function.

7. Conclusion

In this paper, we have argued that it is important to consider the invariant as well as variant parameters in a model of the neural correlates of conscious perception in order to explore the nature of the correspondence between the physical processes in the brain and the phenomenal properties of our conscious experience. We suggest that the implicit assumption behind the conventional treatment of information focused only on explicitly varying variables must be questioned. Through a new look on the relation between the variant and invariant, we might be able to come to a deeper understanding of the mind-brain problem and the foundations of the information representation and processing at the same time.

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