Toward a neurophenomenology as an account of generative passages: A first empirical case study

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ABSTRACT: This paper analyzes an explicit instantiation of the program of “neurophenomenology” (Varela, 1996) in a neuroscientific protocol. Neurophenomenology takes seriously the importance of linking the scientific study of consciousness to the careful examination of experience with a specific first-person methodology. My first claim is that such strategy is a fruitful heuristic because it produces new data and illuminates their relation to subjective experience. My second claim is that the approach could open the door to a natural account of the structure of human experience as it is mobilized in itself in such methodology. In this view, generative passages (Varela, 1997) define the type of circulation which explicitly roots the active and disciplined insight the subject has about his/her experience in a biological emergent process.

1. Preamble

1.1 Purposes of this paper

This paper analyzes an explicit instantiation of the program of “neurophenomenology” (Varela, 1996) in a neuroscientific protocol. This recent work (Lutz et al., 2002) studies the correlation between on-going conscious states and brain coherent dynamics during a simple perceptual task and illustrates how accounts of experience by trained subjects and experimental data from these experiences can share an explicit relation of "mutual or reciprocal constraints" (Varela, 1996). The first claim is that the basic study discussed here already validates this research program because it produces new data and illuminates their relation to subjective experience. It can thus be used as a first-step, toy-model for future investigations.

The second claim is epistemological and theoretical dealing with the specific nature of this circulation. I will argue that this study is an attempt to move beyond a simple "phenomenal isomorphism" and offers a putative example of "generative passages" between the phenomenal accounts and their neurobiological counterparts (Varela, 1997). In this new theoretical approach to the study of consciousness the neurophenomenological strategy is integrated as an active and necessary component of the epistemological relation. Mutual constraints define the type of circulation which explicitly roots the active and disciplined insight the subject has about his/her experience in a biological emergent process. Such a relation was already present as an assumption in the neurophenomenology program. What is at stake is the broadening of the naturalization of experience into the realm of its direct self-manifestation and self-affection[1]. Such a self-referring relation could give immediate insight into the nature of

[1] In Husserlian terms, the issue consists in the possibility of grounding the field of pure phenomenology, as accessed by the reduction (Husserl, 1913*,* §75), in a psychological phenomenology (Husserl, 1925*)*, or even in the natural realm (Husserl, 1918-26). The idea (Husserl, 1913, §57*)* is that once the constitution of the natural object is sufficiently thematized in the phenomenal domain, it can also be viewed as part of psychological consciousness and therefore as part of an organism. This claim will be elaborated throughout this text suggesting that it does not contradict Husserl's anti-naturalist arguments. Such a position still expresses a non-reductive way to study experience. It is strongly inspired by Husserl's later work on the foundational and constitutive role of the body and the world in relation to the world of spirit. See his work on the lived-body (*Leib*) and the life-world (*Lebenswelt*) in Husserl (1966). And see Depraz (1999) for further contemporary developments of this delicate topic.

the causal emergent processes that underlie phenomenal appearance. This will be discussed in a third section in light of the operative concepts of "reciprocal causation" as recently introduced by Thompson and Varela (2001).

1.2 The neurophenomenological approach

The neurophenomenological program encourages researchers to pay attention not only to neuronal or physiological data but also to the data produced by accounts of subjective experience. It has been proposed as a methodological answer to the theoretical debate around the status of phenomenal data in nature (Roy *et al*., 1999).[2] To summarize this current debate, functionalist or connectionist cognitive science can provide theories of how the cognitive mind/brain works *in* itself, but not of how it seems to work *for* itself.[3] Indeed, cognitive events (such as perception, emotion, pain …) are associated with first-person events: things appear and are perceived or felt by a 'self', a 'subject' who can provide an account of it. But, to borrow Joseph Levine's term for it, there is still an "*explanatory gap*" between these subjective attributes[4] and their objective scientific counterparts (Levine, 1983).

One of the virtues of Varela's proposition has been to shift this discussion from a strictly abstract and theoretical framework to a *pragmatic* one that is explicitly anchored in lived experience and open to scientific inquiry. This strategy can be summarized as follows: In line with many authors (for instance: Jackendoff, 1987, Flanagan, 1992,

[2] A phenomenon, as it is used since the Presocratics, describes the fact that something appears for someone. Therefore it is something relational. It is a *being for* in contrast to a *being in itself* independent of its apprehension by another point of view. In the analytical literature this distinction has been captured by Thomas Nagel's phrase "what it is like" to experience something (1970).

[3] For a detailed review see for instance Roy et al. (1999).

Searle, 1992, Chalmers, 1996), and in contrast to the eliminativist position (Churchland, 1992), this approach acknowledges first-person experience as a field of phenomena unto itself, irreducible to any other. Thus subjective phenomena are recognized as having a character of immediate giveness that can be explored. At this point, no particular claims or presumptions need to be made about their epistemic status.

A second principle is that investigation of this field of phenomena requires a specific, rigorous *technique.* What is needed here is to overcome the 'just-take-a-look' attitude with regard to experience that is pervasive in cognitive protocols or the dominant philosophy of mind. Western and Eastern phenomenological traditions have been favored, as we will see later, as appropriate pragmatical tools[5] but other first-person approaches are being explored.[6] The phenomenological methodology relies on the cultivation of a gesture of reflexive awareness, called *phenomenological reduction (PhR)*.[7] The goal of this methodological reduction is to attain intuitions of the descriptive structural invariants of an experience.

This principle was introduced in the context of the following *working hypothesis*: "phenomenological accounts of the structure of experience and their counter parts in cognitive science relate to each others through *reciprocal constraints*" (Varela, 1996). The key point is that both forms of evidence are granted an equal importance and therefore need the same attention. It is easy to understand how scientific data might account for a mental state, but the reciprocal movement, from the experiential to the

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[4] The term "attribute" subscribes tacitly to a formal description of subjectivity as a third-person object. It is usually used as such in the analytic tradition. We prefer here the term "phenomenal account" which seems more appropriate to capture the problem of "what it is like" or "what it is to act as a subject."

[5] Varela (1996), or for a collection of papers see the contemplative and phenomenological section in Varela and Shear (1999) or Petitot et al. (1999).

[6] See the introspection section in Varela and Shear (1999)

[7] For a cross-disciplinary study of this topic see Depraz et al. (2002).

experimental, is usually dismissed. Phenomenological accounts are necessary for at least two reasons: first, they can provide direct experiential validation for a neurobiological proposal (conditional to a rigorous methodological examination); second, structural aspects of human experience itself can constrain the interpretation of empirical results. In this paper, for instance, I will discuss the constraints of phenomenal temporality on neurodynamics. Neurophenomenology thus differs from dualism in that it does not need to assume extra ontological entities to allow us to progress toward bridging the explanatory gap.[8]

1.3 The organization of this paper

Neurophenomenology is thus a pragmatic methodology for combining first- and third- person data. With the notion of mutual constraints, it proposes an approach that explicitly integrates experiential accounts provided by trained subjects with experimental accounts. In the study to be discussed, we have applied it to test a theory that naturalizes the flow and unity of time-consciousness.[9] It is crucial to realize that this theory seeks to give a *natural* account of the capacity of the subject to access his/her own experience, the same particular skill mobilized under the name of phenomenological reduction in neurophenomenology (Varela, 1997, pp. 368). The two domains of discourse (the natural and the phenomenological) are circularly intertwined. This position could be seen as contradictory for those preoccupied by *a priori* argumentation, but those who are sensitive to the pragmatic dimension of knowledge will understand that our main motivation is to gain new insights about this multi-perspectival dynamics of phenomena. In this specific realm of experience, the mutual constraint viewed as a generative passage

[8]For a more elaborate philosophical discussion see Hanna and Thompson (in press).

can be developed at three levels: the methodological (= in regard to developing a praxis), theoretical (= providing a natural account) and epistemological ones (= developing a critical perspective on the conditions and the formation of such theory).

With the experimental studies discussed here, we explore these methodological, theoretical and epistemological claims within a classical neuroscientific protocol. Again it is merely a first step. These three aspects have been conjointly evaluated in order to provide the reader with a case study of the general approach.

My argumentative strategy will be to contrast the neurophenomenological accounts of two cognitive studies involving simple visual protocols: in the first the Mooney face (Rodriguez et al., 1999) and in the second the 3D illusion (stereogram) (Lutz et al., 2002). The neurophenomenological strategy was put to work only in the second protocol. Their differences, as we will see, are not due to the stimuli, but to the role given to the subject and to the way the *joint-analysis* of first- and third-person data was performed. I will start, in the next section, by illustrating the praxis of neurophenomenology. Then, in the section that follows, I will argue that the first protocol instantiates a “phenomenal isomorphic” relation between these perceptive contents and large-scale dynamics whereas the second protocol, which takes mutual constraints into account, leads potentially to the “generative passages” that instantiate the more complex and demanding relations between them. In the last section I will analyze this theoretical interpretation of mutual constraints with illustrations from preliminary data.

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[9] See Varela (1997) for the move to a dual status of neurophenomenology as a method and an object of investigation. See Varela (1999) for the naturalization in itself of time-consciousness.

2. Reciprocal constraints as a heuristic strategy guided by a praxis

2.1 Application to the study of brain dynamics

The driving force of neurophenomenology is its *pragmatic* dimension. The goal of this section is consequently to provide the reader with an explicit case study implementing this approach. In this example we used refined first-person data to validate a scientific proposal about the functional role in cognition of large-scale integration mechanisms. I will now briefly recall the scientific assumption that is central here.

Neural assemblies: a dynamical framework to cognition

It is a well-accepted fact that in the brain any cognitive act is characterized by the simultaneous activity of distributed brain regions that are functionally specialized and constantly interacting. Any assumption about the substrate of a moment of consciousness must therefore account for the self-coordination of these different components necessary to produce a global brain activity that is transiently unified. In neuroscience the notion of *neural assemblies* (Hebb, 1949; Abeles, 1982) has been introduced to provide a conceptual framework for the integration of distributed neural activity. Neural assemblies can be defined as distributed local networks of neurons transiently linked by reciprocal dynamical connections. A useful analogy might be a Word Wide Web system such as Napster, in which geographically distant computers punctually exchange data within transient assemblies that are formed on a static network of hardwired connections (Varela et al., 2001). In the brain, the emergence of a specific neuronal assembly is thought to underlie the operation of every cognitive act. Neurons that belong to a given assembly are linked by selective interactions; they interact preferentially with a sub-ensemble of other neurons that are interconnected. These neural assemblies have a transient and dynamical existence encompassing the span of an elementary cognitive act (a fraction of a second). At the same time, however, this dynamical link has a minimum time span, long enough for this long-distance coordination to emerge. This span necessarily involves several cycles of reciprocal spike(s) exchanges with transmission delays that last tens of milliseconds. So, in both the brain and the Web analogy, the relevant parameter to describe these assemblies is not so much the individual activities of the system as the dynamical link between them.

Phase-synchrony as a large-scale integrative mechanism

For a majority of neuroscientists this dynamical link between components could be mediated by a temporal code constituting a transient functional relation between them (for recent reviews of this see Singer and Gray, 1995; Varela et al. 2001; Engel, Fries and Singer, 2001; and Engel and Singer, 2001). The transient synchrony of oscillating neuronal discharges over multiple frequency bands (4-80Hz) constitutes a plausible mechanism for this link. It has been extensively studied in the last decade and still constitutes an active field of research. Neural synchrony is a multiscale phenomenon in the brain: a local and global scale can be distinguished both at the anatomical and functional levels. Of the two, local synchrony has been the most extensively studied in electrophysiology and refers to a local dynamical link within a specific area or modality. For instance, in vision areas short-scale synchrony has been proposed to subserve the 'perceptual binding', that is the extraction of Gestalt properties of a visual stimulus.

Long-range synchrony has just started to be reported between distant regions and could mediate the global coordination of multi-modal areas during a cognitive act. Such recent data on neuronal synchrony has led several authors to suggest that synchrony could underline the sensory awareness or account for the unity of consciousness. Such propositions are in good agreement with the fundamental phenomenological fact that, in a non-pathological context, the different aspects of an experience (sound, color, movement, feeling) are not fragmented but appear as a coherent whole (see for instance the Gestalt theory, [Köhler, 1947]).

In this section I am not directly concerned with the theoretical relation of large-scale dynamics to first-person data but simply with the more efficient study of these brain integrative mechanisms by the use of first-person data. To showcase the originality of neurophenomenology I will first present a case study that uses a technique of analysis and a type of stimuli similar to our own study, but does not explicitly mobilize the neurophenomenological approach.

2.2 Case study 1 – without the use of neurophenomenology

The Mooney face protocol (Rodriguez et al., 1999)

In this protocol subjects were shown upright and upside-down Mooney figures (high contrast faces) which are easily perceived as faces when presented upright but as meaningless black-and-white forms when upside-down (see figure 1). Subjects were asked to rapidly press a button indicating whether at first glance they perceived a face or not. The electrical activity was recorded at the scalp surface (EEG).

[INSERT FIGURE 1 AND LEGEND AROUND HERE]

Estimation of the local and large-scale integration

The synchronization of neural populations can be observed in the EEG at two complementary levels: (a) either 'locally', in the signal of a single electrode or b) over a longer distance, between the signals of two electrodes.[10] These two measures provide an estimation in extracortical recordings of the short- and long- scale brain synchronies.

Results

The upright presentation of the Mooney face first evoked a brain activity phase-locked to the stimulus around 50-100ms. This activity was followed after an interval of 100-150ms by a first global pattern of long-distance synchronization involving parieto-occipital and fronto-temporal electrodes (figure 1). Such a large-scale pattern of synchrony was not detected when subjects did not perceive a face (with upside-down Mooney figures). This pattern could then be interpreted as the "shadow" of a large-scale coherent assembly subserving the Gestalt perception.

This interval of coherence was interrupted at around 500ms by a massive period of decrease of synchronization compared to a preceding baseline, followed at around 700ms

[10] a) Local synchronization (time-frequency power emission) occurs in EEG when neurons recorded by a single electrode transiently oscillate at the same frequency with a common phase: their local electric fields add up to produce a burst of oscillatory power in the signal reaching the electrode. By averaging such emissions across successive responses to repeated stimulations, we can estimate the latencies and frequencies at which bursts are likely to occur. (b) Long-distance synchrony can occur when two neural populations recorded by two distant electrodes oscillate with a precise phase-relationship that remains constant during a certain number of oscillation cycles. The emergence of such large-scale neural assemblies is believed to result from long-range interactions between neural populations and may mediate the large-scale integration between functionally distinct neural processes. This method estimates for each pair of electrodes the stability in time of their phase difference at a given frequency. This provides a measure of the raw synchrony for a given electrode pair and trial (Lachaux, 1999).

by a second period of synchronization. This second peak was correlated to the motor response in both the perception and non-perception. These data suggest that the two dynamical patterns correlate to the two acts of perception and action. These two patterns were punctuated by a pattern of *phase-scattering*, which can be interpreted as a dynamical transition from the neuronal assemblies involved in perception (associative memory, emotion, vision) to the ones involved in motor response.

Opacity of brain activity: its intrinsic variability

Like most EEG studies, the Mooney face study relies on averaging techniques – across trials and often across subjects. These techniques are very effective in finding the major components of the neural activity. Yet these techniques cannot take into account the highly variable EEG signals. For instance in this study the two patterns of synchronous oscillations were quite variable in latencies, frequencies, and spatial distribution from repetition to repetition. The source of this variability is believed to reside mainly in fluctuations of the subject's cognitive 'context' defined by his attentive state, his spontaneous thought-process, his strategy to carry out the task and so on. This illustrates a well-known fact that even during well-calibrated cognitive tasks successive brain responses to repeated, identical stimuli are highly variable. Such fluctuating brain response derives from the active interaction between this cognitive background and the stimulation that disturbs it: the neural response is shaped by the ongoing activity (Engel et al., 2001). Although it is common in cognitive sciences to control, at least indirectly, some of the factors that condition this ongoing state such as attention, vigilance, or motivation, the ongoing activity has not yet been analyzed systematically. In practice this type of qualitative first-person data has been usually omitted from brain imaging studies and the variability is defined as *noise*. The reason for this is that verbal reports can be biased or untrue making it difficult to collect data about inner experience.

This case study offers a perfect example of how the subject could become an active collaborator in brain analysis and why first-person methodologies are crucially needed to rigorously collect these data. The neurophenomenological program specifically addresses these two issues. We implement its methodology in the recent study described next, which takes into account first-person data about the cognitive context in order to make understandable a variability in the brain neural responses usually defined as noise.

2.3 Case study 2 – employing neurophenomenology

The protocol (Lutz et al., 2002)

This protocol was based on a well-known illusory depth perception task (Figure 2). We chose this paradigm because the perception of a 3-D object arising from an autostereogram (Julesz, 1971) triggers a vivid phenomenal experience with identified neurobiological mechanisms. It is formally very similar to the Mooney protocol: it also uses a visual stimulus and performs the same synchrony analysis techniques.

[INSERT FIGURE 2 AND LEGEND AROUND HERE]

The task began when the subjects fixed a dot-pattern containing no depth information. After an auditory signal, the subjects were asked to fuse two little squares at the bottom of the screen and to remain in this eye position for seven seconds. At the end of this preparation period, the random-dot pattern was changed to a slightly different random-dot pattern with binocular disparities (autostereogram). Subjects were readily able to see a 3-D illusory geometric shape (depth illusion). They were instructed to press a button with their right hand as soon as the shape had completely emerged. This ended the trial, after which the subjects gave a brief verbal report of their experience. In their reports the subjects used phenomenal invariants (or categories) found and stabilized during the training session.

Training session: a broad use of phenomenological reduction

The purpose of this pre-recording session was to invite the subject to carefully explore the variations in his/her cognitive context during repetitive exposure to the task. Subjects were therefore intensively trained to perform the task during this preliminary session. The precise gesture of phenomenological *reduction* was broadly adapted for this study in order to open up the field of investigation. The main concern was to "come back to things themselves" as Husserl frequently urged. Thus the subjects were asked to ascertain their own phenomenal categories. This strategy can be seen as an extension of the traditional procedure in cognitive sciences that is based on the use of verbal reports and questionnaires (Ericsson and Simon, 1984). To gain new descriptive insights, phenomenologists cultivated a specific method based on the gesture of *reduction*. In a nutshell, reduction begins by the bracketing of habitual attitudes in order to shift the attention from what habitually appears in the world, say the 3D percept, toward the immediate arising of the appearance itself, say the process of emergence of the percept. Reduction can be described as a particular reflexive act designed for considering experience differently (Depraz et al., 2002). Varela, in his program, underlined four principal phases in this method: 1) inducing a suspension of beliefs, 2) gaining intimacy, or intuitive evidence with the domain of investigation, 3) extracting descriptive invariants and using intersubjective validations; 4) long-term training to acquire know-how in 1-3 (for details see Varela, 1996).

In this study the gesture of reduction was either self-induced by subjects familiar with it, or induced by the experimentalist through open questions (see Vermersch, 1994 and Petitmengin, 1999). Open questions posed immediately after the task can help the subject to redirect his/her attention towards the implicit know-how he/she implemented to carry it out or towards the texture of his/her experience during the task.[11] Subjects were re-exposed to the stimuli until they found their own stable experiental invariants to describe the main elements of the cognitive context in which they perceived the 3-D shapes.

This training session addresses the need to go beyond the "just-take a look" attitude in order to bring to the fore relevant first-person data. In the next step we tried to collect these first-person data directly during the EEG recording in order to maintain the link between the immediate experience and the scientific measurements.

[11] The experimentalist plays here the role of a mediator who incites the subject to describe his (even pre-reflexive) experience. The formulation of questions is crucial to invite the subject to come back to his/her direct experience. Open questions are used to prevent him/her from theorizing the experience. For example: Experimenter: “What did you feel before and after the image appeared? Subject S1: “I had a growing sense of expectation, but not for a specific object; however when the figure appeared, I had a feeling of confirmation, no surprise at all”; or subject S4: “it was as if the image appeared in the periphery of my attention, but then my attention was suddenly swallowed up by the shape.”

Recording session: joint-collection of first- and third-person data

In a second part, we recorded both subjects' electrical brain activity (EEG) and, *after each trial*, their own verbal report about their cognitive context. Subjects briefly and precisely labeled their experiences based on the invariants found in the training session. These categories were used to divide the individual trials into several *phenomenological clusters (PhC).* We recorded two to three sessions to gather at least 40 trials per PhC.[12] The degree of preparation felt by the subject and the quality of his perception appear as a common factor through the subjects; we used it to cluster the trials into three categories : Steady readiness (SR),[13] Fragmented readiness (FR),[14] and Unreadiness (SU, SIU).[15] Sub-categories, describing the unfolding of the perception for instance, were found in individuals.

Further refinement is needed to capture the potential richness of even this simple perceptual experience. These clusters are clearly just a first step. Yet they already

[12] It is a sufficient number of trials to test the hypothesis that the studied variable is not random.

[13] In most trials, subjects reported that they were 'ready', 'present', 'here', 'well-prepared' when the image appeared on the screen and that they responded 'immediately' and 'decidedly'. Perception was usually experienced with a feeling of 'continuity', 'confirmation' or 'satisfaction'. These trials were grouped into a cluster (SR), characterized by the subjects being in a state of 'steady readiness'.

[14] In other trials, subjects reported that they had made a voluntary effort to be ready, but were prepared either less 'sharply' (due to a momentary 'tiredness') or less 'focally' (due to small 'distractions', 'inner speech' or 'discursive thoughts'). The emergence of the 3D image was experienced with a small feeling of surprise or 'discontinuity'. These trials formed a second cluster (FR) corresponding to a state of 'fragmented readiness'.

[15] In the remaining trials, subjects reported that they were unprepared and that they only saw the 3D image because their eyes were correctly positioned. They were surprised by it and reported that they were 'interrupted' by the image in the middle of a thought (memories, projects, fantasies etc.). This state of distraction occurred spontaneously for S1 and S4, whereas S2 and S3 triggered it either by fantasizing or by thinking about plans (subject 3) or by visualizing a mental image (subject 2). To separate passive and active distraction, these trials were divided in two different clusters, Spontaneous Unreadiness (SU) for S1 and S4 and Self-Induced Unreadiness (SIU) for S2 and S3.

illustrate the pragmatic dimension of the neurophenomenological approach, namely the need for collecting first-person data from trained subjects in a disciplined way.

2.4 Testing the working assumption: Joint-analysis of first- and third- person data

This pragmatic stage allowed us to rigorously collect both relevant phenomenal data and concomitant scientific data (EEG signal). It is thus possible to see if a particular PhC concerning preparation is characterized by a specific brain responses stable through trials. This *joint-analysis* of first and third person material provides an *instantiation* of the mutual constraints. The subject can now play an active role, not necessarily in the sense of being more voluntary during the task (the subject is actually spontaneously distracted in some trials), but because his experience is integrated in the analysis via the phenomenal clustering of trials.

Results

In this section I will analyze only the responses to stimulation. This constitutes half of the data reported in this study. We found that the preparatory state, as reported by the subjects, modulates both the behavioral performance and the brain responses that follow. The reaction times were dependent on the degree of preparation reported by the subjects: they were longer when the subjects were less prepared. The induced response (the oscillatory activity arriving around 250ms in the Mooney face study) was modulated in amplitude in posterior electrodes (visual areas) in function of the degree of preparation. A separate study of each subject and each cluster reveals different dynamical trajectories that are stable- specific to each cluster during the brain responses (for instance see figure 2). In this particular example of clusters we can see a similar topographical pattern of large-scale synchrony during the motor response in the prepared versus unprepared pattern, but occurring respectively at 300ms (on average over 100 trials) and 600ms (on average over 38 trials). This later pattern of synchrony correlates in the unreadiness cluster of trials with longer reaction times. Such highly contextual patterns of synchrony would have been canceled out by a global averaging like the one in the Mooney study. By combining this new type of knowledge, variability in the behavioral and brain responses has became more intelligible compared to the Mooney study and it has generated new data.

A first evaluation:

This simple case study is just a first-step but already illustrates how fertile this approach could be to identify biophysical properties and to understand their relation to experience. In our case this strategy was very useful to take into account fluctuation of the subject's emotional state, attention, or mental strategy which occur and cannot be fully controlled in a protocol. The objective is to pay more meticulous attention to the intimate and direct knowledge that a subject has about his/her experience and to access this knowledge in a sufficiently controlled manner so that it is compatible with the more traditional methods for the collection of neural data. We have taken two steps in that direction, by (a) keeping a trial-by-trial account of the subject's report, and (b) using the subject's own categories to organize the trials into clusters with similar experiential features. Further refinement is needed to capture the potential richness of even this simple perceptual experience. This depends primarily on the possibility of working with subjects trained to discriminate and stabilize their experience.

To summarize, the notion of “mutual constraints” was defined in this first methodological section as a *heuristic* strategy to provide mutual insights between the first-person and scientific accounts. This heuristic method depends on a *pragmatics* for the cultivation of our capacity for attentive bracketing and intuition (reduction). In effect, it is this pragmatic and disciplined dimension of the method which could make it, at the epistemological level, more than a simple heuristic. In this more demanding view the disciplined first-person account would be an integral element for the validation of neurobiological proposals.

This point has been similarly made by Michel Bitbol in this issue of PCS. Yet although I am in complete sympathy with his analysis about the radical procedural dimension of neurophenomenology, I do not subscribe to his view that it is in itself ‘sufficient to dissolve the “hard problem”'.[16] In the science of consciousness, human phenomenality is an empirical question as much as it is a methodological one. Thus bridging the explanatory gap not only means to find a relevant methodology and epistemology but also, in a complementary way, to find an explicit natural theory giving sense to these choices. The fact that Varela introduces neurophenomenology as a “working assumption” and not simply as a methodological principle attests that pragmatic tools, like phenomenological reduction, possess both an instrumental and a theoretical side (Varela, 1997; 1999; Thompson and Varela, 2001). Such a more encompassing view presented in the rest of the paper describes the neurophenomenology project as a triptych with pragmatic, epistemological and theoretical dimensions.

[16] The notion of “hard problem” is used here simply as a label. A recent questioning of such philosophical distinctions can be found in Hanna and Thompson (in press).

3. A typology of reciprocal constraints as a naturalizing account of experience

This section is more epistemological and attempts to analyze, in the light of these two case studies, the nature of the relation established between first-person and third-person data. This topic addresses the possibility of giving a naturalized account of phenomenology. It is well known that this project had been rejected from the start by Husserl who had always argued that something in experience escaped the jurisdiction of the natural sciences. In his view it was the consequence of a fundamental opposition between the exact essences and the ideal concepts of mathematics and the inexact and the morphological essences involved in what we experience immediately (Roy et al., 1999, pp. 42). Yet, as claimed by the editors of *Naturalizing Phenomenology* (Petitot et al., 1999), such a position could be challenged. Indeed the contemporary computational theory and the theory of complexity make it possible to collapse the classical opposition between the body and the mind.[17] On this view, Husserl's anti-naturalism was more a criticism against the sciences of his time than against the naturalization project *per se*.

Among the various ways of naturalization overviewed in this book, I am following a typology of mutual constraints that distinguishes between three types of circulation: (1) bridge locus as analytic isomorphism; (2) phenomenal isomorphism; and (3) generative passages (Varela, 1997). I will first analyze the two former relations and their limits before moving to a close examination of the latter.

3.1 Bridge locus as analytical isomorphism

The first relation, very popular among neuroscientists, consists of interpreting specific neurons or structures like the bridge locus between a phenomenal feature and the neuronal substrate (for a complete discussion see Pessoa et al., 1998). Even if specialized and localized structures can provide the necessary condition for a cognitive act they are not sufficient to account for the whole experience. Indeed as mentioned above cognitive acts involve the distributed and concurrent activity of a mosaic of brain areas. The limitation of this eliminativist attitude is that it does not fully account for the phenomenality of perception.

3.2 Phenomenal isomorphism

In contrast to "analytical isomorphism," which focuses on specific structures, "phenomenal isomorphism" tries to broaden the scope of explanation to the *global* neural operations involved during a cognitive moment. The Mooney face study offers a typical example. It investigates a global process, namely large-scale integrative mechanisms, which is proposed to underline the phenomenal unity of the perceptual and motor experience (the shape, emotion, posture, movement appear for the subject as a coherent whole). This original work demonstrated for the first time a logical isomorphism between the first-person descriptions (perception versus non-perception of the Mooney face) and the third-person descriptions involving a large-scale integrative mechanism (increase versus non-increase of the level of coherence in the gamma frequency band). In this study the phenomenal accounts were used to identify the correct explanatory mechanisms subserving it at the neural level.[18] More generally in this type of relation first-person data

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[17] For an example of a mathematization of perceptual eidetics see Petitot 1999, pp. 330-371.
[18] This study however simply showed a correlative link.

can either validate a link to third-person data or provide constraints invalidating first-person models.

Although it is a fruitful strategy, this interpretation nonetheless has as an implicit premise the separation of phenomenal description and scientific explanation. For instance, in the Mooney face study, the subject only has to activate a button when the Gestalt of the face *passively* emerges to his/her perception. The observer's only role is to assert the concomitance or the *parallelism* between the phenomenal and empirical series. Therefore he/she cannot provide any direct insight into the nature of the causal process which underlies his/her experience. Consequently only the third-person data are relevant in the account.

Such an epistemological choice could be understood as ruled by a principle of prudence: phenomenal consciousness is recognized as a scientific question, but must be reduced to the third-person realm in the final account. This could explain why visual illusions (gestalt or depth illusion, multistable or ambiguous figures) are so frequently used. These stimuli have a direct and contrasted manifestation in the experiential-mental sphere and are still well controlled by the experimentalist. They make possible the discovery of relevant relations between experiential and scientific levels without changing our usual scientific style. But to what degree can this strategy be productive? I will now successively address this question at the experiential, natural, and formal levels.

Limitations from the experiental realm

Indeed, this approach still does not explicitly account for the fact that experience can be *manifested* to itself or *affected* by itself. 'What it is to be a subject doing a visual protocol' changes from trial to trial while something in the phenomenal content of the perception remains the same.[19] Seeing a visual illusion affects my experience, and the texture of this experience is also affected by my ongoing phenomenal state during the stimulation. Husserl remarkably summarized this point:

> Every experience is 'consciousness' (*Bewusstsein*) and consciousness is always consciousness-of … Every experience is itself experienced (*selbst erlebt*) and to that extent also intended (*bewusst*).[20]

This self-affection and self-manifestation of experience attests to a particular mode of access to our own mental life. It has to do with reflection but should not be merely identified with it. It is important here to diffuse a potential misunderstanding. As it has been noted, for instance by Merleau-Ponty (1945/1962), a strict reflexive paradigm, like the early Husserl's, risks overestimating the constitutive role of the "observer" by assuming his/her constant precedence over the appearing object. Among others limitations it can dangerously separate the subject, almost in a dualistic way, from being situated in the world and in relation to his/her body. The notion of being situated is expressed in an auto-affection paradigm (Depraz, 1998) which emphasizes in a complementary way the passive dimension of consciousness. Such a position can thus preserve the unity of experience while still being engaged into a differentiating attitude.

The class of phenomenological invariants, I have just sketched, is unfortunately dismissed *a priori* by the phenomenal isomorphism because the subject's only role is to describe *what* appears to him/her and not *how* his/her own experience appears to him/her as well. The 'experience about an experience' could still be present *structurally* in the neurobiological account, for instance as a particular class of dynamics, if the role of the

[19] Hanna et al. (forthcoming) developed more technically a similar argument;

trained subject in the account was extended past simply maintaining the link between the first-person and third person phenomena. This type of assumption is rejected *a priori* in the phenomenal isomorphism and, therefore, constitutes a damageable limitation to this type of relation.

Limitations from the biophysical account

This issue has already been introduced in the discussion of the problem of variability in the brain responses. The high variability of the synchrony pattern in its latency, topography, or frequency suggests that phenomenal isomorphism can only account for relations between the appearance of an “external” object for the subject and an average pattern of large-scale synchrony. Yet such a relation cannot fully account for the *emergence* of a peculiar configuration of the dynamic during a particular trial. The limitation here is that such emergence has not been related yet to the *genesis* of a particular moment of consciousness as it is experienced.

Limitations from the dynamical framework

This issue is more clear when it is formulated within the dynamical framework of neural assemblies. A stimulation like the Mooney face can be interpreted as an external perturbation of the ongoing state of the system and the induced patterns of synchrony can be interpreted as the average dynamical links common to all the neural assemblies participating in the perception and motor response. The limitation of the phenomenal isomorphism can thus be stated as follows: since ‘what it is like to be a subject doing the task’ is not taken into account, the ongoing neural assembly which is perturbed by the stimulation is not involved in the account but is defined as *neutral*. In practice this is implicitly assumed by defining as a neutral baseline the pre-stimulus dynamical state. The putative role of the current ongoing neural assembly as a *selective* constraint is again implicitly rejected.

To summarize, the phenomenal isomorphism is not satisfying because it is insufficient to account for the emergence of particular phenomenal state and its neurobiological signature in response to a specific external perturbation. At the first-person level the limitation comes from the implicit view of the subject as a passive and disembodied spectator. At the neurobiological level the limitation comes from the simplification of the cognitive system to a context-free input-output device or, at least to a chain of exogenously constrained cognitive processes. At the formal level, modeled as a dynamical system, the limitation comes from the implicit assumption that the system state before stimulation can either be defined as neutral or sufficiently controlled by external forces (for instance distractors, priming).

3.3 Generative passages

The relation of generative passages can first be defined negatively as an attempt to overcome the limits of the phenomenal isomorphism. A positive definition requires a further step, that of extending the mutual circulation between phenomenal account and natural science to the entire phenomenal realm. Therefore, further distinctions are first required to give sense to the substrates of this epistemological relation. This will be done in the next section. So far one can say that such a circulation could become “operationally generative” (Varela, 1997) because reciprocal insights could be grounding explicitly in biological emergence the disciplined experience one can have about one own’s experience (this refers in phenomenology to eidetic descriptions under reduction analysis). Therefore, in this specific realm of experience, the mutual constraint as generative passage can be defined both at the methodological and theoretical levels. Theoretically, mutual constraints have been defined in a neurophenomenological account with three threads (Varela, 1997):

1) phenomenological data and invariant structural features of experience (thread #1)
2) neural and somatic substrates (thread #2)
3) formal dynamical models (thread #3)

In the last section, I will attempt to refine the distinctions within each of these three levels in order to show, then, how they can be fruitfully articulated into an original relation of mutual constraints. To illustrate this theoretical approach I will use data from the protocol on 3D illusion.

4. Reciprocal constraints as reciprocal causation?

4.1 *The dynamical expression of generative passages*

The "enactive" approach

This last expression of reciprocal constraints is more theoretical and participates in the cognitive paradigm of enaction (Varela et al., 1991). In this approach cognition is not understood as abstract, computational processes but as based on situated and embodied agents (see for examples Clark, 1997; Thompson and Varela, 2001). The focus is on (1) the ongoing coupling of the cognitive agents with an environment during sensori-motor activities and (2) how this coupling modulates the ongoing endogenous activity participating in the organismic regulation of the agent's life. This style of explanation of cognition naturally joins the (more general) dynamical approach (for inspiring examples see Haken et al. 1996, Kelso, 1995; Freeman, 1999) and differs markedly from the computationalist (Fodor, 1984; Pylyshyn, 1984) or connectionnist paradigms (McClelland, 1986).[21] Indeed, what is at stake is an understanding of how the system's state changes over time through external perturbations without specifying a pre-given and unique relation between an input and an internal state. Thus for the dynamical approach formal concepts and tools inspired by non-linear dynamical system theory are more adequate than symbolic and information processing models. This is why dynamical concepts have been extensively favored as the formal model (thread #3) in the neurophenomenal account. This theoretical question is still actively debated between partisans of these three paradigms because it directly constrains any account of consciousness.

"Reciprocal" causations

The dynamical expression of mutual constraints (thread #3) has been proposed (Varela 1997, 1999; Thompson and Varela, 2001) from the dynamical analysis of neural assemblies within the theory of non-linear self-organization (for example: Arbib, 1995). Indeed self-organized properties can be modeled with non-linear oscillator networks (for examples: Kopell, 2000; Acebron, 2001) expressing elegantly similar behaviors as the one found in synchronized group of neurons. It is fruitful thus to formalize the collective behavior of a neuronal population as an emergent process. Emergence can be crucially described as a two-directional process. First, there is a local-to-global determination or

[21] For a critical evaluation of these approaches see for instance: Van Gelder, 1998 or Beer, 2000.

'upward causation' by which global processes emerge from the collective interaction of neurons. These global processes are endowed with intrinsic behaviors and specific dynamical properties (for instance their life span). Second, there is global-to-local determination ('downward causation'), whereby the global features (or order parameter[22]) constrain the local activity. The idea is that this collective behavior confines or 'enslaves' (Haken, 1996) the individual components to have specific dynamical interactions with others individuals. In 'Radical Embodiment', Thompson and Varela suggested calling this reciprocal (but not symmetrical[23]) relationship a "reciprocal causality."

Theoretical evaluation

The introduction of reciprocal causation might be perceived as a subtle expression of dualism. It may be useful to highlight that it corresponds to operational distinctions introduced to study the relation between conscious activity and the self-organization of the organism. Self-organization is involved at various scales in the organism (Thompson and Varela, 2001). The relevant level of description favored here is to define local/global at the spatio-temporal scale of short-scale/long-scale synchrony processes[24] (section 2.1). In the particular case of our protocol, the relation between local-to-global and global-to-local processes convey useful distinctions to investigate the mutual constraints between

[22] An order parameter is a collective variable which describes adequately the behavior of a population of variables with a much smaller degree of freedom than the one of the whole population if every variable was independent. It is a central concept in the field of synergetics (Haken, 1996).

[23] Local-to-global process manifests through the dynamical interacting variables, whereas the effect of global-to-local manifests through modifications in boundary conditions and control parameters. For an example see Kelso (1995 p. 6).

[24] Local/global scales of analysis are similar to the mesoscopic/macroscopic scales of recording used by several authors such as Edelman (1987) or Freeman (1999). Microscopic scale refers to the analysis of single-neuron activity. Mesoscopic scale refers to the recording of coordinate behavior of local neuron groups as measured by local field potential. Macroscopic scale refers to extracortical recordings.

the *genesis* of a moment of consciousness belonging to a *flow* of others moments and the formation, maintenance and change of coherent patterns in the brain. The notions of downward/upward causations are potentially fruitful because they express directly a transient *directionality* in the neurodynamical emergence making it possible to root explicitly in such a dynamical principle the intentionality of conscious moments. This formalism is also interesting because it accounts for the intrinsic tendencies of the system to maintain a coordination between neural groups or to spontaneously bifurcate.

Role of the formal level in the relation of generative passages

How could this formal dimension (thread #3) be related to the two others in the neurophenomenological account? Briefly, this component constitutes an intermediate and *neutral* level in which both the experiential and biophysical levels can be expressed.[25] First person data (thread #1) can fully constitute dynamical descriptions (thread #3) as soon as they are *structurally* precise enough (see next section). In that sense they are needed not only to maintain a direct link to the experiential realm but also to explicitly constrain the neurobiological level. Similarly dynamical descriptions can be directly grounded in the biophysical data (thread #2) and illuminate their analysis. Such a formal level is thus essential to mediate a *continuous* passage from experience to natural processes or, to say this differently, to allow mental and natural properties to coexist without contradictions.

At the end of the previous section, generative passages were presented as an epistemological relation attempting to ground explicitly in biological emergence the disciplined experience one can have of one own experience. At the theoretical level, the section justified the need for systemic and dynamical descriptions of the organism. Following several authors the paradigm of self-organizational emergence was favored. Emergence was described as the way a global dynamical behavior results from the interaction of local processes. At the epistemological level, this section justified the need for a formal description as an intermediate level between first- and third-person data. The dynamical distinctions presented here can potentially refine the notion of mutual constraints as soon as a similar granularity is obtained at both the phenomenal and neurobiological levels. The pragmatic requisite of neurophenomenology appears again at this stage, but in a more demanding way.

4.2 The phenomenal region of generative passages

For didactic reasons, the formal level has been analyzed first. Yet, to be rigorous, this phenomenal section should have been presented first, because experiential distinctions precede their theoretical formulations. This section will start thus from the limits, in the experiential realms, found in the phenomenal isomorphism relation. It will attempt to extent the field of first-person data to distinctions insufficiently considered in this previous relation. Several of these distinctions will clearly constitute open questions for further researches. Yet explicit phenomenal features will be presented as counterparts to the previous dynamical distinctions.

The immanent/transcendent distinctions:

The specificity of generative passages is to extend the first-person investigation to the domain of phenomenological reduction (Husserl, 1913). This question has already been addressed (section 3.2) by contrasting "what" appears to the subject to "how" it

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[25] For a discussion of this point see for instance Varela (1997, p.375).

appears to him/her. More technically, this domain is grounded in the distinctions in experience between *transcendent* and *immanent* mode of appearance. (Husserl, 1913). I perceive an object as transcendent when it appears to me as "real," existing in itself, 'there' in space and time. This refers to our daily perception. On the other hand I can suspend my beliefs about what is being examined to turn my attention to the way this event manifests itself to me as a *direct* and *immediate* phenomenon. This notion of immanent describes the intimate mode of access by which conscious activity can perceive itself as being spontaneously changing or being affected. This transient relation to our own experience unfolds a new horizon of meanings which can initiate an attention shift to a new intentional moment. In that sense immanence describes rather the self-motion of consciousness whereas transcendence describes the appearance of something in consciousness (Varela, 1999, p. 295). These two modes are intrinsically linked. This immanent access to experience is a central aspect of the neurophenomenological method. It corresponds to the notion of intuition or intimacy to experience (Varela 1996, p. 345).

The immanent/transcendent domain is crucial because it is where the relations between the mind, the body and the world fully articulate themselves[26]. An exemplary way to investigate such relations is to study their temporal structure and their embodied dynamics. Indeed, objects perceived in the world (transcendent mode) exist in consciousness as temporal object-events. Similarly, I can directly experience the flow of

[26] This region is referred to in the phenomenological tradition as the *lived body* (*Leib*) (Husserl, 1912-28) which is this 'here', this encompassing point of view from where everything which appears takes place in a 'there'. What appears as transcendent can either be objects in the world or my own body viewed as a physical entity (*Körper*). But if natural events, upon which science is based, always occur within the purview of the preexistent lived body (*Leib*), this former is ultimately grounded in the *Körper*, that is my body understood as biological processes. This fundamental duality of appearance is at the heart of the theoretical issue of reciprocal constraints.

temporality (immanent mode), as nicely remarked by Merleau-Ponty: "it is not I who take the initiative of temporality (…) time is fusing through me, whatever I do."[27]

Temporality is furthermore a paradigmatic example at the biophysical level because the brain and the body are intrinsically dynamical processes, as described in the previous section 4.1. Therefore, time-consciousness constitutes a fundamental case study (Varela, 1999).

A complete description of time-consciousness under reduction is clearly beyond the scope of this paper. My purpose here is simply (a) to offer examples of a phenomenal counterpart to the notion of local/global; (b) to suggest that the description of the immanent constitution of temporality is the complementary source of knowledge which is sought for the theorization of generative passages.

Static analysis of time-consciousness

The notion of 'now' is usually employed to describe the temporal side of experience; Husserl preferred to use the term '*living present'* in order to evoke the embodiment of temporality (Husserl, 1928). The 'now' is not like a point in physics but has a complex texture and a flexible span. In a first approximation, the living- present possesses a *center* and a *periphery* analogous to the visual field. The center is what appears in the immediacy of 'now', say the sensory impression of a musical note, whereas the periphery is what appears in the present but as just-past, for example the holding, or *retention* ,of the direct presence of the sound. In brief, sensing a tone appears as a present phenomena, whereas the just-past, even if it is intentionally present, appears

[27] "Ce n'est pas moi qui prends l'initiative de la temporalité, (...) le temps fuse à travers moi, quoi que je fasse" (Merleau-Ponty, 1958, p.489).

as having already slipped in the immediate past. It is the aboutness of my listening which constitutes the just-past act as a *horizon* of the ‘now’ moment. Similarly the living-present is open to the next moment. While I am listening to a song for instance, I am already anticipating the next tone of the melody in the immediate future. This act of anticipation is named *protention* and introduces a level of intentional direction in temporal consciousness.

This center/periphery structure presents thus a distinction between a short elementary event (scale 1/10), for example, the immediate impression (in the “pure present”), from a longer one (scale 1), say the span or the horizon of the living present. Varela’s original intuition (1999, p. 273) is to suggest that these two scales are grounded on different temporal scales according to local and global integrative processes (see section 2.1). A large-scale process requires an incompressive temporal framework to synchronize and coordinate distributed brain areas. Such a span, required to dynamically glue distributed local processes into a larger assembly (scale 1), would account for the ‘depth’ of a moment of ‘now’, that is, the living present.

In our protocol for instance an elementary event corresponds to the impression of the 3D stimulus. The event is rooted in local processes corresponding to the activity of the brain evoked by the stimulation in the early 100ms. Our empirical work is thus an attempt to study how this local perturbation will interfere with the ongoing large-scale dynamics. The way in which this elementary event is lived within the current now-moment can be directly related to the emergence of a particular large-scale pattern of synchrony. This is the core idea of generative passages.

Genetic analysis of time-consciousness:

This notoriously more difficult level of analysis is dedicated to the description of the flow of consciousness, namely, the "primal source-point that from which springs the 'now'" (Husserl, 1966, §36). This immanent constitution of events indicates the passive dimension of consciousness. As Husserl remarked

> the entire life of spirit is traversed by the 'blind' efficacity [*Wirksamkeit*] of associations, of impulses [*Trieben*], of affects [*Gefühlen*] as excitation [*Reizen*] and as the determining sources of impulses, of tendencies emerging [*auftauchenden*] from obscurity etc. which determine the further course of consciousness in accordance with 'blind' rules. (Husserl, 1952, cited in Depraz, 1999, p. 478).

The role of emotion and affect is fundamental to the *self-movement* of the flow. As Merleau-Ponty pithily summarizes it: "time is affection of oneself by oneself [*temps est affection de soi par soi*] (1945/1962, p. 131). The constitutive role played by affect in the dynamics of consciousness is remarked on by Depraz: "Affect is there before being there for me in full consciousness: I am affected before knowing that I am affected" (1994). Emotions are thus constitutive of the next moment because they can interrupt the current 'now' moment, shift attention to another content and lead the subject to become aware of a change in his/her own experience. As suggested by this short description a profound link exists between the arising of affect and the triggering of reflective awareness (for a further development see Depraz, 1994; 1998). Because reflective awareness is an essential aspect of the phenomenological reduction, the extension of mutual constraints to these types of data could provide a way to naturalize the reductive gesture itself.

In our protocol we began gathering such genetic distinctions: for instance, when subjects were unprepared, they frequently reported being 'interrupted' and surprised by the image while in the middle of a thought (memory, fantasy...). This aspect of the experience is genetic because it describes how the spontaneous appearance of the 3D percept affects the ongoing thought processes. This shift of intentional content was usually accompanied by a feeling of surprise. These classes of first-person data could be essential for understanding the flow of the dynamic, that is the bifurcation from one cognitive moment to another.

To further examine the role of affection in the constitution of time, one can describe it in relation to the context provided by the former moment. The disposition to action, for instance, plays a key role (Varela, 1999). This refers to the subject's ongoing active involvement in the world. In our protocol for instance the subject became accustomed to doing the task. The state of readiness then becomes an explicit disposition to quickly press the button. This means the pre-stimulation moment is an active expectation of the next moment, that is the stimulation. Consequently, in clusters of trials with stable readiness, subjects report a feeling of 'continuity' with the pre-stimulation moment and sometime a feeling of 'self-satisfaction'. This suggests that because the stimulation was in accordance with the expectation there was no real emotional shift before the motor response (after it, on the contrary, the feeling of satisfaction could induce a change). On the other hand when the subject was not prepared (distraction, tiredness, etc.), the stimulation triggered a breakdown within the ongoing "now". This is accompanied by a feeling of 'surprise' and discontinuity with the former moment as reported by some subjects.[28] There was thus a close relationship between the disposition to action and the tonality of the next moment, in the subject's experience.

[28]A panoply of emotions can occur: disappointment, anxiety or amusement depending on the degree of commitment to do the task.

As I tried to sketch briefly here, genetic analysis of temporality is about the description of the *self-movement* of consciousness. Emotion, affect, disposition to action and reflexive awareness are typical distinctions within this domain which contains both a spontaneous (passive) and a voluntary side. Their self-referenced features invite us to move beyond the phenomenal isomorphism and its view of the subject as a passive spectator of his/her cognition. They describe an *asymmetrical* relation within the phenomenal sphere between what is experienced as immanent and the experiencing pole. Such asymmetry could be structurally related to the asymmetrical relationship between local and global processes. In order to reveal such an endogenous relation the collection of these data requires the implication of the subjects as active and disciplined collaborators describing precisely the "what it is like to be a subject doing the task."

Dynamical Expression (thread #3) of first-person structural invariants (thread#1)

The "translation" of these first-person data into structural dynamical invariants (thread #3) is more technical because it borrows concepts from the theory of non-linear dynamical system (for details see Varela, 1999). The central idea is that the dynamical trajectories of global moments are shaping the "dynamical landscape" of the system into a specific geometry (named phase space).[29] The emergence of the new global state will depend therefore on these specific dynamical constraints (active side of genetic experience) but also of other boundary conditions such as the ongoing arising of perturbations (either exogenous ones like the contextual setting of the task – i.e., a new stimuli—or endogenous ones – i.e., a spontaneous thought or a somatic event = passive side of genetic data). It is this instantaneous *intertwining* of the ongoing perturbations within the transient geometry of the phase space that accounts for the emergence of a particular large-scale synchrony. The perturbation of the system will attract or draw the ongoing dynamic away from a trajectory or an attractor within this phase space. Kelso and co-workers express a similar view when they propose that the brain is operating in a "metastable" dynamical regime distinguished by a balance between integrating and segregating influences (for this model and experimental data see Bressler et al., 2001). This self-movement of the dynamic system (attraction, bifurcation, repulsion) and the description of the self-movement of consciousness can thus mutually provide one another with insights. As an illustrative example the disposition to action (protention), as described during preparation, can be seen as a self-induced shaping of the phase space in order to create dynamical conditions to coordinate quickly to motor response to the stimulus. The emotional affect during surprise could be seen as a reshaping of this space during the solicitation of the stimulus. In that case the bifurcation of the dynamic and its reorganization to perform the motor response would require a longer relaxation time. This is in strong accordance with the trajectory of the dynamical patterns and the longer reaction time that I would like to describe now.

4.3. *The neurobiological dimension of generative passages*

Finally, the notions of local and global can also have a neurobiological expression (thread #2) based on anatomical and functional distinctions (see section 2.1). We therefore chose, in our study, to detect from EEG signals the local and long-distance synchrony occurring before and after the task between oscillating neural populations (studied from 6 to 60Hz). We call this the *dynamical neural signature (DNS).* The

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[29] This trajectory can be modeled as an order parameter. See Varela (1999), or Freeman (1999);

heuristic strategy of mutual constraints led us to study for each subject the DNS of each phenomenological cluster (PhC) of trials. The idea was to seek a common dynamical trajectory stable through trials presenting the same preparatory context (Lutz et al., 2002). To instantiate further the hypothesis of mutual constraints as generative passages one needs first to find a proper dynamical expression to these spatio-temporal patterns. This part is done now at a speculative level.

Propositions for dynamical expressions (thread #3) of DNSs (thread #2)

I would like to use two of these DNSs as a starting point for a theoretical interpretation of the concepts of reciprocal causations. This descriptive analysis can provide useful intuitions to guide further quantification of these dynamical signatures.

In the first PhC (figure 2, steady readiness cluster) the subject reported that he was prepared and that he immediately saw the illusion. On the DNS a frontal pattern of synchrony gradually emerged in the gamma band several seconds before the stimulus. This contextual activity was still present during perception and motor response and was mixed with fronto-occipital long-distance synchrony induced by the stimulus. In contrast in the other DNS (figure 2 cluster of unreadiness), when the subject was unprepared and surprised by the arrival of the stimulus, there was no stable pattern in the gamma band (around 40Hz) before the stimulation and transitory neural patterns emerged after stimulation, in discontinuity with the prestimulation activity. The effect of surprise was associated with a different temporal structure in the neural response, combining phase-scattering[30] and an increase in synchrony. The motor response was accompanied by a

[30] Phase-scattering is defined as a significant decrease of the synchrony measure compared to the average synchrony in a baseline.

pattern of synchronies that were spatially similar to that observed during preparation, but were delayed by 300ms.

If one defines the brain activity evoked by the stimulation in the first 100ms after the stimulation as an elementary event or local event, then this data could be interpreted as follows. In the case of preparation, expectation is an intentional act about the stimulus and is correlated to a large-scale coherent activity (partially characterized by this frontal pattern) before stimulation. This large-scale activity could be said to have a downward causation on the local, elementary event in the sense that this event appears as integrated, both dynamically and phenomenally in the pre-existing activity. The pre-existing global pattern could act thus as an order-parameter modulating the local processes. In contrast, in the case of surprise, no stable patterns are found on average before stimulation. Therefore, there is a weaker disposition, either phenomenally or dynamically, to perceive the stimulus. The genetic analysis of this cluster suggests that the stimulation induced a transition in the flow of consciousness from one content to another. The neurodynamical and behavioral correlates offer a striking relation with this description: the effect of surprise was associated with a different temporal structure in the neural response, combining phase-scattering (white-line) and an increase in synchrony (black lines).

Phase-scattering thus mediates the necessary transition between two very distinct neural assemblies, in particular during the adaptive response to a salient change in sensory flow. The motor response was accompanied by a pattern of synchronies that were spatially similar to the one observed during preparation, but were delayed by 300ms. In that case it is tempting to say that this local event makes the ongoing activity bifurcate onto another global dynamical trajectory. In that sense it induces a stronger upward causation because it triggers a shift in both the content of the now and the dynamical patterns. This was revealed particularly well by the patterns of phase-scattering, which are already found in the transition between two cognitive moments.

4. 5 Weaving the three threads of generative passages

This part is conjectural and suggests from the previous analysis a possible way to explicitly test the assumption of mutual constraints as generative passages.

In contrast to the phenomenal isomorphism described before this relation expressly mobilizes a formal level (thread #3) and a multi-scale analysis (local/global) within the first-person accounts, the biophysical processes, and the dynamical variables. Such relation is triangular and no longer binary. Thus, providing that the neurophenomenological praxis has been implemented and that the relevant multi-scale dynamical variables have been identified, then the working assumption could be tested as follows: trials could be clustered (a) depending on structural properties expressing a global to local relation as described by phenomenological accounts and (b) depending on dynamical trajectories expressing a reciprocal causation as quantified by the scientific analysis of neurobiological data. A relation of generative passages could be demonstrated if the partitioning of the space of trials in mode (a) significantly overlap the partitioning of space in mode (b).

In Lutz et al. (2002) we have already demonstrated an overlap between phenomenological and behavioral clusters. We then showed significant physiological differences in the self-generated activity before stimulation and the brain responses between the various phenomenological clusters. This result is very encouraging but is insufficient to constitute, strictly speaking, a generative passage because we did not mobilize explicitly a dynamical level. Further quantification is first needed which may not be possible with these current data. Indeed, the lack of spatial resolution of the EEG makes it difficult to interpret the synchrony patterns directly in terms of precise neural networks. Also, neural interactions may take multiple forms that are not detected by linear measures such as phase-synchrony. Finally the cultivation of the reductive gesture and the degree of refinement of first-person accounts may require working with experts. For instance, subjects with long-term training in practices rooted in Eastern traditions such as meditation practice could become paradigmatic collaborators.

Further improvements are clearly required at these three levels of the neurophenomenological accounts. This purpose of this section has been to clarify and exemplify such strategy.

4.5 Toward a typology of reciprocal causations:

This last section attempts to further generalize the distinctions found between these two DNSs.

The first DNS (during steady preparation) expresses an "easy" case of downward causation where global to local can be equated to top-down influences on sensory processing. Such data corroborates with several studies which show that 'expectation' or 'anticipation' do indeed affect the temporal structure both of the ongoing activity pattern and the brain responses (for an recent review see, Engel, Fries, and Singer, 2001). For instance Riehle et al. (1997) showed that, in a delayed reaching task, synchrony occurred particularly when the monkey was expecting a GO signal to appear on a screen. Remarkably, in those trials in which the GO signal appeared after prolonged periods of expectation, the spike synchrony became more precise as the GO cue signal approached.

This attests to a relationship between growing stimulus expectancy and the synchronization of the neuronal network involved in the task. Thus, in this study the level of synchrony appears to have predictive power both on the performance and the reaction times of the animal.

In this first DNS the downward causation can be simply described as follows: the emergence of the act of anticipation corresponds to the constitution of a coherent assembly (upward causation) from which and during which the neural activity in sensory regions will be "*interpreted*". This notion of "neuronal interpretation" (Chiel, 1993; Varela, 1997, p. 367) means that the competitive process underlying emergence consists either in discarding or integrating concurrent local activities into the dominant resonant mode. This federation of the neural activity expresses thus a transient "point of view" or a dynamical "background" from which other local activities are "assessed". This "*hermeneutics*" (Varela, 1997, pp. 367) and *selective* dimension of synchronization offer a striking insight about the processes underlying the immanent constitution of temporality. The quality of preparation (steady or fragmented), for example, can directly provide insights about the selective and competitive process *itself* of emergence underlying the deployment of attention.

The second DNS (unreadiness with surprise) provides intuitions about another, more sophisticated, class of global/local processes mediating the reflective dimension of experience. As I suggested in the previous section, this reflexive gesture was induced by an affective reaction following a shift in the intentional content of the experience. This first-person account was related, in the average DNS, to a massive disorganization in synchrony patterns. This phase-scattering was concomitant to the emergence after stimulation of synchrony patterns between visual and frontal electrodes. This suggests that the emotional shift initiated the emergence of a new large-scale assembly thereby constituting an original point of view. The experience of one's own experience could be mediated by the interpretation within this new assembly of local processes previously implicated in the former dominant assembly. For example, if, before the stimulation, the content of my experience was about a meeting I had to attend after the protocol, then some elements of the neural network involved in this act could be still resonating locally after the perturbation generated by the stimulation. After the phase-scattering, these elementary processes might be *re-enslaved* by the new assembly. This *re-enslaving*, would mediate, I propose, the experience of *reflective awareness*. In contrast to the former class of global to local processes the global activity here would constrain and integrate *endogenous* local processes. This global to local interaction is likely to be mediated by the complex interplay between several oscillatory modes as suggested by the different frequency bands detected during top-down and buttom-up interactions (Von Stein, Chiang, and Konig, 2000). This case of reciprocal causation potentially opens the door to the naturalizing of the reductive gesture itself, providing that reflection triggered by an affective disposition contains some of the structural features of the gesture of reduction (Depraz et al., 2002).

To summarize, this section has illustrated the difference between the 'reciprocal causation' theory and a classical top-down/ buttom-up theories (Mumford, 1992). The latter emphasize the anatomical organization of cognition whereas the former highlights its dynamical self-coordination. For the latter, top-down influences correspond to the activity of feedback connections in a processing hierarchy, whereas in the former it is the temporal structure of large-scale dynamics which influences local processes largely independently from their location. A similar, central role of collective coherent dynamics has recently been presented in Engel, Fries and Singer's "dynamicist" view of top-down influence (2001) or Kelso and Bressler's "coordination dynamics" theory (2001). Mutual constraints theory takes this a step further by attempting to relate these third-person concepts to first-person accounts. The first-person account of immediate experience produced by a trained subject is more than a heuristic: it expresses a hermeneutical and asymetrical process which must be fully integrated as part of the neurophenomenological account. In this sense downward and upward causation are operational concepts for untangling the intertwined relations between local and global processes in order to investigate the *driving or enslaving* effect of an emergent process on others activities and their relations to the phenomenal level.

Conclusion

Neurophenomenology stresses the specific need to start by exploring experience with a rigorous pragmatics before investigating more fully its symbiotic relation to natural entities. A first report from this study is that this strategy is not a thoughtful but impractical method. On the contrary, it is a doable, fruitful and promising approach to the collection of new phenomenal and neurodynamical data and to identify their mutual relationships. Its initial formulation was placed in the lineage of continental phenomenology. This choice could have scared some readers. Yet what we learnt on the job is that these "technical" distinctions are meaningful and inspiring descriptions as soon as we take the time to look at them. The phenomenological tradition can thus provide conceptual tools, stimulating questions and a style of research. A phenomenological reduction was rudimentarily instantiated in our study by training the subject to be aware of his/her preparatory context and by inducing after each trial a reflective gesture on his/her just-past experience. Further refinements are obviously needed. A central issue is to get a better instrumental description of this reductive gesture (see Petitmengin-Peugeot, 1999; Depraz et al., 2002).

The core concept of "reciprocal constraints" was defined in this paper through its methodological, epistemological and theoretical modes. Reciprocal constraints were first read as a heuristic approach guided by a praxis. It was instantiated (a) by training the subject to find his/her own categories to describe his/her preparatory context and visual experience and (b) by doing a joint-analysis of first- and third-person data. This particular approach to mutual constraints was implemented through the characterization of the dynamical neural signatures (DNS) of phenomenological clusters (PhC) of trials.

The second section analyzes and illustrates the limitations of the phenomenal isomorphism. The risks associated with this *static* relation are to dismiss the active, embodied and situated side of subjective experience. The relation of "generative passages" is thus an attempt to do justice to the *genetic* and *emergent* dimension of experience. It provides a way to better interpenetrate experience and its natural substrates. Generative passages can be envisaged thanks to (a) a neurophenomenology framework (b) a multi-scale analysis of these phenomena (c) an extension of first-person data to conscious acts and their self-manifestation and (d) an explicit introduction of a neural dynamical level in the neurophenomenological account.

The question of the relationship between phenomenal isomorphism and generative passages requires further thought. On the one hand, generative passages might simply correspond to a more refined, precise, and accurate version of phenomenal isomorphism. It would be thus a three-way isomorphism (i.e., one-one mapping) among generic-genetic (and static) properties in the phenomenal, neurally emergent, and formal dynamical domains. On the other hand, generative passages might correspond only to an homomorphic epistemological relation among the phenomenal, the neural, and the dynamical (i.e., a reduction of phenomenal structural features when projected onto the neural-dynamical categories). For instance, it might not be possible to map all of the structural-phenomenal features in the neural domain, because the natural domain would need to be broadened beyond the brain to include the organism as a whole (and the organism's environment)[31]. These questions require further empirical investigation.

In Memoriam

This article is dedicated to Francisco Varela in memory of his innovating work, generous teaching and inspiring life. For an obituary see http://psyche.csse.monash.edu.au/v7/psyche-7-12-thompson.html.

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Bibliography

Abeles, M. 1982. *Local Cortical Circuits*. Berlin: Springer.

Acebron, J.A., Perales, A., and Spigler, R. 2001. Bifurcations and global stability of synchronized stationary states in the Kuramoto model for oscillator populations. *Phys Rev E Stat Phys Plasmas Fluids Relat Interdiscip Topics,* 64: 016218.

Arbib, M.A. 1995. *Handbook of Brain Theory and Neural Networks*. Cambridge, MA: MIT Press.

Bressler, S.L. and Kelso, J.A. 2001. Cortical coordination dynamics and cognition. *Trends in Cognitive Science,* 5: 26-36.

Chalmers, D.J. 1996. *The Conscious Mind: in Search of a Fundamental Theory.* Oxford University Press.

Churchland, P.S. and Sejnowski, T. 1992. *The Computational Brain* Cambridge, MA: MIT Press.

Clark, A. 1997. *Being There: Putting Brain, Body and World Together Again*. Cambridge, MA: MIT Press.

Depraz, N. 1994. Temporalité et affection dans les manuscrits tardifs sur la temporalité (1929-1935) de Husserl. *Alter,* 2: 183-247.

Depraz, N. 1998. Can I anticipate myself? Self-affection and temporality. In D. Zahavi (ed). *Self-Awareness, Temporality and Alterity* (pp. 83-99). Dordrecht: Kluwer.

Depraz, N. 1999. When Transcendental Genesis Encounters the Naturalization Project. In J. Petitot, F. Varela, B. Pachoud and J.M. Roy (eds). *Naturalizing Phenomenology*, (pp. 464-83) Stanford, CA: Stanford University Press.

Depraz, N., Varela, F., and Vermersch, P. 2002. *On Becoming Aware: The Pragmatics of Experiencing*. Amsterdam: John Benjamins Press.

Edelman, G. 1987. *Neural Darwinism*. New-York: Basic Books.

Engel, A.K., Fries, P., and Singer, W. 2001. Dynamic prédictions: oscillations and synchrony in top-down processing. *Nat Rev Neurosci,* 2: 704-16.

Engel, A.K. and Singer, W. 2001. Temporal binding and the neural correlates of sensory awareness. *Trends in Cognitive Science,* 5: 16-25.

Ericsson, K.A. and Simon, H.A. 1993. *Protocol Analysis, Verbal Protocols as Data*. Cambridge, CA: MIT Press.

Flanagan, O. 1994. *Consciousness Reconsidered*.. Cambridge, MA: MIT Press.

Fodor, J. 1984. *The Modularity of the Mind*. Cambridge, MA: MIT Press.

Freeman, W. 1999. *How Brains Make Up Their Minds*. London : Wiedenfeld & Nicholson.

Haken, H. 1996. *Principles of Brain Functioning: a Synergetic Approach to Brain Activity, Behavior and Cognition.* Berlin: Springer.

Hanna, R. and Thompson, E. (forthcoming). The Spontaneity of Consciousness: Neurophenomenology and Modal Metaphysics.

Hebb, D.O. 1949, *The Organization of Behavior*. New-York: Wiley-Interscience,

Husserl, E. 1988. *Cartesians Meditations: Introduction to Phenomenology.* Translated by D. Cairns. Dordrecht: Kluwer Academic Publishers.

Husserl, E. 1977. *Phenomenological Psychology. Lectures, Summer Semester 1925.* Translated by J. Scanlon. The Hague: M. Nijhoff.

Husserl, E. 1966. *Analysen zur passiven Synthesis, 1918-26.* Ed. M. Fleischer. The Hague: M. Nijhoff.

Husserl, E. 1952. *Ideen zu einer reinen Phänomenologie und phänomenologischen Philosophie, Book 2: Phänomenologische Untersuchungen zur Konstitution. 1912-28.* Ed. W. Biemel. The Hague: M. Nijhoff.

Husserl, E. 1928. *The Phenomenology of Internal Time Consciousness* [Vorlesungen zur Phänomenologie des inneren Zeitbewusstseins 1893-1917] Translated by J. S. Churchill. Bloomington, IN: Indiana University Press, 1964.

Husserl, E. 1913. *Ideen zu einer reinen Phänomenologie und phänomenologischen Philosophie, Book 1: Allgemeine Einführung in die reine Phänomenologie.* Ed. W. Biemel. The Hague: M. Nijhoff, 1950.

Jackendoff, R. 1987. *Consciousness and the Computational Mind* Cambridge, MA: MIT Press.

Julesz, B. 1971. *Foundations of Cyclopean Perception* Chicago, IL.

Kelso, J.A.S. 1995. *Dynamical Patterns: The Self-organization of Brain and Behavior.* Cambridge, MA: MIT Press.

Köhler, W. 1947. *Gestalt Psychology: An Introduction to New Concepts in Modern Psychology.* New-York: Liveright.

Kopell, N., Ermentrout, G.B., Whittington, M.A., and Traub, R.D. 2000. Gamma rhythms and beta rhythms have different synchronization properties. *Proc Natl Acad Sci USA,* 97: 1867-72.

Lachaux, J.P., Rodriguez, E., Martinerie, J., and Varela, F.J. 1999. Measuring phase synchrony in brain signals. *Hum Brain Mapp,* 8: 194-208.

Levine, J. 1983. Materialism and Qualia: The Explanatory Gap. *Pacific Philosophical Quarterly,* 64: 354-61.

Lutz, A., Lachaux, J.-P., Martinerie, J., and J.F., Varela. 2002. Guiding the study of brain dynamics using first-person data: Synchrony patterns correlate with on-going conscious states during a simple visual task. *Proc Natl Acad Sci U S A*: in press.

McClelland, J.L., Rumelhart, D.E., and Group, T.P.R. 1986. *Parallel Distributed Processing, Vol.2: Psychological and Biological Models* (Cited as *Parallel Distributed Processing, Vol.2: Psychological and Biological Models*). Cambridge, MA: MIT Press.

Merleau-Ponty, M. 1945/1962. *Phenomenology of Perception*, trans. C. Smith. London: Routledge and Kegan Paul. Original publication: *Phenomenologie de la perception*. Paris: Gallimard.

Mumford, D. 1992. On the computational architecture of the neocortex. II. The role of cortico-cortical loops. *Biol Cybern,* 66: 241-51.

Nagel, T. 1970. "What is it like to be a bat?" *Philosophical Review,* 79 : 394-403.

Pessoa, L., Thompson, E., and Noe, A. 1998. Finding out about filling-in: a guide to perceptual completion for visual science and the philosophy of perception. *Behav Brain Sci,* 21: 723-48; discussion 748-802.

Petitmengin-Peugeot, C. 1999. The Intuitive Experience. In F. Varela and J. Shear (eds). *The View from Within* (pp. 43-77). Exeter: Imprint Academic.

Petitot, J., Varela, F., Pachoud, B., and Roy, J.M. (eds). 1999. *Naturalizing Phenomenology*. Stanford, CA: Stanford University Press.

Pylyshyn, Z.W. 1984. *Computation and Cognition*. Cambridge, MA: MIT Press.

Riehle A, Grun S, Diesmann M, Aertsen A. 1997. Spike synchronization and rate modulation differentially involved in motor cortical function. *Science*, 278 : 1901-2.

Rodriguez, E., George, N., Lachaux, J.P., Martinerie, J., Renault, B., and Varela, F.J. 1999. Perception's shadow: long-distance synchronization of human brain activity. *Nature,* 397: 430-3.

Roy, J.M., Petitot, J., Pachoud, B., and Varela, F. 1999. Beyond the gap. An introduction to Naturalizing Phenomenology. In J. Petitot, F. Varela, B. Pachoud and J.M. Roy (ed). *Naturalizing Phenomenology*, (pp. 1-80). Stanford, CA: Stanford University Press.

Searle, J.R. 1992. *The Rediscovery of the Mind*. Cambridge, MA: MIT Press.

Shear, J., ed. 1997. *Explaining Consciousness: The Hard Problem*. Cambridge, MA: MIT Press.

Singer, W. and Gray, C.M. 1995. Visual feature integration and the temporal correlation hypothesis. *Annu Rev Neurosci,* 18: 555-86.

Thompson, E. and Varela, F.J. 2001. Radical embodiment: Neural dynamics and consciousness. *Trends in Cognitive Science,* 5: 418-25.

van Gelder, T. 1998. The dynamical hypothesis in cognitive science. *Behav Brain Sci,* 21: 615-28; discussion 29-65.

Varela, F. 1996. Neurophenomenology : A Methodological Remedy to the Hard Problem. *Journal of Consciousness Studies,* 3: 330-50.

Varela, F. 1997. The Naturalization of Phenomenology as the Transcendence of Nature. *Alter,* 5: 355-381.

Varela, F.J. 1995. Resonant cell assemblies: A new approach to cognitive functions and neuronal synchrony. *Biol Res,* 28: 81-95.

Varela, F., Lachaux, J.P., Rodriguez, E., and Martinerie, J. 2001. The brainweb: phase synchronization and large-scale integration. *Nat Rev Neurosci,* 2: 229-39.

Varela, F. and Shear, J. (eds). 1999. *The View from Within: First-person Approaches to the Study of Consciousness*. Exeter: Imprint Academic.

Varela, F., Thompson, E., and Rosch, E. 1991. *The Embodied Mind: Cognitive Science and Human Experience*. Cambridge: MA: MIT Press.

Vermersch, P. 1994. *L'Entretien d'Explicitation*. Paris: ESF.

von Stein, A., Chiang, C., and Konig, P. 2000. Top-down processing mediated by interareal synchronization. *Proc Natl Acad Sci U S A,* 97: 14748-53.

Legends :

<u>Figure 1:</u>
The shadow of perception. Average scalp distribution of gamma activity and phase synchrony. EEG was recorded from electrodes at the scalp surface. Subjects were shown Mooney figures (high contrast faces), which are easily perceived as faces when presented upright (here Marylyn Monroe's profile), but usually perceived as meaningless black-and-white forms when upside-down. The subjects' task was a rapid two-choice button response of whether or not they perceived a face at first glance. Color coding indicates gamma power (averaged in a 34-40Hz frequency range) over a given electrode and during a 180ms time window. Gamma activity is spatially homogenous and similar between conditions over time. By contrast, phase synchrony is markedly regional and differs between conditions. Synchrony between electrode pairs is indicated by black and green lines, corresponding to a significant increase or decrease in synchrony, respectively. These are shown only if the synchrony value is beyond the distribution of shuffled data sets. Modified from Rodriguez et al., 1999.

<u>Figure 2:</u>
The shadow of perception within an ongoing phenomenal and dynamical context. EEG was recorded from electrodes at the scalp surface. Subjects were shown first a background image with random-dot points. They were asked to fuse two little squares at the bottom of the screen and to remain in this position for several seconds. At the end of this preparation period, a stereogram (3D illusion) was presented. Subjects were instructed to press a button as soon as the shape had completely emerged and to give a brief verbal report of their experience (see section 2.3). Dynamical neural signatures (DNS) of the pre-stimulation activities and the brain responses are presented for one subject during readiness with immediate perception (SR) (154 trials) and spontaneous unreadiness with surprise during stimulation (SU) (38 trials). Color-coding indicates scalp distribution of gamma power around 35Hz normalized compared to a distant baseline ([-8200ms –7200ms], 0ms corresponds to the presentation of the stereogram) (the normalization technique is different than in the Mooney one). Black and white lines correspond to significant increase and decrease in synchrony, respectively, compared to the baseline. For a precise description of the figure see section 4.3. Modified from Lutz et al., 2002.