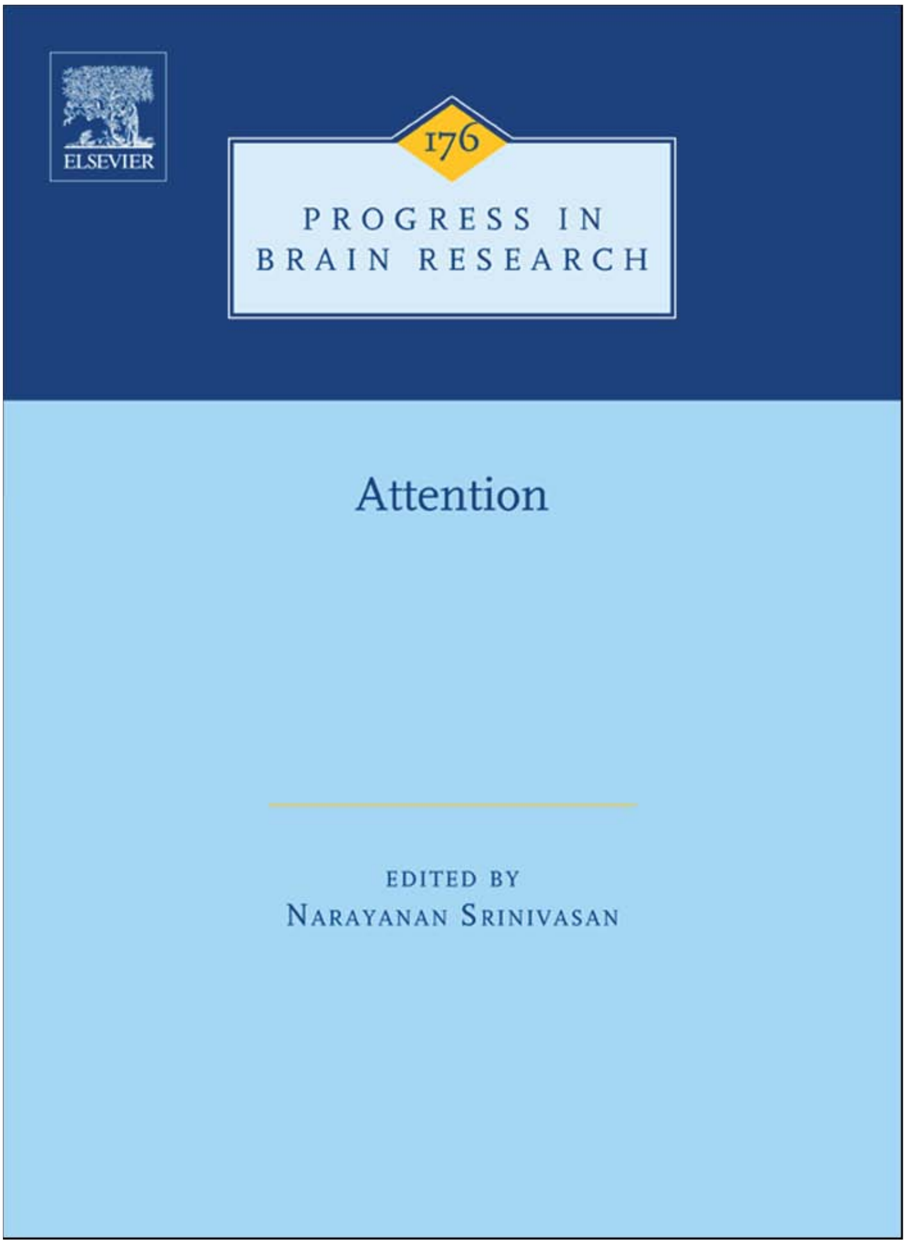

From Elina Birmingham and Alan Kingstone, Human social attention. In: Narayanan Srinivasan, editor: Progress in Brain Research, Vol 176, Narayanan Srinivasan.
The Netherlands: Elsevier, 2009, pp. 309–320.
ISBN: 978-0-444-53426-2

N. Srinivasan (Ed.)
Progress in Brain Research, Vol. 176
ISSN 0079-6123

CHAPTER 11

An adaptive workspace hypothesis about the neural correlates of consciousness: insights from neuroscience and meditation studies

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Abstract: While enormous progress has been made to identify neural correlates of consciousness (NCC), crucial NCC aspects are still very controversial. A major hurdle is the lack of an adequate definition and characterization of different aspects of conscious experience and also its relationship to attention and metacognitive processes like monitoring. In this paper, we therefore attempt to develop a unitary theoretical framework for NCC, with an interdependent characterization of endogenous attention, access consciousness, phenomenal awareness, metacognitive consciousness, and a non-referential form of unified consciousness. We advance an adaptive workspace hypothesis about the NCC based on the global workspace model emphasizing transient resonant neurodynamics and prefrontal cortex function, as well as meditation-related characterizations of conscious experiences. In this hypothesis, transient dynamic links within an adaptive coding net in prefrontal cortex, especially in anterior prefrontal cortex, and between it and the rest of the brain, in terms of ongoing intrinsic and long-range signal exchanges, flexibly regulate the interplay between endogenous attention, access consciousness, phenomenal awareness, and metacognitive consciousness processes. Such processes are established in terms of complementary aspects of an ongoing transition between context-sensitive global workspace assemblies, modulated moment-to-moment by body and environment states. Brain regions associated to momentary interoceptive and exteroceptive self-awareness, or first-person experiential perspective as emphasized in open monitoring meditation, play an important modulatory role in adaptive workspace transitions.

Keywords: consciousness; meditation; prefrontal cortex; attention; global workspace; mindfulness; self-awareness

Introduction

As recently remarked by Gaillard et al. (2009, p. 1), ''the neural correlates of consciousness (NCC) still remain highly controversial. Indeed, the precise timing, location, and dynamics of neural events causing conscious access are not clearly and unequivocally determined. Do the NCC correspond to late or early brain events? Are they systematically associated with reentrant 'top-down' processing? If so, do they necessarily involve long-range coherent activity, including prefrontal cortex

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DOI: 10.1016/S0079-6123(09)17620-3

as an essential node, or can they be restricted to local patterns of reverberating activity? Is the concept of 'integrated information' relevant, rather than the specific localization of the underlying cerebral network?''

Given this problematic scenario, we suggest a theoretical framework for the NCC, in terms of an *adaptive workspace hypothesis*, based on a set of experimental findings and prior theoretical proposals in the field of neuroscience of consciousness and attention, as well as new insights from meditation studies. We will also consider earlier views on consciousness as developed in Buddhist texts. Apart from aspects of visual awareness and attention, which have been intensively studied over the last years (e.g., Dehaene et al., 2006), we will also include into our theoretical consideration other aspects of consciousness, such as *metacognitive consciousness*, that have been emphasized in earlier philosophical (e.g., Kant, 1781/1996) and contemplative approaches (see Wallace, 1999) as well as in recent neuroscientific theories (e.g., Zeki, 2003; Arenander and Travis, 2004).

In this paper we will first review the main aspects of the influential Baars' global workspace (GW) theory, and then a neural model based on GW with reference to brain structures and processes, including prefrontal cortex, long-range recurrent (reentrant) neural interactions, and oscillatory coherence. We will then pay particular attention to the issue of stability and transience of GW brain dynamics that is crucial for our adaptive workspace hypothesis. We will then consider essential aspects of meditation, as well as recent related neuroscientific and cognitive investigations. Indeed, these aspects are crucial for the development of our adaptive workspace hypothesis. Such a hypothesis will then be outlined in the subsequent sections, with reference to endogenous attention, phenomenal awareness, access consciousness, and metacognitive consciousness as well as their interactions, in a preliminary attempt to develop a unitary neurocognitive framework to characterize human consciousness in its integrity and multiform manifestations. Conclusions and prospective aspects are finally presented.

The global workspace model of conscious access

Baars' global workspace theory

One of the currently most influential theories of human consciousness, with fundamental implications for addressing the NCC, is Bernard Baars' GW theory (1983, 1998, 2002; Baars et al., 2003). In this theory, conscious perception enables access to widespread brain sources, in terms of *broadcasting*, whereas unconscious processing involves brain sources processing information in a substantially segregated or modular fashion. According to Baars, consciousness, although limited in capacity at any given time, provides a gateway to extensive unconscious knowledge sources in the brain, therefore creating the conditions for *global access* in cerebral information processing.

To characterize the functional properties of the GW, Baars (1998) used an interesting theater metaphor, which has been substantially maintained through subsequent versions of the theory (e.g., Baars, 2002; Baars et al., 2003). According to Baars, convergence zones (i.e., the *theater stage*) are needed for the emergence of integrated conscious perceptual information (e.g., in the visual domain). Signals from sensory projection cortical areas, ''lit up'' by attentional activation, provide consciousness ''contents'' by converging for integration at the level of more anterior areas. Conscious states can involve a large set of cortical and subcortical brain regions (the *audience*), which can be recruited on an intentional basis for conscious access operations.

A key aspect in Baars' theory is broadcasting of selected contents (i.e., *speaking to the audience*) through which conscious information can be widely disseminated in the brain, in a global access process. Broadcasting occurs through activated distributed (including spatial) maps in the brain, connected through ''labeled line'' systems, with special reference to intra- and inter-hemispheric cortico-cortical connection systems, and thalamo-cortical connection systems (Baars, 1998). Temporal oscillations would also play a role in coordinating the ''speaking to the audience'' process in such a distributed brain network for conscious broadcasting. Significant conscious events can be renewed by inner speech, imagery, or conscious emotional feeling states, with a reinitialization of broadcasting-related activity loops.

In GW theory (Baars, 1998, 2002), unconscious or ''contextual'' brain systems play a role in shaping conscious events, acting as a *backstage* in a theater. Contextual systems in the brain would include the dorsal pathway for visual processing, whereas the ventral visual pathway would produce sensory ''contents'' (Milner and Goodale, 2008). Interestingly, Baars noticed that parietal neglect, the syndrome characterized by an altered spatial framework for vision, is often accompanied by anosognosia, a loss of awareness about one's body space.

To influence decision making, Baars (1998) hypothesized that conscious events involve self-systems in the brain, with special reference to the ''narrative interpreter'' in the left hemisphere (with involvement of prefrontal cortex). This interpreter would act as a *stage director* in a theater. Baars particularly refers to Gazzaniga's (1985) findings with split-brain patients, and argues that the two hemispheres might each have an ''observer'' (or executive interpreter) of the respective conscious flow of visual information.

To address the issue that conscious perception may entail a dialog between specific self-related prefrontal regions (''stage director'' or executive interpreter) and sensory cortex (Baars et al., 2003), brain activity patterns produced by a demanding sensory categorization task was compared to those engaged during self-reflective introspection, using similar sensory stimuli (Goldberg et al., 2006). The results showed a complete segregation between the two brain activity patterns arguing against Baars' hypothesis of involvement of self-related observer-like prefrontal regions in perceptual awareness (Goldberg et al., 2006). Moreover, areas characterized by an enhanced activity during introspection exhibited a robust inhibition during the demanding perceptual task, thus suggesting that self-related brain activities are not necessarily implied during sensory perception, and can rather be suppressed.

We will however consider the notions of broadcasting and contextual systems for conscious access, as related to the theater metaphors of ''speaking to the audience'' and ''backstage,'' in the framework of our model presented in this article. We will also refer to the ''observer'' or executive interpreter function, as related to the ''stage director'' metaphor, in terms of a ''global backstage'' or ''consciousness context assembly'' in the brain, supporting and constraining in ''background'' the evolution of transiently stable content-related ''core assemblies'' characterized by a GW ''foreground'' dynamics. As will be discussed in section ''The adaptive workspace hypothesis'' in our model the interplay between global backstage assembly and core assemblies constrains monitoring functions, as related to perceptual conscious access and metacognitive consciousness, in a self-organizing brain-scale dynamics and recursive functional logic.

Neuronal global workspace model

There is wide agreement and remarkable empirical support for GW dynamics in the brain, related to conscious experience (see Dehaene et al., 2006). In particular, Baars' GW theory has been revisited in a neuronal GW framework by Stanislas Dehaene and collaborators, based on a coherent set of psychophysical, neuroimaging, and computational investigations (Dehaene et al., 1998, 2006; Dehaene and Naccache, 2001; Gaillard et al., 2009). This approach postulates that the global availability of information at the whole brain-scale, i.e., in the GW, is what we subjectively experience as a conscious state. With reference to visual awareness, this neuronal GW model proposes that unconscious visual information processing is characterized by the parallel activation of multiple modular brain networks (Dehaene et al., 1998, 2003, 2006; Dehaene and Naccache, 2001; Gaillard et al., 2009).

In the neuronal GW model, three conditions have to be met to enable the access to consciousness of incoming visual information (Dehaene et al., 2006; Gaillard et al., 2009). Condition 1: Information must be *explicitly represented* by neuronal firing in perceptual networks in visual cortical areas coding for the specific features of the conscious percept. Condition 2: This sensory neuronal representation must reach a minimal threshold of *duration* and *intensity* necessary for access to a second stage of processing involving a distributed cortical network, with special reference to parietal and prefrontal cortices. Condition 3: Through joint *bottom-up propagation* and top-down *attentional amplification*, a coherent self-sustained reverberant state must be ''ignited'' in terms of a brain-scale neural assembly, thus implementing a GW. Neuroscientific findings strongly argue for a major role for prefrontal cortex and anterior cingulate with posterior associative areas that connect to them, in creating the brain-scale workspace dynamics.

The neuronal GW model is characterized by a *winner-take-all* dynamics at higher stages of neural processing (involving prefrontal cortex), a sort of ''neural bottleneck'' such that only one large-scale reverberating neural assembly is active in the neuronal GW at a given moment. These winner-take-all processes have been highlighted in experimental and related computational settings using the attentional blink (AB) paradigm, in which the subjects have to report the identity of two target stimuli (e.g., digits) in a series of rapidly presented visual stimuli, most of which are distracters (e.g., letters). If the second (T2) of the two target stimuli is presented within 500 ms of the first one (T1) in a rapid sequence of distracters, it is often not detected, thus resulting in an AB (Raymond et al., 1992).

Fries (2005) has proposed a large-scale neural oscillatory mechanism to mediate attention-based broadcasting in the brain, which appears of relevance for the neuronal GW model, in the framework of his ''Communication-Through-Coherence'' (CTC) hypothesis. In this mechanism, a preferential routing of selected signals takes place by passing the rhythm of a selected sending group onto other groups of neurons, which would be *entrained* to the selected rhythm by membrane potential fluctuations. This set of entrained neuronal groups would then be made sensitive for the selected input, while neuronal ''broadcasting centers,'' such as aspecific thalamic nuclei with widespread reciprocal connections with cortical areas, would distribute the selected rhythm at a whole brain-scale. Thus, as suggested by Fries, the top-down mechanisms reflecting attentional selection are transformed from a spatial to a *temporal code*, as top-down signals reside in the selection-related, entraining-related, and broadcasted temporal information. This hypothesis appears as an interesting specification of Baars' (1998) earlier proposal of ''labeled line'' systems, coordinated by oscillations, for broadcasting in the GW.

In a very recent intracranial electroencephalographic investigation, Gaillard et al. (2009) have provided an important contribution to characterize the neuronal GW processes, by comparing conscious and nonconscious processing of briefly flashed words. Nonconscious processing of masked words was observed in multiple cortical areas, mostly within an early time window (300 ms), accompanied by induced gamma band activity, but in the absence of coherent long-distance neural activity. In contrast, conscious processing of unmasked words was characterized by the convergence of four distinct neurophysiological markers: sustained voltage changes, particularly in prefrontal cortex, large increases in spectral power in the gamma oscillatory range, increases in long-distance phase synchrony in the beta range, and increases in long-range Granger causality. The analyses of Gaillard et al. (2009) suggest that only late sustained long-distance synchrony and late amplification (after 300 ms) may be causally related to conscious-level processing. In particular, we will focus on the late sustained long-range synchrony reported in the study of Gaillard et al. (2009) for our hypothesis about consciousness presented in this article.

Stability, transience, and adaptive coding in global workspace neurodynamics

As suggested by Maia and Cleeremans (2005) in a connectionist framework, conscious representations involve a distributed network with recurrent connections arriving at an ''interpretation'' of a given input by settling into a *stable state*. This state is therefore regarded as a function of both the network input and the knowledge embedded in the network's connections, in terms of an interpretation process. Thus, Maia and Cleeremans (2005) suggest that conscious experience reflects stable states corresponding to interpretations that the brain makes of its current inputs, based on a brain-scale *global constraint satisfaction* process. We will however emphasize the importance of transient or metastable neural processes for conscious processes in our adaptive workspace hypothesis (see below).

In line with the GW model, these massive global interactions based on large-scale recurrency are regarded as necessary to reach a stable state supporting a given conscious experience, in terms of a winner-take-all dynamics. As related to Varela and Thompson's (2003) notion of ''local-to-global and global-to-local'' causality, Maia and Cleeremans (2005) also argue that *strong* and *sustained* neuronal firing at the (global) assembly level makes it more likely that the corresponding representation will reach the conscious level, in a neural competition process at brain-scale level. Conversely, at the local level, neurons characterized by high firing strength and stability are more likely to be inscribed in a winning coalition, and thus receive a higher amount of excitation from the coalition itself. The fact that information that does not enter consciousness tends to decay quickly can be explained in these terms (Dehaene and Naccache, 2001; Maia and Cleeremans, 2005).

Essentially, Maia and Cleeremans' (2005) connectionist framework provides an integrated view of attention, working memory, cognitive control, and consciousness based on a single mechanism: global competition between representations, with top-down biases from prefrontal cortex. A similar integrated approach was proposed earlier by John Duncan (2001), in terms of an *adaptive coding* model of prefrontal cortex function. Based on single-cell recording and neuroimaging data, the central idea of Duncan's adaptive coding model is that, throughout much of prefrontal cortex (with special reference to the lateral areas) the response properties of single cells are highly adaptable, as any given cell has the potential to be driven by many different kinds of input via a dense network of associative synapses. In such a model, prefrontal cortex acts as a GW or working memory onto which the fact needed in a current mental program can be written. Thus, in a particular task context, many neurons become adaptively tuned to code information that is specifically relevant to that task.

Duncan's (2001) approach also refers to the notion of *integrated competition* in visual attention, with emphasis on the problem of *processing coherence*. In this view, despite the fact that the neural representations of an object's features — such as location, color, shape, and motion — are distributed across multiple, partially specialized areas of extrastriate cortex, cognitive experiments show that visual objects are attended as wholes, as directing attention to an object makes its multiple features concurrently available to awareness (Duncan, 1984). According to the integrated competition hypothesis (Desimone and Duncan, 1995; Duncan et al., 1997), objects compete in parallel for representation in multiple extrastriate systems. As an object gains dominance in any one system, its representation is also supported in the other areas, thus resulting in a multiple system convergence. Duncan (2001) suggests that prefrontal cortex plays a guiding role in this integrated competition and convergence with processing coherence, and reflecting the current behavioral significance of objects in terms of adaptive coding and attentional bias. In other words, to achieve processing coherence, multiple brain systems share a strong tendency to converge to represent similar or related information, guided by prefrontal cortex depending on the behavioral or task context. We will also emphasize processing coherence and adaptive coding in prefrontal cortex in the framework of the hypothesis about consciousness presented here.

Global integrative processes for the emergence of consciousness in brain dynamics are also central to Francisco Varela's approach (Varela, 1995; Varela et al., 2001), with a special emphasis on *transient resonant assemblies* and serially established global brain patterns of oscillatory synchronization and desynchronization. In Varela's encompassing view, *for every cognitive act, there is a singular and specific large cell assembly that underlies its emergence and operation*. This approach can also be related to the ''dynamic core'' model of consciousness (Tononi and Edelman, 1998) that is based on neural complexity and the interplay between integration and differentiation of coherent as well as constantly changing large-scale neural activity patterns.

In Varela's working hypothesis (see also Rodriguez et al., 1999; Le Van Quyen, 2003), the brain-scale endogenous dynamics related to cognitive acts and the emergence of consciousness is characterized by *metastability*, as global activity patterns arise in succession in conditions of dynamical instability, in the absence of settling in any particular state (attractor). In such a framework, global resonant assemblies emerge rapidly in a time frame of 100–300 ms, via widespread cortico-cortical and cortico-thalamic reentrant parallel interactions establishing coherent neural processes. Varela et al. (2001) therefore suggest that large-scale neural integration must implicate not only the establishment of dynamic links, but also their active uncoupling to give way to the next cognitive moment. The integration process is therefore regarded as stemming from the interplay between phase locking and phase scattering across different frequency bands and at different moments in time. In this light, a dynamic neural synchronization model with self-organized spike (burst) synchronization and desynchronization reflecting processing coherence across multiple feature modules was simulated by Raffone and van Leeuwen (2003).

VanRullen and Koch (2003) more recently suggested a mechanism based on neural oscillatory *multiplexing* to account for visual perception and the awareness-related structure of neuronal representations, based on a discrete perception view that may be related to earlier Buddhist texts (von Rospatt, 1995) and psychophysical investigations (see Poeppel, 1997). The mechanism is based on ''slow'' (especially alpha) and ''fast'' (gamma) oscillations that are common in the thalamus and visual cortex. In such a mechanism, slow waves would constitute the ''context,'' and fast waves the ''content'' of neural representations. With reference to an earlier proposal by Llinas et al. (1998), VanRullen and Koch (2003) hypothesized that a nonspecific network or ''matrix,'' a distributed neuronal thalamic network connected with virtually all cortices, in association with the reticular nucleus and modulated by cortical feedback, would be capable of supporting globally coherent oscillations in the alpha range, as a ''context'' for neuronal representation. Content neural representations would be mediated by specific networks or ''core,'' neuronal subpopulations present in various sensory nuclei of the thalamus, with reentrant connections restricted to the corresponding cortical regions (maps). These specific thalamo-cortical loops would sustain fast (gamma) activity waves. In such a functional logic, the ''matrix'' and ''core'' thalamo-cortical networks together would support global and local orchestration of brain activities, implementing a multiplexing oscillatory scheme. We will also refer to the functional and neurodynamical distinction between context (matrix) and core (content) networks in the framework of the hypothesis about consciousness presented in this article.

Finally, the issue of ''strength and stability'' (as emphasized by Maia and Cleeremans, 2005) versus ''transience and rapid integration'' (as emphasized by Varela, 1995; Varela et al., 2001) in the dynamics of consciousness, appears also reflected in Block's distinction between *phenomenal consciousness* and *access consciousness* (Block, 1995, 2007). Access conscious content is content information that is ''broadcasted'' in the GW and phenomenally conscious content is what differs between experiences, say of red and green. Specifically, Block characterizes contents of access consciousness in terms of information that is made available to the brain's ''consumer'' systems: systems of memory, perceptual categorization, reasoning, planning, evaluation of alternatives, decision making, voluntary direction of attention, and more generally, rational control of action. We will consider these ''consumer'' systems as an explicit component of our model of metacognitive consciousness presented here.

When we view a complex visual scene, we experience a richness of content that seems to go beyond what we can report, Block proposed a distinct state of ''phenomenal consciousness'' prior to global access or GW broadcasting. Block's proposal was also based on the report of participants claiming to see the whole array of flashed letters, although they could later report only one subsequently cued row or column in experiments with Sperling's iconic memory paradigm. Along these lines, it has been suggested that access consciousness is related to *more stable* working memory representations, and phenomenal consciousness to a *more transient* iconic memory (Lamme, 2003; Block, 2007). However, this proposal has been criticized by claiming that Block's phenomenal consciousness would just correspond to a preconscious state, and the perceptual awareness experience of viewers in iconic memory experiments to an illusion (Dehaene et al., 2006).

Focused attention and open monitoring in meditation

Meditation can be conceptualized as a family of complex emotional and attentional regulatory practices, in which mental and related somatic events are affected by engaging a specific attentional set. Many recent behavioral, electroencephalographic, and neuroimaging studies have revealed the importance of investigating meditation states and traits to achieve an increased understanding of cognitive and affective neuroplasticity, attention and self-awareness, as well as for relevant clinical implications (Cahn and Polich, 2006; Lutz et al., 2008).

Given that regulation of attention is the central commonality across the many different meditation methods (Davidson and Goleman, 1977), meditation practices can be usefully classified into two main styles — *focused attention* (FA) and *open monitoring* (OM) — depending on how the attentional processes are directed (Cahn and Polich, 2006; Lutz et al., 2008). In the FA (‘‘concentrative’’) style, attention is focused on an intended object in a sustained fashion. OM (‘‘mindfulness-based’’) meditation involves the nonreactive monitoring of the content of experience from moment-to-moment, primarily as a means to recognize the nature of emotional and cognitive patterns.

Focused attention meditation

Apart from sustaining the attentional focus on the intended object, FA meditation also entails the regulative skills of monitoring the focus of attention and detecting distraction, disengaging attention from the source of distraction, and (re)directing and engaging attention to the intended object (Lutz et al., 2008). FA meditation techniques involve monitoring of experience fields by allowing other thoughts and sensations to arise and pass without clinging to them, keeping on or bringing attention back to a specific object of concentrative (or focused) awareness to develop an internal ‘‘witnessing observer’’ (Cahn and Polich, 2006). The attentional and monitoring functions in FA meditation have been related to dissociable systems in the brain involved in conflict monitoring, selective and sustained attention (Corbetta and Shulman, 2002; Lutz et al., 2008; Weissman et al., 2006).

It has been observed that FA meditation practice leads to a reduced effort in sustaining the intended focus. The regulative skills of noticing distractions, disengaging from the source of distraction, and redirecting promptly the attentional focus to the chosen object are more frequently involved in novices than in more expert FA meditation practitioner. Expertise in FA meditation would also lead to an attentional focus resting more readily and stably on the intended object, with a more acute monitoring ability to detect any arising distraction or mind wandering, thus implying a reduced cognitive effort in the practice (Lutz et al., 2008).

In Buddhist texts, consciousness is described as a ‘‘momentary collection of mental phenomena’’ or ‘‘distinct moments’’ (von Rospatt, 1995). In such texts it is asserted that the continuum of awareness is characterized by successive *moments*, or *pulses*, of cognition (Wallace, 1999). Based on a view of consciousness as consisting of sequences of discrete events (see also Poeppel, 1997; VanRullen and Koch, 2003), Wallace (1999) argued that the degree of focused *attentional stability* during FA meditation increases in relation to the proportion of ascertaining moments of cognition of the intended object. In this view, in a continuum of perceptual experience, a large amount of moments of awareness consist of non-ascertaining cognition, as objects *appear* to this inattentive awareness, but they are not *ascertained* (Lati Rinbochay, 1981; Wallace, 1999).

As attentional stability increases, a reduced number of moments of ascertaining consciousness are focused on perceptual objects other than the intended object, thus resulting in a homogeneous series of moments of ascertaining perception or perceptual awareness of the chosen object. In this process, the degree of *attentional vividness* corresponds to the ratio of ascertaining to non-ascertaining cognition moments: the higher the frequency of ascertaining perception, the greater the vividness (Wallace, 1999). In FA meditation practice, high attentional stability and vividness are achieved in a mental state of concentrated calm or serene attention, denoted by the word *Samatha* (with the literary meaning of *quiescence*) in the Buddhist contemplative tradition (Wallace, 1999), by FA meditation. By using a telescope analogy, Wallace (1999) observes that the development of attentional stability may be likened to mounting a telescope on a firm platform, while the development of attentional vividness is like highly polishing the lenses and bringing the telescope into clear focus.

Transcendental meditation (TM) can be broadly included in the FA meditation category, as its practice centers on the repetition of a mantra. However, TM primarily emphasizes an absence of concentrative effort and the development of a witnessing, thought-free ''transcendental awareness'' or ''pure consciousness.'' Maharishi Mahesh Yogi, who brought TM to the West from the Vedic tradition of India, characterized the experience of pure consciousness as follows (see Arenander and Travis, 2004): ''When consciousness is flowing out into the field of thoughts and activity it identifies itself with many things, and this is how experience takes place. Consciousness coming back onto itself gains an integrated state … This is pure consciousness.'' Pure consciousness is thus regarded as ''pure'' in the sense that it is free from the contents of knowing. It is a state of consciousness in which the individual is fully aware, with the ''content'' of pure consciousness being awareness itself (Arenander and Travis, 2004). TM meditation practitioners report that the absence of any concentration or effort unfolds experiences of ''unboundedness'' and the ''loss of time, space, and body sense.'' These ''pure consciousness'' or ''thoughtless awareness'' experiences were associated with profound bodily relaxation, marked by spontaneous breath quiescence and global, high amplitude, slow frequency (alpha) EEG patterns which are general highly coherent across frontal leads (Arenander and Travis, 2004; Travis and Wallace, 1999).

Interestingly, Zeki (2003) has recently considered a similar construct of unified or pure consciousness in his hierarchical theory of consciousness. Zeki's theory includes three hierarchical levels of consciousness: the level(s) of micro-consciousness, the level(s) of macro-consciousness, and unified consciousness. With reference to Kant (1996), Zeki regards this pure, unified, or ''transcendental consciousness'' as consciousness of oneself as the perceiving person, and as amounting to being aware of being aware. Zeki then places it at the apex of the hierarchy of consciousnesses, and remarks that it is the only consciousness that can be described in the singular.

A recent study with a binocular rivalry paradigm showed that Tibetan Buddhist monks were able to perceive a stable, superimposed percept of two dissimilar, competing images presented to separate eyes for a longer duration both during and after FA meditation, but not during and after a form of compassion (emotional OM) meditation (Carter et al., 2005). These extreme increases in perceptual dominance durations suggest that extensive training in FA meditation might improve the abilities to sustain attentional focus on a particular object and to control the flow of items being attended to and accessing consciousness.

A recent functional resonance imaging (fMRI) study investigated the neural correlates of FA meditation in experts (following Tibetan Buddhist traditions) and novices, with meditation focus on an external visual point (Brefczynski-Lewis et al., 2007). FA meditation compared with a rest condition, was associated with activation in multiple brain regions involved in monitoring, such as dorsolateral prefrontal cortex, attentional orienting (e.g., the superior frontal sulcus and intraparietal sulcus), and engaging attention (visual cortex). Srinivasan and Baijal (2007) used the mismatch negativity (MMN) paradigm, that is an indicator of preattentive processing, to investigate the effects of FA (Sudarshan Kriya Yoga) meditation. Meditators were found to have larger MMN amplitudes than non-meditators. The meditators also exhibited significantly increased MMN amplitudes immediately after meditation suggesting transient meditation-related state changes. These findings indicate that FA meditation practice enhances preattentive perceptual processes, enabling better change detection in auditory sensory memory.

Open monitoring meditation

OM meditation involves no explicit attentional focus, and therefore does not seem to be associated to brain areas implicated in sustained or FA, but to brain regions involved in vigilance, monitoring, and disengagement of attention from sources of distraction from the ongoing stream of experience (Lutz et al., 2008). OM practices are based on an attentive set that is characterized by an open presence and a nonjudgmental awareness of sensory, cognitive, and affective fields of experience in the present moment, and involves a higher-order (meta-) awareness of the ongoing mental processes (Cahn and Polich, 2006). The cultivation of this ‘‘reflexive’’ awareness in OM meditation is associated to a more vivid conscious access to the rich features of each experience and enhanced metacognitive and self-regulation skills (Lutz et al., 2008).

Unlike FA meditation, OM meditation does not involve explicit focusing on any object in the field of awareness, and therefore thus not involve attentional selection and de-selection processes. Therefore, in OM meditation cognitive monitoring is reflected in an open-field capacity to detect arising sensory, feeling, and thought events in an unrestricted ‘‘background’’ of awareness, without ‘‘grasping’’ any of these events in an explicitly selected foreground or focus as in FA meditation. In a transition from a FA to an OM meditation state, an object as primary focus is gradually replaced by an ‘‘effortless’’ sustaining of an open background of awareness without explicit attentional selection (Lutz et al., 2008). We will return in next sections of this article to the constructs of OM and awareness background as revealed through OM meditation, in the framework of our model of metacognitive consciousness.

In contemplative practice, as in the Buddhist tradition, attentional stability and vividness (acuity), as developed in FA meditation, are regarded as necessary for deep and reliable introspection to take place, as in the practice of *Vipassana* (insight) OM meditation. As remarked by Wallace (1999), Tsongkhapa (1357–1419), an eminent Tibetan Buddhist contemplative and philosopher, refers to another analogy to highlight the importance of attentional stability and vividness for the cultivation of contemplative insight. If an oil-lamp which is both radiant and unflickering is used at night to light a hanging tapestry, the depicted forms can be vividly observed. By contrast, if the oil-lamp is either dim, or, even if it is bright, flickers due to wind, the depicted images cannot be seen.

In the Buddhist contemplative tradition, introspection, as performed in OM insight meditation, is regarded as a form of metacognition, thus raising the important problem of whether or not it is possible for the mind to observe itself. As Buddhists generally assert that at any given moment consciousness and its concomitant mental processes have coherently the same intentional object, and at any given moment only one consciousness can be produced in a single individual (Vasubandhu, 1991), the problem of whether or not it is possible for the mind to observe itself raises (Wallace, 1999). With this respect, a famous discourse attributed to the Buddha states that the mind cannot observe itself, just as a sword cannot cut itself and a fingertip cannot touch itself; nor can the mind be seen in external sense objects or in the sense organs (*Ratnacutasutra*, cited in Shantideva, 1971 and Wallace, 1999).

To avoid an infinite regress in terms of a noted observer and the one who simultaneously note that observer, the 8th-century Indian Buddhist contemplative Shantideva suggested that instead of such metacognition occurring with respect to a simultaneously existing cognition, a *recollection* of past moments of consciousness would rather take place. In Shantideva's view, when one remembers seeing a certain event, one recalls both the perceived event and oneself perceiving that event. The subject and object are recalled as an integrated, experienced event, from which the subject is retrospectively identified as such; but Shantideva denies that it is possible for a single cognition to take itself as its own object (Dalai Lama, 1994; Shantideva, 1997; Wallace, 1999).

Wallace (1999) suggests an interesting example to clarify Shantideva's view on introspective metacognition: "When one's attention is focused on the color blue, one is not observing one's perception of that color. However, when one's interest shifts to the experience of blue, one is in fact recalling seeing that color just a moment ago. In this process, one conceptually and retrospectively isolates the subjective element from the remembered experienced event, in which the blue and one's experience of it were integrated. Thus, when the attention is shifted back and forth between attending to the color and to remembering seeing the color, it seems as if such a shift is comparable to shifting the attention from the objects at the center of consciousness to those at the periphery. But according to Shantideva, the attention is instead shifted from the perceived object to a short-term recollection of a previous event. And in remembering that event, the subject is isolated and recalled, even though it was not its own object at the time of its own occurrence. When one is recalling a perception of an earlier event, there is still a sense of duality between oneself and the perception that one is recalling. A single cognition does not perceive itself, so the subject/object duality is sustained" (Wallace, 1999, p. 179).

This view of metacognition and conscious access appears converging with a contemporary connectionist approach to metarepresentation, the creation of representations that are then available for reprocessing by the same network, thus implementing a (meta)representational and (recursive) processing cycle that could be regarded as the parallel distributed processing basis of the "stream of thought" (Maia and Cleeremans, 2005). The same operational principles might be underlying a global constraint satisfaction dynamics characterized by sequential (recursive) GW ignitions and transitions, and involving multiple brain systems in parallel. We will return to this aspect in the next section of this article.

Behavioral studies have shown a more distributed attentional focus (Valentine and Sweet, 1999), enhanced conflict monitoring (Tang et al., 2007), and reduced AB or more efficient resource allocation to serially presented targets (Slagter et al., 2007) in OM meditation practitioners. Specifically, Slagter et al. (2007) found that 3 months of intensive OM meditation lead to an observable reduction of elaborative processing of the first of two target stimuli (T1 and T2) presented in a rapid stream of distracters, as indicated by a smaller T1-elicited P3b, a brain potential index of resource allocation. Remarkably, such a reduction in resource allocation to T1 was associated with improved detection of T2. Slagter et al.'s study indeed suggests that an intensive training in OM meditation might result in the development of efficient attentional regulative skills to flexibly engage and disengage from target stimuli in a given task-setting.

Lutz et al. (2004) found a high-amplitude pattern of synchrony in the gamma oscillatory band in expert meditators during an emotional version of OM meditation (non-referential compassion or loving kindness meditation). In that study, compared with a group of novices, the practitioners (with a mental training of 10,000–50,000 h over time periods ranging from 15 to 40 years) self-induced higher-amplitude sustained gamma band oscillations and long-range phase synchrony, especially over lateral fronto-parietal electrodes, during meditation. This pattern of gamma band oscillations and synchrony was also significantly more pronounced in the baseline state of the long-term practitioners compared with the novices, thus suggesting a neuroplasticity-based transformation in the default brain mode of the practitioners.

Lutz et al. (2008) regard that these OM meditation-related neuroelectrical findings suggest the emergence of large-scale coherent neural assemblies which can influence local neuronal processes. They suggest that "some meditation states might not be best understood as top-down influences in a classical neuroanatomical sense but rather as dynamical global states that, in virtue of their dynamical equilibrium, can influence the processing of the brain from moment to moment'' (Lutz et al., 2008, p. 5). Indeed, in some versions of OM meditation practitioners drop any explicit effort to control the arising of thoughts or emotions to further stabilize their meditation. Moreover, practitioners with high expertise in FA meditation can sustain attentional focus on the intended object and regulate attention with a low effort. Lutz et al. also argue that: ''In this view, the brain goes through a succession of large-scale brain states, with each state becoming the source of top-down influences for the subsequent state. We predict that these large-scale integrative mechanisms participate in the regulatory influence of these meditation states'' (Lutz et al., 2008, p. 5).

The adaptive workspace hypothesis

The *adaptive workspace hypothesis* of the interdependent emergence of endogenous attention, access consciousness, phenomenal awareness, and metacognitive consciousness, in a NCC framework, is based on a set of interrelated explanatory and predictive aspects, as characterized in the following subsections.

Adaptive coding net

As considered earlier, firing of a large population of adaptive coding neurons in prefrontal cortex can be driven by different kinds of synaptic input sources which are widespread in the brain (Duncan, 2001; see also Duncan and Miller, 2002). We hypothesize that the *resonant* or recurrent involvement of such adaptive prefrontal neurons is necessary for any form of access-based consciousness to take place, either in terms of access (working memory related) consciousness of specific sensory and thought contents, or content-independent metacognitive consciousness. We refer to the neuronal population of prefrontal adaptive coding neurons as to the *adaptive coding net* (ACN).

We also hypothesize that at any time the number of *dynamic links* that ACN neurons can form is limited. This limitation would be the basis of the notion of limited cognitive resources for conscious access (e.g., Dehaene et al., 2003, 2006). Notice that here we are formulating the limited capacity of conscious access in terms of a neural binding or integration process, centered on the ACN. In biologically and cognitively plausible terms, we further hypothesize that the recurrent signal exchanges involving the ACN are reflected in an enhancement of both neural *co-activation* (neuronal firing rates) and *coherence* (enhanced spatiotemporal correlations in neuronal firing) neural patterns.

The ACN dynamic linking mechanism might involve *short-term plasticity* (von der Malsburg, 1981, 1999; Tononi et al., 1992) or a competitive opening and closing of neural transmission *gates* in hierarchical processing lines, as recently proposed in Bundesen et al's. (2005) Neural Theory of Visual Attention (NTVA). Another possible mechanism can be based on an oscillatory synchrony-based entrainment (Fries, 2005). However, the specification of the hypothesized ACN dynamic linking mechanisms demands further dedicated experimental and modeling investigations.

Consumer systems related to conscious access

In a neurocognitive ''working scenario,'' characterized by a task or performance setting with specified goals and context of stimulus-response mappings, the executive dynamic links of ACN neurons are plausibly established with the *consumer systems* (i.e., systems of explicit memory, perceptual categorization, reasoning, planning, evaluation of alternatives, decision making, voluntary direction of attention, and more generally, rational control of action) for access consciousness (Block, 2007). Such consumer systems are mediated by a large set of anterior and posterior associative (neo)cortical areas, and subcortical regions, such as the hippocampus and related structures in the medial temporal lobe.

In such a scenario, conscious access is oriented by *selective endogenous attention*, thus providing a ''working access bias'' toward response-relevant (target) stimuli and stimulus-response mappings. A number of ACN dynamic links (e.g., in dorsolateral prefrontal cortex, anterior prefrontal cortex, and anterior cingulate cortex), however, can be allocated to performance *monitoring*.

Metacognitive consciousness and adaptive workspace

We hypothesize that *metacognitive* or *reflexive* consciousness, as reflected in performance monitoring in a cognitive working or goal-based scenario, is mediated by intrinsic ACN dynamic links, i.e., dynamic links established within the population of adaptive coding neurons in PFC.

Therefore, at any given time the degree of metacognitive consciousness can be limited by the number of dynamic links between ACN neurons and consumer system neurons involved in a given task or performance. Note that this aspect of our hypothesis prevents a dual view ultimately leading to an infinite regress argument or homunculus assumption. Indeed, in our hypothesis the neural correlate of what we subjectively experience as an ongoing observation or conscious monitoring of our experience or cognitive performance, would be given by dynamic links within active ACN neurons. The same neurons and dynamic linking mechanism would be involved in a working memory related conscious access to given sensory or thought contents. Rehearsal and active control processes for maintenance in working memory would be activated via dynamic links of rehearsal-related neuronal populations with the ACN, in interaction with dynamic links established recurrently *within* the ACN populations. This aspect relates to the metacognitive (metamemory) character of implemented memory strategies and mnemotechnics (e.g., Sternberg, 2008).

More specifically, we hypothesize that neurons in anterior or rostral prefrontal cortex (Broadmann Area 10, or BA10), especially on the lateral surface, are implied in this reflexive awareness function. Indeed, area BA10 is a very large brain region in humans, is in relative terms twice as large in the human brain as in any of the great apes. Furthermore, this region is possibly the last to achieve myelination, and it has been observed that tardily myelinating areas are implied in complex functions highly related to the organism's experience (Fuster, 1997, p. 37). Such a region does not seem characterized by a primary involvement in standard executive and working memory tasks (Burgess et al., 2005), and has been associated to various aspects of metacognition (e.g., Christoff and Gabrieli, 2000). Moreover, activity or structural changes in Area BA10 have been associated to meditation states and traits (Cahn and Polich, 2006; Lazar et al., 2005).

Distributed endogenous attention and adaptive workspace

We further hypothesize that endogenous (top-down) attention, which is plausibly regarded as crucial for conscious access (e.g., Block, 2007; Dehaene et al., 2006), is generated by dynamic links established between the ACN and a set of prefrontal, parietal posterior, and thalamic nuclei involved in endogenous attentional orienting (Bundesen et al., 2005; Posner and Petersen, 1990). Indeed, it has been recently shown that endogenous attention is guided by prefrontal cortex, with a key role played by oscillatory synchrony in the beta oscillatory range (Buschman and Miller, 2007).

In the adaptive workspace framework, when conscious access demands a high amount of dynamic links with ACN neurons, the otherwise free endogenous attention resources are reduced. This reduction is shown in the inattentional blindness phenomenon, when a perceptually salient stimulus (even if presented within the fovea for a long duration) does not access visual awareness when subjects are engaged in intense mental activity such as in detecting certain stimuli or counting (Simons and Chabris, 1999).

As considered above, Dehaene et al. (2006) stress that top-down attention is necessary for access to consciousness. However, in their neuronal GW model it appears unclear from where this top-down attention derives. In our view, an unfortunate implication of this uncertainty might be a homunculus-like structure or process projecting a top-down attentional bias toward intended representations in perceptual maps. Our proposal here is that endogenous attention is potentially ongoing and open field, i.e., primarily *distributed* (see also Srinivasan et al., 2009, in this volume).

We also hypothesize that when a task is to be performed or some information needs to be accessed, the usually distributed endogenous attention becomes focused or selective (see Srinivasan et al., in this volume). Thus, a goal-based task-setting makes endogenous attention selective (Desimone and Duncan, 1995; Maia and Cleeremans, 2005). Such a task-based setting can be encoded within the ACN population itself (Duncan, 2001). On a trial-by-trial basis, this endogenous attention selectivity can be implemented by transient dynamic links between ACN neurons and fronto-parieto-thalamic neurons (e.g., in parietal posterior cortex and in the pulvinar) which have been shown to be involved in top-down attentional orienting (e.g., Bundesen et al., 2005; Buschman and Miller, 2007; Posner and Petersen, 1990). In such a goal-based selective or biased competition setting, the anterior cingulate cortex would play a crucial role in monitoring and controlling the maintenance of the selective attention (cognitive) focus against arising distractions (Cahn and Polich, 2006; Posner and Petersen, 1990). Conscious access processes based on endogenous attention selectivity can be mediated by dynamic links between ACN neurons and perceptual networks, via fronto-parieto-thalamic neurons (e.g., in parietal posterior cortex and in the pulvinar) involved in endogenous attention orienting. Indeed, a main assumption of the neuronal GW model (Dehaene et al., 2006; Gaillard et al., 2009; see above) is that information in a conscious percept must be *explicitly represented* by neuronal firing in perceptual networks.

The notion of distributed endogenous attention is however different from vigilance (Dehaene et al., 2006). Vigilance mainly refers to a global enabling condition mainly driven by ‘‘ascending’’ projections from mostly ‘‘aspecific’’ subcortical centers. In contrast, in our present hypothesis, endogenous attention is characterized in terms of synaptic signals ‘‘descending’’ by anatomical back-projections from the ACN and dynamically linked cortical areas (e.g., parietal posterior cortex). Our notion of nonselective endogenous attention is also different from an exogenous attention concept, as such a bottom-up form of attention is based on a rapid reactive (automatic) orienting process, likely to be driven by bottom-up neural signaling from posterior cortical areas (e.g., Buschman and Miller, 2007).

Here we endorse Burgess et al.'s (2005) *gateway hypothesis* of rostral prefrontal cortex (Area BA10) function. In the gateway hypothesis, the relative activation of lateral and medial regions of Area BA10 guides the switching of processing resources between stimulus-independent thought (SIT) and stimulus-oriented thought (SOT). Indeed, medial BA10 appears activated in conditions in which subjects attend stimuli in the external world, even when a ‘‘shallow’’ processing of them is required. Lateral BA10, by contrast, shows increased activation when the recollection or manipulation of the products of previous processing is required, and as related to expected targets, even when such targets are not presented (see Burgess et al., 2005). In our present adaptive workspace hypothesis, medial and lateral BA10, in terms of their direct interaction and larger interactions with a set of ACN neurons, would therefore play a key role in governing the ongoing open field or distributed neurodynamics of endogenous attention. When attention becomes selective in a goal-based setting, dynamic links for a sustained selective attention without (before) target appearance can be prominently mediated by lateral Area BA10, and dynamic links for a transient selective enhancement of stimulus-related neural activity by medial Area BA10.

In synthesis, dynamic links within medial and lateral ACN neurons would be differentially associated to two main forms of metacognitive or *second-order* awareness. This would depend on whether endogenous attention and conscious access broadcasting are distributed ‘‘externally’’ or ‘‘internally.’’ External metacognitive awareness involves the experience of external stimulus contents (e.g., ‘‘I am aware that I am experiencing the sight of a red cherry’’) and internal metacognitive awareness involves the experience of thought contents (e.g., ‘‘I am aware that I am recollecting an episode of my adolescence’’). A transcendent form of awareness, characterized as pure ‘‘being aware of being aware’’ (beyond an experiential first or second order ‘‘subject–object’’ awareness), which may be called *third-order*, *non-referential*, or *unified* consciousness, might be characterized by dynamic links and neural activity coherence across medial and lateral Area

BA10, modulated by a background of synaptic signals from ‘‘momentary self’’ or ‘‘I’’ related brain areas (see below).

Adaptive workspace dynamics of first, second, and third-order consciousness

In the adaptive workspace hypothesis each core *refers* to a unique integrated content as explicit in consciousness. As suggested by Baars (1998), however, a larger set of backstage or context neurons can support and modulate the current GW assembly (core). We hypothesize that the phenomenal awareness or the subjective aspect of experience related to a given perceptual object is implicit or contextual when the active core refers to the object features, in terms of explicit mapping to the object neural codes (e.g., in sensory maps). This explicit mapping would be mediated by dynamic links with ACN neurons. However, such implicit (subjective) context would emerge in ‘‘foreground’’ at the decay of the associated object core (assembly): the dynamic links between ACN and explicit object codes in sensory maps would be ‘‘released’’ (e.g., by phase scattering, see Varela et al., 2001), with a complementary enhancement of neural activation and coherence patterns involving neurons formerly in the ‘‘backstage,’’ thus resulting in first-person phenomenal awareness of subjective (‘‘I’’) states (see below). A new implicit context (backstage) could then be formed, which support a subsequent core integrating the perceptual object codes and their implicit (subjective-related) context of experience in the previous consciousness core, by neural broadcasting. Thus, in the second integrated core the subjective aspect of experience as bound to a given perceptual object can become itself an object of conscious access (see the text above about Shantideva and Wallace’s views). Alternatively, the second core could just refer to subjective states in backstage during the earlier core, without reference to an external perceptual object, and available for conscious access and possibly ‘‘introspective’’ examination.

This consciousness dynamics can be expressed in terms of global constraint satisfaction and recursive patterns, i.e., sequential (recursive) GW ignitions and transitions, and might plausibly involve multiple brain systems in parallel for broadcasting. Given the emphasis on reversible temporal formation and dissolution of large-scale resonant assemblies, in this view the consciousness-related system neurodynamics would be characterized by transience (metastability), as emphasized in Varela’s (1995) approach, rather than in terms of stable attractors (Maia and Cleeremans, 2005; Rumelhart et al., 1986).

In the adaptive workspace hypothesis, the core–context neural assembly transitions are hypothesized to depend on dynamic links with the ACN, linking either with explicit perceptual maps or with *implicit self* neural states. To clarify the last aspect, according to William James (1890) any discussion of the self needs to refer to the distinction between the self as object (the ‘‘Me’’ or explicit self) and the self as subject (the ‘‘I’’ or implicit self) of experience. James stated: ‘‘The consciousness of Self involves a stream of thought, each part of which as ‘I’ can remember those which went before, know the things they knew, and care paramountly for certain ones among them as ‘Me,’ and appropriate to these the rest.’’ Despite a number of controversial stances, James’ distinction between I and Me has been substantially maintained over the decades (see Northoff et al., 2006).

We therefore hypothesize that the awareness of subjective or phenomenal aspects of experience demand the establishment of dynamic links between ACN neurons and neuronal populations involved as neural markers of transient body states, in particular, right lateralized exteroceptive somatic and interoceptive insular cortices (Craig, 2004; Critchley et al., 2004; Damasio, 1999), in a transient neural broadcasting process. Given the transient character of the dynamic links between ACN neurons and somatic marker neurons, it can be assumed that interference on intrinsic ACN dynamic links is limited. By contrast, the consumer systems associated to conscious access broadcasting (see above) are likely to operate on the basis of more sustained reverberations associated to working memory, thus causing larger perturbations of intrinsic ACN patterns.

As remarked by Baars (1998), spatial neglect is often accompanied by anosognosia, a massive loss of awareness about one's body space, thus suggesting a uniform neural context for visuo-spatial awareness and body awareness. Differently, as seen above, brain areas implied in narrative or objective self representation would not participate in perceptual awareness (Goldberg et al., 2006). Finally, somatic marker or momentary self-awareness areas have also been implied in OM meditation (Farb et al., 2007; Lutz et al., 2008).

Our hypothesis is therefore consistent with Thompson and Varela's, (2001) *radical embodiment* view of the neurodynamics of consciousness. Thompson and Varela's approach aims to map the neural substrates of consciousness at the level of large-scale, emergent, and transient dynamical patterns of brain activity, and suggest that the processes crucial for consciousness cut across the *brain–body–world* divisions, rather than being brain-bound neural events. In the adaptive workspace hypothesis, the ongoing coupling between the ACN and body-related and momentary self-related neuronal populations enables the creation of a large set of possible transient resonant modes in the brain, embedded in a rich background of body and environmental states, thus increasing the neurodynamical complexity associated to conscious experience (Le Van Quyen, 2003; Tononi and Edelman, 1998). Based on the high degree of coding adaptivity and intrinsic as well extrinsic synaptic recurrency of its neuronal populations, the ACN would dynamically set the endogenous attention and metacognitive constraints necessary "to go beyond the stimulus given," in the brain–body–environment interplay.

The metacognitive consciousness capabilities related to the ACN would also potentially enable "going beyond the experience given." Indeed, intrinsic links within ACN neurons would mediate the metacognitive consciousness of being aware of either an object or a subjective experience of cognition of an object, where such an object is an external stimulus, an inner thought, or feeling state. In our view, this metacognitive consciousness would be "transversal" to any form of awareness based on the subject–object cognitive duality, whether it refers to an external or internal object per se (first-order consciousness), or to the subjective or phenomenal experience of such an object (second-order consciousness). As such, the intrinsic dynamic links within the ACN can be *non-referential*, and then be related to a third-order (metacognitive) consciousness, going beyond the cognitive subject–object duality, as the "awareness of being aware" (Arenander and Travis, 2004; Zeki, 2003). In our view, this transcendent awareness per se can only be developed as a meditation-based intuition, and can thus also be characterized as an *intuitive awareness* (Sumedho, 2004). This intrinsically unified consciousness would reflect itself as referential and context-dependent metacognition in the processes and neural operations underlying access and phenomenal consciousness. Indeed, in the adaptive workspace hypothesis intrinsic (established within the) ACN and extrinsic (established without the) ACN dynamic links are interacting at any time. We will characterize these interdependent consciousness dynamics with reference to OM and FA meditation in the next subsections, although such interdependent processes are regarded as potentially observable in a wide range of cognitive settings and experiential contexts.

Open monitoring meditation and adaptive workspace

In an OM meditation scenario, attention and monitoring functions are nonselective or open field, inclusive of external sensory fields as well as of internal thoughts and feelings. In light of what has been argued above about the primary nature of endogenous attention in the adaptive workspace model, OM meditation can be regarded as the context for the most direct and natural manifestation of distributed endogenous attention, unbounded to specific goal-related performance (task) settings.

In line with the adaptive coding model of prefrontal cortex function (Duncan, 2001; see also Maia and Cleeremans, 2005), endogenous attention, monitoring, and executive control functions may all be related to underlying ACN dynamics guiding the integration of brain-scale activity patterns. The notion of *mindfulness*, derived from Buddhist texts and always more emphasized in cognitive and clinical psychological contexts (e.g., Cahn and Polich, 2006; Kabat-Zinn, 2003; Sumedho, 2004), might provide a unifying construct for endogenous attention, monitoring, and executive control functions. Indeed, OM meditation is also referred to as *mindfulness meditation* (Cahn and Polich, 2006).

In the adaptive workspace hypothesis, it would therefore be implied that in OM meditation, ACN neurons can dynamically link with multiple brain maps in parallel, such that a large repertoire of ACN firing patterns is available at any time, in resonance with such distributed maps. Related to this aspect, it has been shown that *differentiation*, together with *integration*, is a crucial aspect of large-scale neural processes related to conscious experience, in terms of intrinsic *neural complexity* and in *matching* external stimuli (Tononi et al., 1994, 1996; Tononi and Edelman, 1998). It can therefore be hypothesized that the complexity of ACN resonance repertoires increases with the expertise of OM meditators, probably as a capacity to reflect or match changing patterns of body and environmental states and associated "cognitive" and "affective" responses in distributed brain maps, in ACN firing constellations. Moreover, the fact that endogenous attention more easily rests in an open and nonselective state, i.e., *receptive* state, in (expert) OM meditation practitioners (Cahn and Polich, 2006), can be regarded as in line with a primary nonselective and open field characterization of top-down attention in the adaptive workspace hypothesis.

Specifically, we hypothesize that OM and the related conscious experience reflect the rapid formation and decay of dynamic cores which are assembled via dynamic links with ACN neurons. Metacognitive consciousness would be maintained or enhanced by signal exchanges within the ACN, *induced* by incoming signals from the widespread outer and inner content-related maps. As the goal-related consumer systems (see above) are de-emphasized in meditation, it can be hypothesized that a larger subset of intrinsic dynamic links are available both within the ACN and between the ACN and sensory maps, thus resulting in enhanced metacognitive consciousness as well as phenomenal and a more immediate access awareness of sensory contents. Moreover, any distraction in terms of entrainment in thinking during OM meditation would perturb activity coherence in the ACN, as correlated to distraction awareness and disengagement of ACN (e.g., neurons in medial and lateral BA10) from the distracting process. This monitoring process would be enhanced and more effortless in expert meditators. We will consider this aspect in more depth also with reference to FA meditation in the next subsection.

Related to the findings of Lutz et al. (2004), transient oscillatory coherence in the gamma band might play a crucial role in reversible binding and unbinding of dynamic cores (or proto-cores, see the next subsection) in OM meditation (see also Lutz et al., 2008). A more efficient binding (dynamic linking) and unbinding of neural assemblies encoding for serially presented targets with ACN neurons might explain the reduced AB observed by Slagter et al. (2007).

Focused attention meditation and adaptive workspace

As in OM meditation, goal-based consumer systems for conscious access are likely to be de-emphasized in FA meditation. Given that in FA meditation endogenous attention is focused on a chosen object in a sustained fashion, in our adaptive workspace framework it is hypothesized that driven by the task-setting encoded in the ACN itself, a relatively large subset of ACN neurons are dynamically linked with neurons explicitly encoding for the intended object by long-distance recurrent connectivity. Lateral Area BA10 might plausibly be involved in encoding the FA meditation task-setting and the intentional object-related bias, and medial Area BA10 in the sustained selective conscious access involving the sensory maps for the intended object.

According to our hypothesis, in FA meditation, a relative stability would characterize dynamic core (GW assembly) transitions, possibly in terms of overlapping neurons and ACN dynamic links recruited in subsequent cores and associated contexts (backstage neurons), as related to attentional stability (Wallace, 1999; see above).

Attentional vividness (acuity) could be mediated by the number of ACN neurons and dynamic links recruited in each core, as bound to the neural maps for the intended object.

The monitoring skills of noticing distractions, disengaging from distraction sources, and redirecting attention to the chosen object, would be mediated by dynamic links mostly involving the anterior cingulate cortex in novice practitioners, as related to effortful control, and a more automatic ACN coherence perturbation-based process in expert FA meditation practitioners. It can also be hypothesized that in expert FA meditators, transitions between subsequent dynamic cores are more rapid, with a relative integration between such cores, thus resulting in a reduced occurrence probability of distractions, whereas the anterior cingulate cortex activation would be needed to control transitions between dynamic cores in novices. The slow oscillations observed in the theta and alpha bands during FA meditation (Cahn and Polich, 2006) might then modulate transitions between dynamic cores. In particular, the power of the frontal midline theta, associated to anterior cingulate cortex activation, might correlate with the degree of effort during FA meditation.

During FA meditation, even if the endogenous attention focus is sustained on a chosen object, other events arising in sensory and thought-(feeling) related fields are typically noticed in ''background'' (Cahn and Polich, 2006; Lutz et al., 2008). In our adaptive workspace framework this can be explained in terms of *proto-cores*, i.e., transient resonant assemblies in the brain which may coexist with a dynamic core or GW assembly for ''foreground'' conscious access. A similar mechanism has been suggested by Block (2007) for phenomenal consciousness, in terms of loosing neuronal coalitions in posterior associative (e.g., parietal posterior) cortex, maintained in parallel with a winner-take-all GW coalition for access consciousness.

In adaptive workspace terms, such phenomenal consciousness proto-cores would be created as transient perturbations of ongoing ACN-linked activation and coherence patterns. The transience would be emphasized by the ''switched-off'' state of the consumer systems, and by endogenous attention and conscious access being oriented toward the intended meditation object by reentrant signaling between ACN neurons, selectively accessed sensory maps, and endogenous attention orienting neurons. A mechanism based on proto-cores might also be involved in OM meditation, as related to an open ''background'' awareness of rapidly changing experience contents (Lutz et al., 2008). Joint FA and OM meditation expertise, as in the practice of the Buddhist *insight meditation* integrating *Samatha* (FA) and *Vipassana* (OM) practice aspects, could then be reflected in an enhanced allocation of neural activity patterns (ACN dynamic links) to metacognitive consciousness (by intrinsic ACN signal exchanges), with a joint reduction of neural signaling (long-range signal exchanges with object-related maps) related to endogenous attention. A transition from phenomenal consciousness proto-cores to access consciousness cores would however be possible at any time, by endogenous attention driving an extended brain broadcasting process, as related to a complementary introspective or investigative stance in the (insight) meditation. Cognitive control processes (e.g., by inner speech or imagery) can be used to reiterate broadcasting in such a sustained conscious access (Baars, 1998).

Finally, as seen above ''pure consciousness'' (or third-order consciousness in our terminology) experiences during TM meditation are associated to global EEG patterns in the alpha band, which are characterized by a high coherence across frontal leads (see Arenander and Travis, 2004). In an adaptive workspace framework, such a frontal coherence can be related to an intrinsic ACN coherence, i.e., to the brain process that we have associated to the ongoing ''awareness of being aware'' in the present moment. The observed slow rhythm coherence might be supported by recurrent interactions between the ACN and aspecific thalamic nuclei (such as the intralaminar thalamic nucleus) with widespread cortical projections, possibly in terms of broadcasting of frequency and phase of a selected or emerging rhythm (Fries, 2005; VanRullen and Koch, 2003; Varela et al., 2001). The last idea would nicely fit with the earlier Luria's (1980) integrated working brain model, with reference to interactions between a first subcortical functional unit and a third prefrontal functional unit.

Conclusions and perspectives

The adaptive workspace hypothesis proposed in this paper emphasizes the role of neuronal populations with adaptive coding properties in prefrontal cortex for the emergence of consciousness. The adaptive coding model of prefrontal cortex function (Duncan, 2001; see also Duncan and Miller, 2002), however, needs adequate specification and more supporting evidence. We have also drawn ideas from the gateway hypothesis of anterior prefrontal cortex function (Burgess et al., 2005). A precise functional characterization of such a region, however, is still lacking. On the other hand, given the still relatively unspecified roles of adaptive prefrontal coding and of medial and lateral areas of anterior prefrontal cortex, the primary involvement of prefrontal cortex and its top-down connections in conscious access seems quite well established (Block, 2007; Dehaene et al., 2006).

It also remains to be seen how brain areas involved in momentary self-awareness (Damasio, 1999; Farb et al., 2007) interact with anterior prefrontal cortex and other areas showing adaptive coding responses. Moreover, in light of our adaptive workspace hypothesis it appears interesting to conduct a variant of Goldberg et al's. (2006) fMRI paradigm. In such a variant brain activations in a demanding visual categorization task and a momentary self-awareness (rather than narrative self-awareness) task condition (see Farb et al., 2007), are contrasted. Possibly, a group of OM meditators and a group of control subjects can be involved, to shed light on the role of interoceptive and exteroceptive brain areas in visual awareness.

The neural correlates of different aspects of phenomenal, access, and metacognitive consciousness as characterized in the adaptive workspace hypothesis might be evidenced in the context of FA and especially OM meditation settings. To this aim, the *neurophenomenology approach* (Lutz and Thompson, 2003; Varela, 1996) can be endorsed, with the participation of highly trained meditators capable of switching between different consciousness modes, and to direct attention to sensory or ''internal'' fields of experience. In the neurophenomenology approach quantitative measures of neural activity are combined with first-person data about the subject's inner experience. Participants' reports can thus be useful in identifying variability in brain activity from moment-to-moment; this unique information might guide the detection and interpretation of neural processes correlated to different aspects of conscious experience. Finally, large-scale computational models with biological and cognitive constraints (see Dehaene et al., 2003; Tononi et al., 1992) would also contribute to shed light on the neural mechanisms implied by the adaptive workspace hypothesis.

Acknowledgment

We would like to thank Dr. Gianluca Baldassarre and Prof. Gezinus Wolters for their very useful comments and suggestions.

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