

# The function of the cerebellum in cognition, affect and consciousness

## Empirical support for the embodied mind

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*Editors' note:* These four interrelated discussions of the role of the cerebellum in coordinating emotional and higher cognitive functions developed out of a workshop presented by the four authors for the 2000 Conference of the Cognitive Science Society at the University of Pennsylvania. The four interrelated discussions explore the implications of the recent explosion of cerebellum research suggesting an expanded cerebellar role in higher cognitive functions as well as in the coordination of emotional functions with learning, logical thinking, perceptual consciousness, and action planning

**Keywords:** cerebellum, emotion, action, dysmetria of thought, embodied mind, cerebellar vermis, schizophrenia, autism, consciousness

### Introduction

(Natika Newton)

A growing movement in cognitive science views consciousness and cognition as self-organizing systems involving emotion and sensory-motor agency (e.g. Damasio, 1994, 1999; Clark, 1996; Glenberg, 1997; Hurley, 1998). The view that cognition is best understood as embodied is replacing models involving amodal symbol systems like the arbitrary, intrinsically meaningless symbols of computer programs, which notoriously fail to explain common-sense reasoning and consciousness. The embodied-cognition approach sees such behavior as

extensions of the animal's value-laden interaction with its environment.

How can abstract reasoning (e.g., logic and mathematics) make use of bodily action abilities? Many theorists argue that sensorimotor imagery, conscious or semiconscious activated memory traces of the experiences of performing basic actions, functions not only in action contemplation and planning but also in the mental manipulation of objects in abstract reasoning. Abstract thought builds on basic action schemas: bodies interacting with objects in space (e.g., Huttenlocher, 1968; Newton, 1996).

Fortunately, this issue is now fully testable. To those claiming to lack such imagery, it can be argued that such images are not necessarily fully conscious, and brain imaging studies are now available that can decide such matters. But it is important to be clear on what is meant by the term "image." There is an entrenched tendency to think of all images as visual. But while that is the traditional meaning of "image," there is a very good reason to expand the term to include representations of all sensory, motor, proprioceptive and affective states, not just visual ones. The mechanisms of visual imagery, which include many areas also involved in visual perception, are completely analogous to those involved in reactivated experience in other modalities. Motor images, for example, appear to involve activity in the motor cortex identical to that present in actual motor behavior (Jeannerod, 1997). In short, we can imagine anything we can experience, it appears, and imagining hearing, touching, tasting, feeling emotion, or performing specific motor actions, is entertaining images of those activities.

If it is indeed possible for us to form images in any modality, then many if not all of the traditional objections to an imagistic view of cognition collapse. Pylyshyn, for example, argued that mental representation is propositional, not imagistic, because we can represent relations that cannot be captured pictorially:

... while two visual images of a chessboard may be pictorially identical, the mental representation of one might contain the relation between two chess pieces which could be described by the phrase 'being attacked by' while the representation underlying the second image might not.... For this reason, it would be reasonable to expect that the mental representation of a configuration of pieces on a chessboard would be much richer and highly structured for a chess master than for an inexperienced chess player (Pylyshyn, 1973, p. 11).

Pylyshyn is arguing that the relation is not part of the image, since that is available to both the master and the novice, but is contained in information represented in propositional form, available only to the master.

But if we expand the notion of "image" to encompass experiences in all

modalities, including motor, proprioceptive, and emotional, then we can easily form an image of two chess pieces in the “attack” relation. One way we can do this is to evoke sensorimotor imagery of the possible moves of the two pieces, combined with affective imagery of hypothetical “emotional states” of the two pieces: aggression in the one, fear or defensiveness in the other. This description may sound farfetched, but in fact is perfectly consistent with the language used by Pylyshyn to describe the relation: “being attacked by” is a relation inherently associated with affect. To be attacked is to be in danger; to be in danger is bad. Chess is an abstract game, but unless abstractions are grounded in concrete states that we can understand from our own experience, they cannot be meaningful and hence useful to us.

These concrete states are representations of action, but always of action in a situational context that is wider than simply the motor movements of the body. Actions require motivation. Even subtle actions such as covert attention shifts depend on emotional interests of the organism; subcortical structures such as the amygdala, hippocampus and hypothalamus influence voluntary attention mechanisms in the anterior cingulate. Actions imagined but not performed are both activated and inhibited in the frontal lobes and motor cortex; inhibition, controlled in large part by the hypothalamus, allows action images to be consciously experienced (Jeannerod, 1997) along with the emotional values associated with the actions as well as aspects of the material world upon which the action depends.

The theory of cognition as based in sensorimotor imagery — cognition as embodied — cannot be fully defended here. Recent proponents include Clark (1997); Damasio (1994); Glenberg (1997); Lakoff (1987); Newton (1996); Sheets-Johnstone (1990); Thelen and Smith (1994); Varela et al. (1993). (Not all of the preceding agree that discrete mental representations play a distinctive role in cognition, but all do agree that cognition emerges from bodily activity; for discussion see Newton, 2001).

The combination of the above approach with recent work on emotion is powerful, allowing the formation of a global theory of brain function in which dynamic interactions among brain areas and brain events can be mapped at many levels of organization. An important prediction of the approach is that brain mechanisms once thought devoted to motor activity are also active in emotional and cognitive activities. Our example is the cerebellum. As we shall see, it appears that the cerebellum is not only a coordinator of motor actions, but also of reasoning and, most recently discovered, of emotional with cognitive states. If reasoning and other cognitive activities make use of motor schemas,

this is exactly what one would expect. The cerebellum appears to be not just an organ for the coordination of actual motor activities, but also for coordinating the output of both cortical and subcortical structures involved in affect-laden cognitive activity at all levels.

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## **Dysmetria of thought: The role of the cerebellum in cognition and emotion** (Jeremy D. Schmahmann)

The traditional teaching in clinical neurology and in neuroscience has been that the cerebellum is crucial for motor control. The role of the cerebellum, we have understood, is confined to the coordination of gait and posture, speech, and extremity and eye movements (Adams and Victor, 1993). The term dysmetria refers to the disordered or chaotic movements resulting from cerebellar lesions, and it has been used to describe the incoordination and staggering gait of cerebellar patients. It appears, however, that this motor control theory of cerebellar function is only part of the story. Mounting evidence from clinical, anatomical, physiological, and functional imaging data suggests that the cerebellum is an essential component of the distributed neural circuitry subserving not only sensorimotor performance, but also cognition and emotion, and that the cerebellum is important for modulating all aspects of neurological function (see Schmahmann, 1997).

Anatomical and physiological studies that demonstrate pathways linking the cerebellum with brain regions necessary for complex behaviors are of great interest in this analysis. Cerebellar influences upon levels of alertness (Manzoni et al., 1968) and electroencephalographic patterns (Moruzzi and Magoun, 1949) have been supported by studies showing cerebellar connections with the reticular system known to be important for arousal (Andrezik et al., 1984; Noda et al., 1990). The cerebellum has connections with the hypothalamus that is involved in autonomic function (Haines et al., 1997); with the limbic system that subserves the experience and expression of emotion (Heath et al., 1974); and with neocortical association areas and paralimbic regions in prefrontal, cingulate, parietal and temporal lobes that are critical for higher order functions including the cognitive dimensions of affect (see Schmahmann, 1996a; Schmahmann and Pandya, 1997). The anatomic connections from the association areas of the cerebral cortex to the relay nucleus to cerebellum situated in the brainstem (the basilar pons) are precisely organized. Furthermore, these cortico-pontine projections are not overshadowed by the efferents from the motor related cerebral areas. Projections from the pons to the cerebellum are also discretely arranged, such that the cerebellar posterior lobes in particular, receive information from parts of the pons that are invested with associative information derived from the cerebral cortices (Brodal, 1979; Schmahmann, 1996a). The cerebrocerebellar circuit is completed when the cerebellar nuclei send information by way of the thalamus back to the cerebral cortex. Like the

feedforward loop of this system, the feedback system is also topographically organized. The dorsal part of the cerebellar dentate nucleus sends its outflow to the motor cortex, whereas the ventral parts of the dentate are linked with the prefrontal cortices (Middleton and Strick, 1994). The cerebellar outflow is directed back to the other association areas as well, but the topography of this projection pattern within the cerebellar nuclei has yet to be established. The existence of highly organized anatomic subsystems within the cerebrocerebellar communication supports the notion that there are functional subunits within this linkage, and that the incorporation of the cerebellum into the associative and paralimbic circuits is the anatomic underpinning of the cerebellar contribution to cognition and emotion (Schmahmann, 1991, 1996a).

Anecdotal clinical reports in the latter part of the eighteenth and throughout the early and middle nineteenth centuries described behavioral changes in patients with degenerative or congenital abnormalities of the cerebellum (see Schmahmann, 1991). These were complemented by experiments in monkeys (Berman et al., 1978) and cats (Moruzzi, 1947; Reis et al., 1973) showing cerebellar influences upon complex behaviors including grooming and aggression. The anatomical investigations bolstered the conclusion that the cerebellum was involved in higher order behavior (Snider, 1950; Dow, 1974; Heath, 1977), but the demonstration of a clinically significant contribution of the cerebellum to intellectual functioning and to mood, personality, and self awareness has only recently become available.

Behavioral changes in adults with focal cerebellar lesions, manifesting a *cerebellar cognitive affective syndrome* (CCAS) have provided clinical support for the relationship between the cerebellum and cognition (Schmahmann and Sherman, 1998). The CCAS is characterized by impairments in executive functions such as planning, set-shifting, verbal fluency, abstract reasoning, and working memory; difficulties with spatial cognition including visual-spatial organization and memory; language deficits including agrammatism and dysprosodia; and personality change with blunting of affect or disinhibited and inappropriate behavior. These behavioral changes are clinically prominent in patients with lesions involving the posterior lobe of the cerebellum and the vermis, and in some instances are the most noticeable aspects of the presentation. Lesions of the anterior lobe of the cerebellum produce only minor changes in executive and visual-spatial functions. The cerebellar vermis has been noted in particular to be implicated in the modulation of aggression and mood, as described in the original report of the CCAS, as well as in subsequent studies in adults (Malm et al., 1998 Neau et al., 2000) and children (Levisohn et al., 2000;

Riva and Giorgi et al, 2000). A posterior fossa syndrome consisting of mutism and regressive, disinhibited behavior has been reported in children following neurosurgical manipulation or incision through the vermis (see Pollack et al., 1995; Levisohn et al., 2000). These clinically relevant impairments of executive, spatial, and linguistic functions, as well as mood and personality alterations following focal or diffuse cerebellar lesions are supplemented by a growing awareness of clinically important psychiatric disturbances in patients with cerebellar disease. These include depression, paranoia, delusions, autistic and obsessive behaviors that require specific targeted intervention (Schmahmann and Sherman, 1998; Riva and Giorgi, 2000; Leroi et al, 2001). The realization that cerebellar pathology is associated with clinical features considered to fall within the psychiatric domain has brought new clarity to the long appreciated finding of cerebellar anatomic anomalies in schizophrenia including small vermis and large fourth ventricle (see Taylor, 1991; Loeber et al., 2001), and in patients in whom psychosis may be the presenting manifestation of midline cerebellar pathology such as cysts, tumors and abscesses (Heath et al., 1979).

The observations indicating a role for the cerebellum in complex nonmotor behavior have been enhanced by the finding of cerebellar activation in a number of functional neuroimaging experiments. These studies over the past decade have revealed cerebellar involvement in sensory perception, motor and nonmotor learning, mental imagery, conditional associative learning, language functions such as verb-for-noun generation and word-stem completion, working memory, hypothesis generation, attentional modulation, the experience of different mood states, and the appreciation of pain, hunger, and thirst, among others (e.g. Desmond et al., 1997; Parsons et al., 1997; see Schmahmann, 1997, 2000a,b). Moreover, meta-analysis of the locations within cerebellum of the activations in these different studies suggests that the cerebellum, like the cerebral hemispheres, is functionally organized into distinct regions (Schmahmann et al., 1998; Schmahmann, 2000a,b). The somatosensory homunculus and motor functions are represented in the “motor cerebellum” in the anterior lobe (lobules IV and V in particular) with a secondary representation in lobules VIII and IX in the medial part of the posterior lobes. Cognitive operations are represented in the “cognitive cerebellum” in the more recently evolved (Leiner et al., 1986) lateral hemispheres of the posterior lobes (the neocerebellum in lobules VI and VII and their hemispheric extensions into crus I, crus II and lobule VIIB). Emotion is particularly influenced by the midline, or vermis, region, suggesting that the phylogenetically older fastigial nucleus, vermis and flocculonodular lobe constitute the “limbic cerebellum” (Schmahmann, 2000b).

How does the cerebellum influence the neural systems that subserve higher order function, and what is its fundamental role in the cognitive operations that underlie complex behaviors? In our *dysmetria of thought hypothesis* (Schmahmann, 1991, 1996a,b, 1998) we proposed that the cerebellum serves to maintain behaviors around a homeostatic baseline. The cerebellum has an essentially uniform cortical architecture consisting of repeating units of corticonuclear microcomplexes (Ito, 1993) that represent the interaction between cortical neuronal circuits and the deep cerebellar nuclei. In contrast, the connections that link the cerebellum with the cerebral hemispheres consist of discretely organized anatomic subsystems that serve as the substrates for differentially organized functional subunits (Schmahmann, 1996a). This arrangement, of uniform architecture acting upon anatomically and functionally diverse streams of information allows the cerebellum (i) to perform a constant modulation of the neural information to which it has access, and (ii) to do this in a topographically precise manner. Thus, the homogeneity of cerebellar cortical architecture permits the cerebellum to perform a unique function, the universal cerebellar transform (UCT), that is applied to the multiple, anatomically precise, diverse streams of information to which it has access (Schmahmann, 2000b). The “black box” of the cerebellum is thus unbundled, and the functional topography within cerebellum, conferred by the anatomically precise connections, allows the cerebellum to maintain behaviors around a homeostatic baseline in the realms of motor, cognitive, and affective/autonomic behaviors. In the same way, then, that the cerebellum regulates the rate, force, rhythm, and accuracy of movements, so can it regulate the speed, capacity, consistency, and appropriateness of cognitive and emotional processes. The UCT allows the cerebellum to detect (Ito, 1993), prevent, and correct mismatches between intended outcome, and the perceived outcome, of interaction with the environment. It facilitates actions that are harmonious with the goal, appropriate to context, and judged accurately and reliably according to the strategies mapped prior to and during the behavior (Schmahmann, 1991, 1996a).

If the modulation of information by the cerebellum is unique and constant (i.e. the UCT), then the necessary corollary is that the impact of cerebellar lesions should also be constant. The dysmetria of thought hypothesis, therefore, holds that lesions of the cerebellum, or those that disrupt the neural circuitry linking cerebellum with the cerebral hemispheres, prevent the cerebellar modulation of functions subserved by the affected subsystems in a predictable manner. This universal cerebellar impairment (UCI), the hypothesis states, is dysmetria (Schmahmann, 1991, 2000b). The UCI has different clinical

manifestations, depending on the location of the lesion in the cerebellum. The UCI in the motor domain includes dysmetria of extremity or eye movements, dysarthric speech, ataxia of gait, or difficulty with equilibrium and posture. Dysmetria of movement is matched, in the cognitive realm, by an unpredictability and illogic to social and societal interaction. The overshoot and inability in the motor system to check parameters of movement is equated with a mismatch between reality and perceived reality, and erratic attempts to correct errors of thought or behavior. The UCI in the realm of higher order behavior, or dysmetria of thought, is the proposed fundamental mechanism underlying disorders of intellect and emotion resulting from cerebellar dysfunction. The clinical manifestations of dysmetria of thought include the different features that together constitute the cerebellar cognitive affective syndrome.

These notions of the role of the cerebellum in cognition and emotion may provide useful insights into the evaluation of the possible contribution of cerebellum to conscious experience and unconscious motivation.

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## The integrative role of the cerebellar vermis in cognition and emotion (Carl M. Anderson)

*“The winds of heaven mix forever with a sweet emotion.<sup>1</sup>”*

– Shelley

*“Spirit borrows from matter the perceptions on which it feeds, and restores them to matter in the form of movements which it has stamped with its own freedom.<sup>2</sup>”*

– Henri Bergson

Bergson renders in *Matter & Memory*, through an exploration of the *common sense*<sup>3</sup> nature of memory, the neural and metaphysical processes by which thought is integrated into action and movement. Linkage of common sense or *sensus communis*<sup>4</sup> with the cerebellar vermis, by way of the pineal gland, and Descartes’s “*le bon sens*”, is clearly and wonderfully described by Lokhorst (2001, pp. 6–18). Descartes proposed the pineal as the seat of the *sensus communis*, because of his desire to connect the soul with a single point in the body “because our soul is not double but simple and indivisible....For as to the cerebellum...[and] even its vermiform appendage, which resembles a simple body to the greatest extent, is divisible into two halves.” Descartes was perhaps ignorant of Costa ben Luca’s view of the central role of the cerebellar vermis in thinking and recollection<sup>5</sup>; therefore the concept of the cerebellum as the meeting place of the five senses has only emerged again through the work of modern neuroscience.

However, the first comprehensive anatomical descriptions of the human cerebellum, many of them still in use today, can be found in the 16th century works of Malacarne (1776). Malacarne, likely one of the first cognitive neuroscientists, correlated intelligence with the total number of cerebellar folia possessed by individuals (he counted upwards of 500 to 780 surface folia or “laminettes”), after observing the large difference in the number of folia between the brains of those with normal intelligence and the brain of an idiot (Larsell, 1967, pp. 3–7). A cerebellum, whether it is only a few folds or the enormous mass of the electric mormyrid fish, is a structure central to the design of all vertebrate brains. The form of the cerebellum may vary considerably within and between vertebrate classes, from a simple ridge in agnathans, the so-called jawless fish such as the hagfish or the parasitic lamprey, to the highly

complex cerebelli of birds which have many similarities to those of mammals. Current theories of cerebellar function are based on the premise that while the cerebellum is essential for an animal's smoothly coordinated and accurate movement, it does not generate or modify signals that control movement (Paulin, 1997, pp. 515–533). Recent re-analysis by Clark (2001, pp. 189–193) of mammalian brain morphometric data show that the size of the cerebellum changes proportionally with overall brain size, and not simply with the volume of neocortex. This work strongly suggests that the cerebellum provides a heretofore-unrealized general function to the entire mammalian brain, but it also undergoes evolutionary elaborations for special sensory rather than motor systems. Paulin (1993, pp. 39–50) points out that cerebellar size and complexity in mammals are most strongly associated with the sensory tracking of one's movements and of the movements of objects in the environment. For example, the midline vermal lobules VI–VIII of the cerebellum of echolocating carnivorous bats (the insect-eating microchiropteran) or toothed cetaceans (whales and dolphins) are enlarged in comparison with those of the non-echolocating fruit-eating bats (megachiropteran) or baleen (filter feeding) whales (Paulin, 1997, pp. 515–533). Cells in lobule VII of the vermis of bats and cats are activated by sound source trajectories and lobules VI and VIII may integrate this information with eye and head proprioceptive and motivational state. In summary, Paulin (1997, pp. 515–533) proposes that central brain function provided by the cerebellum is one of dynamic state estimation (enabling the control, perception and imagination of dynamical systems in motion). I propose, based on the following discussion of the midline vermis, that a general function provided by the cerebellum to human consciousness is cognitive/emotional synergy (facilitating the control, perception and imagination of emotional states in one's self and others).

The cerebellar vermis and its primary output nucleus, the fastigial nucleus, will be treated as the “the cerebellar vermis-fastigial nucleus” (VFN) complex for the purposes of this discussion. The fastigial nucleus is phylogenetically one of the oldest of the cerebellar nuclei and has been shown to influence eye movements, posture, equilibrium and autonomic activity (Beitz, 1982, pp. 233–249). Ontogenetically the fastigial nucleus precedes the other cerebellar nuclei and in the three-month-old human fetus is the first to be well defined and have differentiated cells (Larsell et al., 1972, pp. 65–68). Purkinje cells in the ten lobules of the mammalian cerebellar vermis primarily project circumferentially to the oval fastigial nucleus as if each lobule were a number and the nucleus a clock face (Haines et al., 1982, pp. 320–371). In the five- to six-

month-old human fetus, following the developmental lead of the fastigial nucleus, the myelination of the cortex and fiber tracks of the vermis is only preceded by the evolutionarily older vestibular nuclei (Larsell et al., 1972, pp. 137–142) and PET imaging studies of newborn human infants have indicated the activity of the VFN is greatly enhanced in accordance with its key role in breathing and behavioral state (Chugani, 1998, pp. 184–188; Chugani et al., 1987, pp. 487–497; Harper, 2000, pp. 140–142; Harper et al. 2000, pp. 125–131; Parsons et al. 2001, pp. 2041–2046). The new role for this precocious VFN complex in adult cognitive/emotional synergy is supported by imaging studies and by observations of its focal and myriad interconnections among key brainstem nuclei and bi-hemispheric networks of motor and limbic system structures.

Over the past three decades, and especially in the past five years, neural imaging, clinical and preclinical studies have consistently expanded the role of the cerebellum in cognitive, emotional and motor domains (Schmahmann, 2000a, pp. 189–214; 2000b, pp. 207–259). Recent reports indicate that the neocerebellar hemispheres, the lateral extensions of the VFN, are activated during the formation of mental imagery, tactile learning and language and sensory-processing (Imamizu et al. 2001, pp. 192–195). Although, motoric aspects of articulation, balance and bimanual coordination seem to involve the more medial areas of the cerebellum or VFN, this region is also nonspecifically activated during many of the same functional imaging studies of neocerebellar activation. It is this apparent lack of specificity, along with its early ontogeny that provides clues to the deep-seated role of the VFN in consciousness. In the following, a brief overview of past and current research findings implicating the VFN in the neurodevelopment of psychopathology is presented. Next, the possible role of VFN influences on chaotic synchronization within pontine cerebro-cerebellar loops during cognitive/emotional synergy will be described, as well as the place of the VFN within the theoretical context of vertically convergent fractal time processes during fetal REM sleep and the self-organized ontogeny of consciousness.

*Homo Erectus*, more than any other mammal, relied heavily on the VFN for integrating visual, vestibular and proprioceptive cues during upright locomotion. Bipedal standing, especially the toe to heel stance of the sobriety test, studied with PET imaging, robustly activates the anterior and posterior vermal regions (Ouchi et al., 1999, pp. 329–338). Indeed, the unique ability of humans to laugh and create spoken language could hinge on our flexibility, associated with the development of bipedalism, to consciously control breathig,

by way of the VFN, during rest and locomotion (Harper, 2000, pp. 140–142; Harper et al. 2000, pp. 125–131; Parsons et al. 2001, pp. 2041–2046). However, chronic alcoholism, which is associated with destruction of the vermal cortex (Sullivan et al., 2000, pp. 341–352), is characterized by an out-of-balance staggering gait ataxia, resulting from inflexible coordination of visual, vestibular and proprioceptive feedback. So, as the VFN forms a bridge between the two cerebellar hemispheres, pathology of the VFN appears to connect many apparently unconnected psychiatric disorders.

As Freud proposed in his seminal work, “The Etiology of Hysteria,” childhood trauma underlies many psychiatric disorders; it now appears to result also in pervasive damage to the cerebellum. Like the cortex, corpus callosum, and hippocampus, the cerebellum has a protracted postnatal ontogeny, and is markedly affected by early exposure to corticosteroids (Altman, 1987 pp. 153–168; Lauder, 1983, pp.121–155). In addition, the cerebellar vermis appears to play a role in the development of epilepsy or limbic seizures (Heath, 1976, pp. 1037–1051; Cooper et al., 1974, pp. 347–390; 1985, pp. 811–813; Lawson et al., 2000, pp. 1456–1462; Strain et al., 1979, pp. 651–654; Riklan et al., 1976, pp. 282–290). An association between the VFN and limbic seizures was first observed in electrical recordings from the hippocampus and fastigial nucleus of the violently aggressive adult Harlow monkeys (Heath, 1972, pp.157–163). Aggressive behavior in these animals resulted from total deprivation of maternal contact during early life (Harlow, 1971, pp. 368–375; Prescott, 1980, pp. 286–296). Bremer (1997, pp 111–119; Kling et al., 1979, pp. 18–28) subsequently found that lesions of the vermis, but not the cerebellar hemispheres, tamed their aggression, suggesting that deprivation had disordered the ornate networks of granule cells in the vermal cortex. Heath used these observations as a basis for his use of electrical stimulation of the vermis (which inhibits the cortex and disinhibits the output nucleus) to relieve psychotic symptoms in human patients with many successes (Heath, 1980; ). Interestingly, research by Mason (Mason and Berkson, 1975, pp. 197–211) has shown that vestibular stimulation, in the form of rocking during early life (which stimulates the VFN [Clark et al., 1977, 1228–1229; Buttner-Ennever, 1999, pp. 51–61]) markedly attenuates the adverse effects of rearing primates without maternal contact. As with maternal neglect, sexual or physical child abuse has also been associated with dissociation, increased prevalence of abnormal EEG’s (Ito et al., 1998, pp 298–307), and development of symptoms suggestive of limbic seizures (Teicher et al., 1993, pp. 301–306). Many researchers believe that child abuse causes a limbic “kindling” that produces epilepsy in experimental animals. Electrical stimulation of the

limbic system, which evokes neural discharge in experimental animals, can, if repeated frequently, lead to seizures. Similarly, the repeated trauma of verbal or sexual abuse may result in limbic electrical abnormalities in humans associated with epileptic-like behavioral experiences (Teicher, 2000, pp. 50–67). The cerebellar vermis appears to play a role in the control of epilepsy as clinical studies in humans have found that electrical stimulation of the VFN suppresses the spread of epileptic seizures (Heath, 1977, pp. 300–317; Cooper and Upton, 1985, pp. 811–813).

We used fMRI to assess the relationship between symptoms of limbic kindling, and blood volume in the cerebellar vermis of young adults with a history of childhood sexual abuse or intense verbal abuse (Anderson et al., 2001b, in press). After completing an extensive questionnaire covering childhood experiences, family history and psychological characteristics, subjects were further screened by a clinician for a history of psychiatric illness, physical injury or trauma. The limbic system checklist-33 (LSCL-33), a self-report questionnaire developed to evaluate how frequently abused subjects experience 33 symptoms of temporal lobe epilepsy, was also part of the questionnaire (Teicher et al., 1993, pp. 301–306). A typical LSCL-33 question is: “How often have you experienced the sudden, abrupt and unexplained onset of the sensation of something crawling under your skin or a rising or sinking feeling in your stomach — like being in an elevator?” Previous studies by our group have shown that adults abused prior to age 18 frequently self-report these experiences. Blood flow estimates were examined in the left and right hemispheres of the cerebellum, the vermis, the anterior temporal lobe and entire left and right cerebral hemispheres. A multiple step-wise regression was used to identify how blood flow in these brain regions was related to subject ratings on different psychiatric tests including the LSCL-33 (Anderson et al., 1999b, p. 1637). Blood flow in the vermis was found to be more strongly correlated with LSCL-33 scores than blood flow in other brain regions. When we examined substance abuse frequency in a large sample of subjects from the same population who had also completed the LSCL-33, we found a monotonic increase in checklist and depression scores (Anderson et al., 2002, pp. 231–244). Taken together these findings suggest that early abuse and later substance abuse maybe associated with a functional deficit in limbic-VFN networks. Blood flow in the vermis increased with greater LSCL-33 scores, possibly representing efforts by the VFN to modulate and contain limbic kindling.

Although the VFN is not a brain region we normally think of as playing an important role in psychiatric symptomatology, there is now an enormous

convergence of data suggesting that abnormalities in the VFN may be involved in a wide array of psychiatric disorders including bipolar and unipolar depression (Fischler et al., 1996, pp. 175–183; Lauterbach, 1996, pp. 726–730; Loeber et al., 1999, pp. 81–89; Beaugregard et al., 1998, pp. 3253–3258; Shah et al., 1992, pp. 474–479), schizophrenia (Eliez et al. 2001, pp. 540–546; Levitt et al., 1999, pp. 1105–1107; Loeber et al., 1999, pp. 81–89; Jacobsen et al., 1997, pp. 1663–1669), autism (Courchesne, 1991, pp.781–790; Ornitz, 1970, pp. 159–173) substance abuse (Volkow et al., 1988, pp 201–209; 1991, pp 69–78; 1995, pp. 510–506; 1996, pp. 29–38) and ADHD (Castellanos et al., 2001, pp 289–295; Berquin et al., 1998, pp.1087–1093; Mostofsky et al., 1998, pp. 434–439). The VFN exerts strong modulatory effects on the locus coeruleus (LC), ventral tegmental area (VTA), substantia nigra (SN), and midline raphe which are cell body regions for projection of the noradrenergic, dopaminergic and serotonergic pathways (Ikai et al., 1992, pp. 719–728; Reis & Golanov, 1997, pp. 121–149; Snider & Maiti, 1976, pp. 133–146; Snider et al., 1976, pp. 714–728; Tellerman et al., 1979, pp. 135–155).

Supporting a regulatory role of the VFN in dopaminergic transmission, we found a strong dose-dependent effect of methylphenidate on blood flow in the VFN of children with ADHD (Anderson et al., 2000, p. 106S; 2001a, p. 324). Progressively higher doses of methylphenidate decrease blood flow in the VFN, which correlated with significant improvements in attention and diminished motor activity. Presumably this occurs through direct effects of methylphenidate on dopamine transporters in the basal ganglia and lobules II-III, VIII, IX of the vermis (Melchitzky & Lewis, 2000; Anderson et al., 2001a, p. 324). As a result of the enhancement of synaptic dopamine by methylphenidate in the forebrain and cerebellum, the need for vermal regulation of the SR and VTA appears reduced, possibly freeing VFN resources for improved cognitive and emotional function. These findings demonstrate that the ability to shift and coordinate, depending on the social context, attentional and emotional resources, may well be dependent on a fully functional VFN. Functional lesions of the VFN, consequently, may result in the inability to flexibly shift attention or react appropriately to perceived hostility and thus may severely limit skills in navigating the complexities of language, emotional experience, and social interaction.

In brief, early trauma appears to predispose one to life-long impairments of emotional coordination. But how can an impaired VFN interfere with attentional shifting or interhemispheric shifting that underlies perceptual and cognitive flexibility? Recent work by Pettigrew (1998, pp. 2141–2148) demonstrating that interhemispheric switching mediates hemispheric rivalry suggests

one possible mechanism by which the VFN can influence these processes. During binocular rivalry, perceptual alternations in Necker cube representations occur with a switching frequency that is characteristic of an individual. Transcranial magnetic stimulation applied to one hemisphere, or unilateral caloric vestibular stimulation, has been found to change the time spent in completing Necker cube perceptual states, suggesting that competition for awareness occurs between, rather than within, each cerebral hemisphere. Caloric stimulation would directly activate the vermal cortex, as the lateral vestibular nucleus projects to the posterior vermis. Pettigrew has also found that the rate of perceptual rivalry is slow in bipolar disorder. Pettigrew's concept of an interhemispheric "sticky switch" in manic or bipolar depression could be due to VFN pathology which has been observed in those with this disorder (Lauterbach, 1996, pp.726–730).

The VFN complex may contribute to switching behavior and coordinate attentional processes via its projections to key sites in the pons and reticular formation where network cascades are easily activated. Fastigial electrical stimulation has long been known to result in desynchronized EEG (Sawyer et al., 1961, pp. 405–412), characteristic of behavioral states such as REM sleep and attentional orienting. Snider et al. (1976, pp. 714–728) demonstrated direct projections from the VFN to the LC as well as indirect projections by way of the pedunculopontine tegmental nucleus (Ruggiero et al., 1997, pp. 272–276) and paragigantocellularis (Astier et al., 1990, pp. 141–146) and parabrachial nuclei (Supple & Kapp, 1994, pp. 561–574) — all regions that could contribute to desynchronized EEG as well as facilitate cortical binding. Electrotonic coupling via gap junctions is also present in the LC and cerebellar cortex and nuclei. Ushur (1999, pp. 544–554) has proposed that electrotonic coupling within the LC plays an important role in attentional modulation and the regulation of goal-directed versus exploratory behaviors. This electrotonic syncytium structure (Kashimori et al., 1998, pp. 1700–1711) also pervades the cerebellar cortex and nuclear groups and may well represent the fingerprint of dynamical internal models in the cerebellum (Imamizu et al., 2000, pp. 192–195) These dynamical internal models exist in the oscillatory interactions between cerebellar input neurons in the inferior olive, which projects by way of climbing fibers to the only output neurons of the cerebellar cortex, the Purkinje cells, which in turn project to the cerebellar output nuclei. The output nuclei, such as the dentate, interpositus and fastigial, feed back on the inferior olive; by altering gap junction connectivity, they synchronize inferior olive neurons into functional ensembles. Recent work by Makarenk (1998, pp. 15747–15752) has

demonstrated that the synchrony of inferior olive neurons arises out of the chaotic behavior of the subthreshold oscillations in these cells which imparts unique spatial patterns to the ensemble synchrony. Individual inferior olive neurons, while having maximum functional permissiveness, can also transform rapidly into “robustly determined functional patterns of multicellular coherence”. Taken together with a recent hypothesis of how pontine organization may be controlled by the cerebellum to promote the binding of assemblies of cortical-striatal-thalamic loops into coherent motor strategies (Schwarz & Their, 1999, pp. 443–451), these findings suggest that consciousness (in terms of motor patterns) may arise and be refined in the spatial-temporal chaos of phase synchronized pontine olive ensembles. A possible disadvantage of this mechanism, which forms rapidly occurring and highly correlated spatio-temporally functional groupings during the self-organization of motor patterns, comes as a result of pathological signals from the output nuclei, the result of VFN trauma or malformation.

Drug addiction is highly associated with early child abuse, ADHD and bipolar disorder — conditions with an equally strong association with VFN pathology. One of the most potent anti-addiction drugs is ibogaine, an indole alkaloid compound that causes hallucinations, cerebellar tremor, transient ataxia, and vermal lesions in rats. No evidence of cerebellar lesions has been found in humans treated with ibogaine for drug addiction; however, the course of treatment strongly suggests that ibogaine strongly activates climbing fiber activity at the level of vermal Purkinje cells (O’Hearn & Molliver, 1997, pp. 8828–8841). The auditory and visual hallucinations that follow treatment with ibogaine indicate that the efferent copy mechanism in the cerebellum which allows the brain to distinguish its internal activity from sense data is impaired. For example, during ibogaine treatment, a high pitched humming or oscillatory sound is heard by many subjects, most likely due to the overactivation of climbing fiber activity in the olivocerebellar system (O’Hearn & Molliver, 1997, pp. 8828–8841). The visual hallucinations are characterized as “waking dreams” described as a rapid visual presentation of various images, sometimes specifically reviewing traumatic events or circumstances from their childhood in the form of “a movie run at high speed” or “slide show with each slide rapidly appearing as a movie”. When the drug effects subside, the subject can sleep for up to 24 hrs and awaken with a complete remission from all addictive behavior (Kovera, 1999, p. 1564). The dream-like experience coupled with the REM-rebound-like behavior associated with ibogaine (similar to *Delirium tremens* following alcohol withdrawal) lead the author to suggest a connection between

the mechanism of ibogaine action and changes in the fractal organization of REM sleep during ontogeny (Anderson, 1998, pp. 5–14). The cerebellar vermis is most active during REM in many mammals especially human infants (Chugani, 1998, pp. 184–188). In fact, the findings of Schlesinger et al. (1998, pp. 49–52) demonstrate that nightly periods of REM are essential for normal postural control and attention, suggesting that VFM function is greatly impaired after REM deprivation. When interpreted in the context of vertically convergent fractal time processes, early stress appears to result in disruptions of vertical integration of fractal patterns, leading to an alteration of patterns of nuchal atonia occurring during REM sleep in fetal and neonatal mammals (Anderson, 1995, pp. 1–217; Anderson et al., 1998, pp. 351–357; Anderson, 2000, pp. 193–226). In this new light, a connection between REM sleep, the VFM and cognitive/emotional synergy and the fractal time clustering of REM episodes appears more clearly. The effects of stress alter the output of Purkinje cells, resulting in pathological fastigial regulation of chaotic spatial-temporal patterns of pontine olive ensembles. As the VFM appears to influence the architecture of REM sleep, the abnormal spatial-temporal patterns become locked into a negative feedback loop which results in further disorganization of pontine olive ensembles. Ibogaine, by overdriving VFM climbing fiber activity, is able to break these cycles of negative feedback, resulting in REM rebound and the flooding of abuse memories as efferent copy mechanisms are reset during the treatment, possibly restoring, as shelly reflects, “The winds of heaven [to] mix forever with a sweet emotion.”

Thus, VFN influences on chaotic synchronization within pontine cerebro-cerebellar loops can enhance or disrupt cognitive/emotional synergy. Lesions or electrical stimulation of the pathological vermal cortex appear to restore fastigial output. Ibogaine appears to break the habitual cognitive-emotional patterns of drug addiction by resetting VFM networks and restoring pre-abuse ensemble organization. The fractal time organization of phasic REM processes could provide a natural mechanism to resynchronize VFN regulation of cognitive balance on a nightly basis.

## Notes

1. Shelley, *From Love's Philos.* 6
2. Henri Bergson, *From Matter & Memory* (Authorized translation by Nancey Margaret Paul and W. Scott Palmer; published by Doubleday Anchor Books, Garden City, New York, 1959.)

3. That is to the continuous experience of the real (“le bon sense” or Descartes *sensus communis*).
4. The part of the mind/brain responsible for binding sight, touch, smell, taste into a coherent and understandable representation, and for capturing in the mind/brain the so called “common sensibles”, those spatio-temporal aspects of the world known as primary qualities.
5. From Costa ben Luca (ca. 864–923 A.D.) *On the difference between spirit and the soul*,

The brain is divided into two parts, an anterior part, which is the larger one, and a posterior part. In the anterior part there are two ventricles which have an entrance to a common space in the middle of the brain. In the posterior part however there is one ventricle which is connected with the just-mentioned space which is common to both ventricles in the anterior part of the brain. When the delicate pulses sent from the net below the brain [i.e., the *rete mirabile*] arrive in the interior of the brain, they propel the vital spirit to the ventricle in the anterior part, and from there it travels to the other ventricle where it becomes finer and is purged and prepared to receive the power of the soul, which as it were digests it and converts it into a finer and clearer spirit. From there it travels, passing from one space into the other, to the posterior ventricle, following the canal from the common space in the middle of the brain to that ventricle.

And in this passage and canal, that is, in this entrance, traversed by the spirit, there is a certain space and a certain small part of the substance of the brain, similar to a worm, which moves upwards and downwards in its path. When this small part is in its top position, the foramen between the common space which connects the ventricles (on the one hand) and the ventricle in the posterior part of the brain (on the other) is open; but when it is down, the foramen is closed. When the foramen is open the spirit goes from the anterior part of the brain to the posterior part, but this does not occur unless it is necessary to remember something which has passed into oblivion, at a time when one is thinking about the past. If the foramen is not open, however, there is no flow of spirit to the posterior part of the brain and the person does not remember and will not respond to the questions he is asked. This opening of the foramen which occurs when that body which resembles a worm is raised, differs in quickness and slowness between people. For it is slower in some, which causes a slow memory and slow responses in those who have to think hard. This also explains why someone who wants to remember something lifts his head and tilts it backwards and looks upwards with staring eyes, because this position or posture facilitates the opening of the just-mentioned foramen and the upward motion of the worm-like body.

Understanding and thinking and looking ahead and cognition are however mediated by the spirit which is in the ventricle which forms part of the two ventricles which are in the anterior part of the brain. When somebody thinks or foresees something, it is necessary that the canal — that is, the route and the foramen — between the common space which connects the two ventricles in the anterior part of the head (on the one hand) and the ventricle in its posterior part (on the other) is closed; in this way the spirit in the common space can rest,

become stronger and increase its power to think and understand. This explains why someone who thinks bends his head towards the earth and watches it intently and stoops forward, as if he were writing some document and drawing some figures on it, because this as it were facilitates the downward motion of that body which we have described as being similar to a small worm, and which is positioned above the foramen through which the spirit passes on its route towards the posterior parts of the head.

The spirit in this space in the middle ventricle differs between people. It is subtle and clear in some, and these people are rational, of a thoughtful disposition and intelligent. But in some people it has a bad quality, and these are insane, irrational, shallow and stupid” (as it appears in Lokhorst, 2001, pp. 6–18).

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## A theoretical model of the role of the cerebellum in cognition, attention and consciousness

(Ralph Ellis)

*a. Embodied action and higher cognition.* There are two ways to look at the theoretical implications of the above findings for the role of the cerebellum in cognition. One is to say that, whereas we used to think that the cerebellum was geared primarily toward executing action routines, we now realize that the cerebellum has multiple functions that are not essentially interrelated. The other is to say that the integral role of the cerebellum in cognition shows that cognition essentially involves implicit action routines, and hence that the functions of the cerebellum are not modular, but fundamentally interdependent. A hint that this latter view is correct can be seen if we combine Damasio's (1999) notion that cognition involves imagery with Jeannerod's (1994, 1997) observation that action imagery involves the inhibition of actual efferent action commands in the brain, and Merleau-Ponty's (1942) suggestion that the intentional representation of any object involves imagining how we could act in relation to the object. As Merleau-Ponty says, knowing involves "knowing-how." Dewey (1981) also held that cognition was dependent upon action. This view has recently been elaborated into a full theory of intentionality in Newton (1996). The work discussed here does not prove the dependence of cognition upon action, of course; it does, however, fulfill some predictions of that approach.

If we combine the new data about the cerebellum with what is already known about other brain areas, we can develop a clearer picture of the role of the cerebellum in all cognitive processes, including thinking, perception, emotion, learning, and consciousness itself. This role essentially involves the construction of intentional representations of the world and of our bodily activities in the world. There is, to be sure, widespread disagreement about the importance of mental representations in some aspects of cognition, and dynamical systems theorists tend to downplay it (Thelen and Smith, 1994). With regard to phenomenal consciousness, however, mental representation seems indispensable (Humphrey, 2000). If we posit that phenomenal consciousness involves self-consciousness, and if we posit that the self is experienced as embodied (Clark, 1997), the contribution of the cerebellum is essential to our capacity for fully-realized, self-conscious sensorimotor experience. That we are justified in positing these claims will be argued below.

We can construct a five-step model of the patterns of neural activation that must be present in order for the brain to execute the transformations involved

in the information processing needed for intentional representation. When brainstem-hypothalamic loops (1) sense a homeostatic imbalance for the organism, they (2) activate neurotransmitter pathways in the interest of general arousal, and begin sending efferent signals to alert the brain that action is needed. This process includes looping with the cerebellum, because the cerebellum can activate highly specific action sequences, based on past learning. The cerebellar-brainstem loops then send efferent action commands as far as the motor cortex. When (3) these action commands are inhibited by prefrontal signals, the result, as Jeannerod points out, is (4) action imagery. When the action imagery is fully informed by specific action commands in response to environmental stimuli, the resulting “object understanding” (Newton, 1996) becomes an intentional image schema, which vaguely represents categories of possible objects, but only in terms of their action affordances. (In other words, the organismic needs and the bodily situation of the subject determine the nature of external objects for that subject.) When the imagery resonates with the primary and secondary sensory areas (e.g., in the occipital or temporal lobes) either because the latter has been triggered by perceptual input or because the image schemata are so powerful that they activate the occipital or temporal areas on an efferent basis, the result is vivid perceptual (sensorimotor) imagery or actual perceptual consciousness. In neurophysiological terms, this state is correlated with the parietal P300 electrical potential, which registers the resonance between anterior and posterior cortical regions (Aurell, 1989).

What is the role of emotion in this process? Briefly, the process is permeated by emotion. Emotion in the form of primitive organismic motivation is involved in the beginning stages of the cycle, when organismic imbalances are registered in brainstem-hypothalamic regions, through the selection of appropriate action in the anterior cingulate and the cerebellum, through the evaluation of the action affordances of possible objects, to the final conscious experience, which is always an affective experience. The entire process exists for the purpose of satisfying the emotional needs of the organism by means of adjustments to, and/or interactions with, the environment. Thus every conscious experience, whether imagistic or perceptual, exists to inform the organism of the value for it of its current and possible states of being. We experience this value in the experience of emotion.

For this reason, conscious experience tends to involve the representation of highly specific sensorimotor states, rather than general or vague ones. The more specific the imagery, the more accurately will the organism judge the value of performing the action, and disinhibit or inhibit it accordingly. Essentially, then,

the role of the cerebellum here is, instead of generating efferent commands to take some action in general, generating very specific action commands by initiating the thalamocerebellar and hypothalamocerebellar loops (Haines et al., 1997), and also hippocampal-cerebellar loops, so that the action that is commanded (and which then gets inhibited in the motor cortex to form consciously-accessible action imagery) is a highly specific action, rather than just an efferent command to act in a general way (i.e., “Don’t just stand there; do something!”). That this specificity arises early in the activation sequence has been seen experimentally. In eyelid conditioning the cerebellum responds within 20 ms. of the delivery of the airpuff (Woodruff-Pak, 1997); Coles et al. (1990) report finding a hippocampal ERP as early as 18 ms. after presentation of a novel stimulus. Both of these ERPs occur long before the occipital 100N and 200N “mismatch negativity,” and probably reflect early activation of the hippocampal-cerebellar loops that Haines et al. (1997) report, along with cerebellar-PAG loops (Panksepp, 1998). After chemical neurotransmitters (acetylcholine, norepinephrine, and many others) have alerted the brain that action is needed, the subsequent electrical nervous impulses are ways of elaborating what specific action should be taken. This process represents a monumental computational task, so it makes sense that the cerebellum, which comprises 50 percent of the brain’s neurons, must be recruited for it.

In some instances, brainstem emotionally-initiated neurotransmitters tell us to take action, but without the electrical circuits being able to give us a clear indication of what specific action is needed, and this is when we feel ourselves in the grips of powerful, disturbing emotions like anger, fear, grief or anxiety. As soon as we start taking the needed action, the anger, fear, etc. feels less cataclysmic, because we are not just getting the neurotransmitter rush in its purity, but rather as tempered by the fact that some of our attention is taken up with the specificity of the action commands. The cerebellum’s role here is to make the action commands specific enough so that we can “understand the objects” of cognitive, perceptual, or emotional states. When the neurotransmitters are delivered to the various brain parts, the expectation is that specific action commands will be not far behind, so to receive the neurotransmitter activity without any action commands can be very disturbing. Consider, for example, the difference between thinking about imminent dire circumstances, calling for urgent action, when one is trying to get to sleep at night, and thinking about them in the light of day when one is ready to do whatever is necessary. Here again, the specificity of the action commands depends on the cerebellum.

Recent research (e.g. Schmahmann, 1997) shows that the cerebellum is not only a coordinator of motor actions, but also of reasoning (Ito, 1993; Ito et al., 1998; Chourchesne, 1991), tool use (Imamizu et al., 2000) and of emotional with cognitive states (Anderson, 1998; Anderson et al., 1999; Lauterbach, 1996; Loeber et al., 1999). Neurophysiological studies have focused increasingly on the cerebellum's role in cognition, since cognition is empirically studied more easily than consciousness. But by looking at the cerebellum's role in cognition, we can see quite easily why it would be important for consciousness as well, notwithstanding the fact that animal studies which amputate the cerebellar *cortex* (in contrast to the cerebellar *nuclei* which are virtually inseparable from PAG and midbrain structures) may leave some rudimentary, everyday conscious activities intact (Anderson, 1998). We can thus achieve a better understanding of the relationship between cognition and consciousness by noting the brain systems that include the cerebellum in the coordination of both cognition and consciousness.

*b. Attention and consciousness.* There are good, if not decisive, reasons to believe that the activity of the cerebellum is an important determinant of the structure of conscious as opposed to nonconscious processing. One is that, as Ito (1993), Schmahmann (1997) and others have shown, the cerebellum plays a coordinating and synchronizing role in the brain. Conscious processing is arguably a widely distributed brain activity of a self-organizing system (Ellis, 2000) and cannot result merely from passive stimulation; the global nature of conscious activity is strongly implied by, among many other empirical findings, the fact that occipital stimulation alone does not yield perceptual consciousness (Aurell, 1984, 1989; Posner and Rothbart, 1992); recent perceptual studies by Mack and Rock (1998) also entail this conclusion although the authors do not discuss the neurophysiology involved (this inference from the inattentional blindness phenomenon is discussed further in Ellis, 2001). It is difficult to see how such whole-brain activity could operate independently of the brain's major organizing structure.

Another reason to link the cerebellum with consciousness is the fact that cerebellar activity is very similar in abstract thought, physical movement, and even the mere imagination of physical movement (Ito, 1993). This strongly suggests that the cerebellum plays an important role in the most sophisticated intellectual operations, and that intellectual understanding is accomplished as an extension of the manipulation of action affordances (Newton, 1996; Varela et al., 1993). In addition, as noted above, recent research increasingly indicates

an important role for the cerebellum in the most sophisticated mental operations, including learning and abstract thought.

If the cerebellum is centrally involved in conscious mental activity, what exactly is its role? A promising hypothesis is that by acting to synchronize diverse forms of brain activity, the cerebellum prepares the organism for recognizing and responding to salient stimuli; in effect, the cerebellum tells the rest of the brain to “look for” input that corresponds to current organismic needs or expectations. As the Mack and Rock (1998) inattentional blindness studies suggest, it seems to be only when one looks for something that one is able to recognize it when it appears. In what follows we examine the way in which synchronizing activity of the cerebellum prepares the brain for dealing appropriately with impingements of the external world.

It has been known for some time (e.g., see Asimov, 1965; Anderson, 1998) that conscious wakefulness results not from the activity of one particular brain region, but from the synchronization of wave patterns in diverse regions, especially between the midbrain, the thalamus and the cortex. Since the cerebellum controls widely distributed synchronizations, this means that the cerebellum is crucial for the difference between sleep and wakefulness — and the implications of this fact for understanding the physiological correlates of consciousness are obvious. A fact less often mentioned but equally important is that coordination between the hippocampus and other subcortical regions, and the effect of this coordinated activity on the extended reticular thalamic activating system — which in effect “tunes” the thalamus to select for incoming stimuli that have emotionally important action affordances — may well be necessary for *perceptual* consciousness as well. Occipital processing alone is not conscious. Before we are conscious of a visual stimulus, subcortical and limbic brain areas must be activated, as well as more anterior areas such as the anterior cingulate, and this activation must take place in response to a motivational-emotional evaluation. Since all of this activity involves synchronization of wave patterns in different brain areas, the cerebellum also plays a part here. In short, if all consciousness begins with action affordances, or Damasio’s (1999) “as if body loop,” then the cerebellum — the brain area most important for coordinating bodily actions — must be pivotal for understanding consciousness.

The hippocampus shows an event related potential (ERP) within about 18 ms. of presentation of a novel perceptual stimulus (Coles et al., 1990), followed closely by cerebellar activation at about 20 ms. (Woodruff-Pak, 1997) — indicating subcortical activation involving wave synchronization phenomena, implying cerebellar involvement as well — whereas the first occipital ERP does

not begin until around 100 ms. The anterior and subcortical activation therefore does not seem to be a response to an occipital stimulus, but instead this activation must already have taken place before perceptual consciousness is possible, and the extended reticular thalamic activating system, guided by emotional subcortical purposes involving action affordances, seems to play a role in determining whether any given perceptual input will even register in consciousness, i.e., will be attended to. The cerebellum, as suggested above, must play a role in commanding specific actions in response to the early thalamic input, prior to occipital processing, and in turn lead to action commands which are then inhibited by anterior brain activity to form sensorimotor action imagery that allows understanding the environment in terms of its affordances.

When a visual stimulus is unexpected, from the time occipital processing is complete to the time when all the other brain processes needed for perceptual consciousness are activated, there is a time delay of about 1/4 second (McHugh and Bahill, 1985; Srebro, 1985; Aurell, 1989) — much too long to be accounted for simply by the speed of spreading activation. Instead, the 1/4-second delay probably results from the time needed for the emotional areas to activate the anterior cingulate, frontal and parietal areas to “look for” important categories of objects which the thalamus, in response to hippocampal and cerebellar tuning, has already alerted the organism might have relevant action affordances. This looking-for activity, with its cerebellar involvement, has already begun to activate sensorimotor imagery associated with possible action affordances before the signal undergoes much occipital processing at all. Bernstein et al. (2000) provide ample evidence that a looping between the anterior cingulate and the prefrontal cortex is necessary for the voluntary direction of visual attention, while Mack and Rock (1998) have shown that the attentional act is a necessary condition that must precede any state of perceptual consciousness. Haines et al. (1997) show that the cerebellum coordinates the timing of these limbic-frontal loops, which actually can now be viewed as limbic-frontal-cerebellar loops.

Someone might naturally question whether this is true in cases of involuntary attention, and in cases of complete frontal lobectomy. But even in these cases, the emotional brain areas still play a role in gating incoming stimuli to reflect the general motivational purposes of the organism, especially the “seeking” motive explored by Panksepp (1998). With frontal lobectomy, attention can be gated by means of subcortical control of neurotransmitters as their distribution controls resonance between subcortical and the intact

posterior cortical activity (Damasio, 1994; Watt, 1998; Faw, 2000); this allows consciousness rather than mere blindsight or implicit knowledge to result. Moreover, a person with no anterior cingulate apparently would be in a persistent vegetative state (Damasio, 1999), so even involuntary attention would be impossible without it. Thus the model of the mind as a passive receiver of causal work done by stimulus inputs places the cart before the horse.

This way of looking at the neurophysiological substrates of perception is a relatively new way of interpreting the causal sequencing of brain events in conscious perception. Earlier, it was thought that perception drove emotion, which in turn drove action (Goleman, 1994, p. 18). The findings cited above show that just the reverse is the case. The organism is first prepared to look for environmental conditions that are potentially useful for its purposes; the most important environmental conditions are the ones that involve action and are thus tied to cerebellar functions. This subcortical tuning, with the help of the cerebellum, activates the frontal and limbic regions to begin "looking for" important categories of items, in effect forming preconscious image schemas (in terms of Jeannerod's sensorimotor action imagery), which is associated in cerebellar action routines with the relevant environmental stimuli, prior to the actual presentation of the stimulus on a given occasion. If the presented stimulus resonates with this self-generated activity, as reflected in the parietal P300 ERP, then a relatively vivid image of the object is formed in consciousness; in this case the image is the image of a present perceptual object rather than a mere mental image (Aurell, 1984, 1989). For example, as we track the movement of an aircraft in the dark, we can see it quickly if our expectation as to where we should look (as motivated by subcortical and limbic activity) closely enough matches where the aircraft actually is. If the aircraft is suddenly where we are not looking for it, we may have a mental image of it where it should have been, but the process of finding and registering its new location in consciousness, if we believe the Aurell, Srebro, and Runeson studies cited earlier, will require at least a fourth of a second. The motivation to attend thus must precede perceptual processing. A motivated pattern of activity is always already ongoing for the organism; this activity, since it is self-organizing, must also be holistically coordinated, and here again the evidence suggests that the cerebellum is crucial for the synchronizations needed for this purpose. In some instances, the emotional motivations themselves may be activated in a primitive, preperceptual way in the initial thalamic registering of the stimulus that is presented, through the thalamus's direct communication with the emotional brain prior to extensive perceptual processing. But here again, the cerebellar-

thalamic and cerebellar-PAG loops investigated by Haines et al. (1997) are already at work from the very earliest activation of the thalamic-subcortical (e.g., hippocampal) connectivities.

If frontal and parietal areas must be activated by lower, emotional brain areas (anterior cingulate, hypothalamus, hippocampus, cerebellum and amygdala), then we can also make better sense out of Wertz's (1987) phenomenological observation that we see the sinister nature of a smile without noticing the details that tell us it is sinister, and Merleau-Ponty's remark that we notice the disorder in a room before we notice the crooked picture frame that makes it look disorderly (Merleau-Ponty, 1942, p. 173). We do not merely develop abstract concepts out of our perceptions, but the perceptions are already guided and shaped by concepts. The role of the cerebellum plays up how much of these concepts that guide perception are categorized in terms of sensorimotor action imagery, and thus dependent on previously learned cerebellar action routines.

These considerations would also seem to entail that consciousness cannot occur in nonliving information-processing beings, such as digital computers, but can occur only when activated by an enactive, self-organizing system that has emotional purposes as a result of the self-organizational aim of the organism to maintain a total homeostatic balance. The role of the cerebellum thus underscores how important emotion is for consciousness in general, and not just for affective consciousness. But at the same time, emotion obviously is not a sufficient condition for consciousness. Plants and very low animal species have organismic purposes, and are self-organizing, but have little if any consciousness. Consciousness must therefore occur only when emotion is combined with something else — representation. When representation occurs, not as a passive reaction, but as an activity of the emotionally directed organism, then consciousness can occur. Emotional agnosias occur when patients cannot represent what their emotions are “about.” They cannot form imagery that is appropriate to consciousness of their emotions. This does not mean that they do not have the emotions. We become conscious of emotions by forming representations. And even when we are unconscious of the emotions, they are still present, and therefore still drive the representational processes in which we do engage, e.g., as in tracking soccer balls and having our attention pulled by sinister smiles and crooked picture frames. Even pure curiosity is an emotion that motivates us to explore our environment and represent what is there (Panksepp, 1998). We may be unconscious of the fact that emotions drive these

perceptual and imaginative processes, but the above data would seem to indicate that they are so driven nonetheless.

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