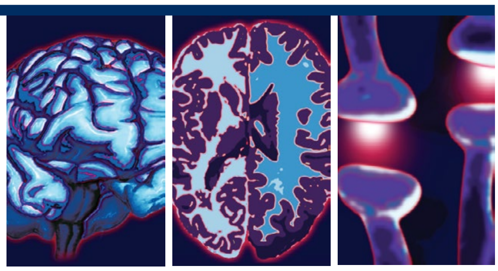
Thesis



Time Engineering, The Cerebellum and Volition

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Introduction

Present-day neuroscientific investigation of volition is mostly restricted to its supra-tentorial, conscious dimensions. This consciousness informs intentions, but does not create them. Consciousness provides the sense of agency, and enables motor control, but it is secondary to volition [1-3]. A discussion of Libet, vis-à-vis consciousness and free will, dealing as it does with those supra-tentorial parameters of volition, is beyond the remit of this article, which addresses its sub-tentorial parameters [4].

Sherrington acknowledged that all conduct, including mental conduct, has a motor component, even when it is secondary [5]. But not all volition is addressed to that motor dimension of conduct. It is addressed much more widely to both its material and mental objectives. The purpose of this study is to build a model of volition in terms of the subjective and objective parameters of effort, which is anterior to consciousness, superordinate rather than subordinate to cognition in mentation, and whose vector is bottom-up, from small brain to large brain. It is synergistic with top-down neuroscientific models of mentation, whose vector is from the large brain to the small.

The material, moral, mental, and spiritual aspects of volition were constitutive to religion and philosophy in the pre-modern period. Volition was excluded by cognition, and has yet to find a place as an autonomous, albeit composite mental entity in modern neuroscience. Three, historically-conceived, functional revolutions in cerebellar studies are posited: motor, cognitive, and cerebellar. A fourth, moral-spiritual revolution in cerebellar-cum-cerebral studies is portended.

The method of articulating the present model consisted in collection and analysis of candidate data drawn from historical and contemporary sources. The principal historical sources in philosophy were Maine de Biran, Alfred North Whitehead and Henri Bergson, and in psychology, Pierre Janet.

The Three Revolutions in Cerebellar Studies

Neither Aristotle nor Galen considered the cerebellum as a part of the brain [6]. They termed it the para-encephalon, and located it adjacent to the encephalon, or brain proper. It kept its secrets until Vesalius. Probably influenced by classical, ventricular theory, he associated it with memory; an early portent of the direction the neuroscientific field would eventually take [7]. But he was against the neuroscientific grain. Willis, then Rolando, Flourens and Magendie, established the link with involuntary motor functions [8]. This was what one might call the first revolution in cerebellar studies. The second was a cognitive revolution and the third and fourth have yet to get underway: the volitional, and the moral/spiritual. The key findings of the first two revolutions are briefly surveyed because they are constitutive to the third and fourth. Thus volition subtends motor, cognitive and moral/ spiritual function.

Cerebellum and Motor Function

The study of motor control in the central nervous system did not get off the ground until the enabling methodologies were developed in second-half of the twentieth century. Perhaps the key neuroscientific finding was that motor systems, both large and small brain, are not static, ‘etched in stone,’ but dynamic. They evolve in

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response to experience throughout ontogenesis. Early studies using electrophysiology in non-human subjects were confirmed and extended by functional neuroimaging studies in humans. Plasticity was demonstrated in cerebellar circuits that exchange information with the cortex in the automation of higher order motor control in the motor cortex, and to lower-order response rules in the prefrontal cortex [9]. Evidence for this obtains both in vitro and in vivo, notably supporting evidence from studies of cerebellar Long Term Depression (LTD).

Motor learning appears to rely on information flow between both frontal and prefrontal cortical motor areas, and the cerebellar cortex. Cortico-cerebellar loops relay in the pontine nuclei, and return to the cortex via the cerebellar nuclei and the thalamus. Cerebellar control systems employ motor maps that first draw upon, and then process and return information first derived from the cerebellum. That cerebellar processing of motor maps involves mimesis is suggested by bilateral mu rhythm suppression in the cerebellum, and by mu rhythm suppression in the left medial frontal gyrus, right temporal lobe and thalamus [10,11]. Cerebellar motor control integrates controlled and effortful information processing, with automatic information processing, as described in Schneider's and Shiffrin's dual process model [12,13]. The integration is based in interaction between the lateral PFC and the cerebellar cortex.

Cerebellum and Cognitive Function

The second revolution in cerebellar studies linked motor function with mental function [14]. It gave the field hope that the cerebellum would, in Ito's words, "provide the clues we need to attain our long-standing objective to decipher the meaning of the brain's neuronal circuits (and so to) transform our understanding of brain function" [15]. Schmahmann led the way with his studies of the cerebellar cognitive affective syndrome [16]. In addition to defects in executive functioning, symptoms related to the cognitive-affective domain can include: blunting of affect, distractibility, hyperactivity, impulsiveness, disinhibition, anxiety, ritualistic and stereotypical behaviors, illogical thought and lack of empathy, aggression, irritability, ruminative and obsessive behaviors, dysphoria and depression, tactile defensiveness and sensory overload, apathy, childlike behavior, and inability to comprehend social boundaries and assign ulterior motives [17].

The second or cerebellar revolution also generated dysmetria of thought theory. Dysmetria is a type of ataxia, an inability to judge distance or scale. According to Andreasen, when applied to cognitive dysfunction in schizophrenia, it infers, "difficulty in prioritizing, processing, coordinating, and responding to information" [18]. Schmahmann holds that in cognitive dysmetria, a universal cerebellar transform facilitates automatic modulation of behavior around a homeostatic baseline, and the behavior being modulated is determined by the specificity of anatomic sub-circuits, or loops, within the cerebro-cerebellar system.

Increasingly studies of natural, and experimentally-induced pathology, are being augmented by experimental manipulation in functional neuroimaging. The most recent survey of neuroimaging literature of cerebellar cognition was published in 2012 by Chen et al [19]. They performed a meta-analysis of 88 neuroimaging studies, and employed the activation-likelihood estimate method. Task performance identified activation of working memory, executive function, timing, music, emotion and language. In regard to the latter, to motor coordination, and balance was added the function of motor speech [20]. In the postoperative Cerebellar Mutism Syndrome (CMS), language defect was also prominent [21].

The relationship between cerebellar structure and function, derived from the study of lesions and defects, is as follows: the anterior cerebellar lobe hosts the primary sensorimotor region. The medial aspect of the posterior lobe is a secondary sensorimotor region. Cerebro-cortical association areas subserving cognition are preferentially connected to the lateral hemispheres of the cerebellar posterior lobe. These connections consist in feed-forward loops via the nuclei of the basilar pons, and feedback loops from deep cerebellar nuclei via the thalamus. There are also reciprocal connections between the cerebellum and hypothalamus mediating, emotion and autonomic function. Critical for the present study is the differentiation of disorders of affect and cognition, most notably the Cerebellar Cognitive Affective Syndrome (CCAS), from disorders of volition. This has yet to be carried out. Schmahmann acknowledges the volitional component of motor processing, but has yet to differentiate the cognitive and the affective modes from the volitional.

Cerebellum and Volition

The third revolution in cerebellar studies seeks to link and illuminate two recondite, scientific fields: the study of the cerebellum and the study of volition. The evolution of knowledge of the cerebellum has been slow but progressive; that of the will has been slow and interrupted. Until now, their paths have hardly met. A previous article, examining temporal disorganisation in schizophrenia, presented evidence for the cerebellum as a high-velocity, neurological organ of time and timing [22]. In the present article, the notion of the cerebellum as an organ of time (future-in-the-present) is extended to the cerebellum as an organ of volition, acting via a proposed 'cerebellar lobe executive'.

It is held that volition, most fundamentally conceived as effort, is an autonomous, brain-mind 'faculty.' It cannot be reduced to the processes of affect, behaviour or cognition, as has been done since volition exited mainstream psychology in the modern period. Rather it is augmented by these processes, so that pre-verbally experienced effort is subsequently complemented by consciousness of effort, and by combined conscious and non-conscious direction of that effort. Will, in its material, moral, mental and spiritual aspects is thus anterior to, and supervenes over consciousness in the course of brain-mind functioning. It is oriented to the future via the ever-unfolding present.

It is hypothesized that the cerebellum, as the organ of time, is the primary organ of volition. It functions, bottom-up. The cerebrum is the primary organ of consciousness, but the secondary, organ of volition. It functions top-down via mechanisms of feedback, which can be fruitfully conceptualised according to Perceptual Control Theory [23]. The cerebellum relates to the future via non-conscious mechanisms of supervised learning, based in feed-forward (future-in-the-present). The data derived thereby is integrated by a putative, 'cerebellar lobe executive' with three feedback data sources (past-in-the-present): longer term, ontogenetic and phylogenetic volitional data, derived from procedural memory, located in a cerebellar, volitional, memory store; data derived by operant conditioning from the basal ganglia; and, data derived from unsupervised learning, especially via classical conditioning, and principally originating in the cerebral cortex.

The volitional, feed-forward process enters conscious awareness, by way of non-conscious, short-term memory, of which working memory is emblematic, originating in the cerebellum, and transmitting to the cerebrum. This process manifests in the awareness of effort, albeit often liminal, or even subliminal. Each of the biopsychological components of volition is potentially dissociable in neurological time and place, and hence is open to investigation, both via natural experiment, essentially employing the disease model, and via 'laboratory' experiment. Currently, the most promising form of psychobiological exploration of volition combines empirical psychological exploration with integrated EEG/fMRI.

Psychological Effort and the Brain

Effort, the most fundamental form of expression of volition, is non-consciously and objectively mediated by the small brain, and consciously and subjectively experienced by the large brain. Effort can be dichotomised between effort underpinning mental processing, for example in attention, concentration, problem solving and decision making; and, effort underpinning material activity, most fundamentally, in locomotion. William James' example of effortful, 'taking mental possession' has not been bettered [24]. It went as follows, "We know what it is to get out of bed on a freezing morning in a room without a fire, and how the very vital principle within us protests against the ordeal. Probably most persons have lain on certain mornings for an hour at a time unable to brace themselves to the resolve". James was apt to link that consciousness of absence of will that awareness of incapacity for mental effort, with defects in what he termed, ideomotor functioning. These notions were closer to metaphysics of morality and spirituality than to physical science. To this day, although appealing, ideomotor theories describe as yet un-validated reifications of mental schemata.

The brain-mind operates as a general system in the sense of general systems theory [25]. There are vertical and lateral factors: top-down, bottom-up, and side-to-side. Most models eschew the bottom-up vector, preferring some form of top-down hierarchy. But, bottom-up control, a reverse hierarchy, acting synergistically with top-down control, is fundamental to volition, and probably to brain-mind function overall. Representative of the bottom-up model, which stood in contrast to the top-down models of Jackson, Head, and von Monakow, was that of Luria [26]. He proposed three, complex, functional units operating across three vertical zones: low, comprising waking and attention; mid-level, a zone of emotion and sensation; and, high, a zone of programming and regulating mental activity. These three zones broadly corresponded to Paul Maclean's evolutionary, triune, large-brain (or forebrain), formulated in the 1960s, and summarised in 1990: telencephalon (mammalian brain), diencephalon (amphibian brain), and mesencephalon (reptile brain) [27]. The model enunciated in this article critically augments these tripartite models with a fourth neurological element, the small-brain, or cerebellum.

Historical Antecedents of Will as Effort

Volition, principally in terms of conscious free-will rather than unconscious will-power was long an autonomous, religious and philosophical concept. It was constitutive, first to ancient, secular, moral standards, centring on Aristotle's Nicomachean Ethics, and then to medieval religious ethics, centring on Thomas Aquinas' Summa Theologica [28]. In Aristotelian, scholasticism, in so far as volition had a psychological dimension this was in relation to moral psychology. As such, it was considered a power higher than the intellect. The empiricist-rationalist schools of philosophy, notably in the work of Bacon, Descartes, Hobbes, Spinoza, Locke and Hume did not differentiate between will, as conation, meaning directed effort, and free will [29]. It was considered essentially an appetitive faculty with conscious, cognitive contingencies. Rousseau enunciated a general will shared by the whole of society [30]. Schopenhauer's notion of the world as will took volition down a metaphysical blind alley [31].

Volition was only briefly a mechanistic, mental concept, before it was supplanted by instinct in behavioural psychology, motivational drive in dynamic psychology, and the frontal lobe executive in behavioural neuroscience [32]. It foundered for lack of technical means for relating structure to function in the brain. The English physiologist, Carpenter's tantalising concept, unconscious cerebration, faltered for this very reason: brain biology required a further century-and-a-half of scientific investigation before the neurobiological and psychobiological basis of volition, and its sister mental faculties, could begin to be addressed [33]. The demise of the investigation of will in neurology and psychiatry was accompanied by retardation in interest, but not in the frequency of its disorders: aboulia and impulse disorder in psychiatry, the latter notably accompanied by a propensity to harm to self and others, and their counterparts in neurology. Aboulia in the former is the inability to 'initiate' effort; and, in the latter, it is the inability to initiate movement.

Volition in psychology and psychiatry lingered on as an outlier. It was saddled by a Cartesian model of mentation based in cognition and consciousness. Volition briefly revived in the dynamic psychology of the psychiatrists, Sigmund Freud and Pierre Janet. The former relinquished volition qua volition. He jettisoned its more formal, psycho-biological, 'up-stream' aspects for down-stream, cognitively and emotionally, allied, desire, the realm of cognitive-emotional wants and cognitive-emotional wishes rather than emotional effort per se. For the latter, although conduct was axial, it was preceded by volition as an autonomous psycho-biological faculty [34].

Maine de Biran

Janet's approach to volition was influenced significantly by the French philosopher, Maine de Biran. The latter was considered by Victor Cousin, French proponent of the Scottish Common Sense Realism, to be the greatest French metaphysician since the time of the French, rationalist philosopher, Malebranche. For Maine de Biran the basis of human conscious experience was in the consciousness of self as an active, volitional, striving power [35]. The sensory and perceptive, 'vie sensitive,' was transformed by volitional effort into the 'vie active' (or reflexive), and, transformed again by freedom of will into "la vie divine". This conceptualisation was adumbrated by a psychologically-informed, religious philosophy, itself based in the reality and irreducibility of the mental and spiritual nature of man. According to Ellenberger, Main de Biran considered the basic fact of the human mind to be 'effort' [36]. The self is an effortful and active agent rather than a speculative entity ie the self is, fundamentally and primarily, will. Consciousness is the apperception by the self of that effort.

Descartes' principle 'I think, therefore I am' (ergo cogito sum), which dominated modern philosophy of mind, and modern cognitive neuroscience, was shadowed, from the late eighteenth century, by Main de Biran's, 'I will, therefore I am' (ergo volo sum) [37]. Cogito ergo sum subtended the mind-body problem, as the problem of consciousness, latterly construed as the binding problem. Ergo volo sum, which supervened over ergo cogito sum, subtended a more fundamental problem: the problem of purpose, not in the teleological sense, but in terms of the binding of volition as experience, to volition as neurological, and more specifically cerebellar, process. In Main de Biran's system, voluntary effort uplifted the mind from sensation to perception and thence to its higher operations in consciousness.

The British logician and historian of philosophy, Bertrand Russell, regarded this French movement, which appeared to deviate from materialism and determinism towards spiritualism and free will, as irreconcilable with modern scientific rationalism [38]. But, by including Main de Biran in this critique, he threw the baby with the bathwater. Main de Biran's model was, and indeed is, open to rational and empirical investigation, as modern studies in moral psychology and social cognition, such as those of Ham and Van den Bos, and attest [39].

Pierre Janet

Janet always acknowledged his intellectual debt to Maine de Biran. He was inclined to recognise volition as psychological effort. Volition was fundamental to the evolution of the conceptualisations which underpinned his three, complementary, hierarchical, models of the personality: the first, the model of conscious versus sub-conscious conduct and volition, or mental automatism; the second, the energetic model of consciousness, conduct and volition; and, the third, the model of conduct based in conscious and subconscious, volitional 'tendencies' [40]. All three of Janet's hierarchical models were top-down models vis-à-vis their structure, operation and contribution to mind-brain control. The present model reverses the vector. It is a synergistic, bottom-up model of volition and a top-down, model of consciousness, and so of awareness of volition.

Janet's doctoral thesis in psychology, and his first book (one of 26), L'automatisme psychologique (1889), was a study of primitive conduct, and of impaired consciousness and volition [41]. Maine de Biran called the latter impairment 'resistance to the will' It manifested in 'passivity' Janet's first, hierarchical model differentiated between active, higher order conduct, more highly willed, less subconsciously dissociated and less dissociable (synthetic), from passive, lower order, automatic conduct, more highly dissociative and more dissociated. Meares linked Janet's top-down approach to dissociation with the findings of Hughlings Jackson [42].

Janet's energetic model was presented in his magisterial study, Les Obsessions et la psychasthenie (1903) [43]. It posited that conduct could be characterised, amongst other psychological dimensions, by mental energy, termed psychological force, and by mental organisation, termed psychological tension [44]. Janet was influenced in formulating these energetic and organisational mental notions by William James and Henri Bergson. The highest levels of personality functioning in Janet's second hierarchy were characterised by highly energised and highly organised mental effort, or volition. Janet called this mental organisation, realisation. It was the structural and function dimension of reality. Realisation too was dichotomised between the mental processes of synthesis and decay, of aggregation, and disaggregation or dissociation.

Janet's third and final model was a top-down model of conduct [45]. Volitional tendencies underpinned that conduct, from highly-adapted to poorly-adapted mental functioning. In this model he differentiated an up-stream form of volition as unconscious effort, from a down-stream form as conscious effort directed towards a specific set of conducts, via an underlying set of specific volitional tendencies. These were analogous to the psychological tendencies enunciated by McDougall in his hormic psychology [46].

Janet preferred the notion of tendency, endowed with latent energy, to that of instinct. Once activated by suitable stimulation, they could be brought, more or less, to consummation. Tendencies were more varied, more flexible and could combine with each other. Janet modelled these tendencies in his second and third hierarchical models of mentation, his energetic model and his model of conduct, respectively. He enunciated a three-level hierarchy of tendencies: low, middle, and high. The lowest tendencies were reflexive, perceptive-suspensive, socio-personal and the most elementary intellectual; the middle tendencies consisted in immediate actions and assertive beliefs, and reflexive actions and beliefs; and, the higher, in rational-ergetic, experimental, and progressive tendencies. Treatment, in part, consisted in psychological analysis of the tendencies.

Janet's research was marginalised. It was jettisoned, not only by dynamic psychology, but by psychology and psychiatry as a whole in favour of the afficionados of another psychological 'ABC,' namely that of affect, behaviour, and cognition. Volition (and so, mental effort) was reframed in terms of varying combinations of that psychological ABC. In short, volition was again relegated. This time it was not relegated as an ecclesiastical relic, but it was scientifically reduced to an alternative set of psychological phenomena.

Janet's scientific work was carried out employing human subjects, with clinical conditions. Janet characterised volition by its disorders, principally by its diminution, aboulia, and by its augmentation, various kinds of impulsivity [47,48]. Typography of these myriad, clinical, psychiatric disorders of volition, informed by the models employed by Janet, and comparable authors, has yet to be published. It is beyond the remit of this article. Suffice it to say, that Janet principally studied volitional impairment in the neuroses: hysteria and psychasthenia, present day dissociative and somatoform, and obsessive compulsive disorders, respectively. Aboulia was a feature of the most serious mental illnesses, the severe neuroses, personality disorders and psychoses, especially when these are accompanied by, or accompany depression.

Today, there is increasing interest in volitional impairment in psychiatric disorder, especially schizophrenia, and severe forms of depression, and in neurological disorder, ranging from the commonest neurological condition, stroke, to Parkinson's disease, traumatic brain injury, progressive supra-nuclear palsy, and many rarer, focal neurological conditions. In both psychiatric and neurological disorder impairment is traditionally explained in terms of top-down interruptions in frontal-subcortical circuitry [49]. The latter generally only extend to the caudate nuclei, midbrain, and thalamus. In the present model, equally important bottom-up interruptions are considered, emanating from the cerebellum.

Time, Volition and the Cerebellum

Volition primarily operates via the cerebellum, both in present time, and most importantly, in anticipation of future time. It requires a model of time which captures immanence, process, expectation and creation. Consciousness of time, its so-called subjective element, is a supra-tentorial mental function, secondary to sub-tentorial volition and to the exertion of effort.

Science early opted for a scalar model of time, completely inadequate to its task. It was linked with mathematics and certainty in the ancient, Greek tradition of Aristotle and Euclid. Whitehead called it the ontological error [50]. The physical sciences clawed back territory through the dynamic notion of relativity, but the psycho-social sciences remained scalar, and unidimensional. To this day, psychology regards the temporal dimension of conduct as secondary. Its pursuit of a-temporal, quasi-universals attenuated its agenda.

The consequences of that ontological error for volition were fateful. It simply exited the scientific canon. Volo ergo sum was replaced by cogito ergo sum. The exit of volition also compromised models of consciousness. The psychologist, erstwhile ordained priest, Brentano, in the pursuit of scientific empiricism, felt forced to return a scholastic model of consciousness based in intentionality [51]. This is defined by the American heritage dictionary as, "The property of being about or directed toward a subject, as inherent in conscious states, beliefs, or creations of the mind, such as sentences or books". That is Brentano abandoned the psychological subject in introspectable time, and opted for the subject as object in 'extrospectable' space.

The rehabilitation of volition requires the adoption of relativistic, philosophical models of truth and reality. Two process models stand out: those of Whitehead and Bergson: first, Whitehead (op cit, 50). Whitehead dichotomised reality between actual entities and abstract entities. Although actual entities are utterly determinate, completely concrete, basic realities with singular causality they are nonetheless conceived in process terms. Note that for Aristotle, actual entities were substances, and for Leibniz actual entities were monads.

Whitehead divided actual entities into two kinds, temporal and atemporal. All actual entities in the natural world are temporally contingent. These are occasions of experience, which must not to be conflated with consciousness, at least not in its reflective form. This is because a human being is composed of indefinitely many occasions of experience, which are not necessarily the object of awareness. One exceptional actual 'entity' is at once both temporal and atemporal: God. He is objectively immortal, as well as being immanent in the world. He is objectified in each temporal actual entity; but He is not an eternal object.

Inherent in each actual entity is its respective dimension of time. Each occasion of experience is causally influenced by prior occasions of experiences, and causally influences future occasions of experience. This is the process in process philosophy. Such process is never deterministic. Consequently, according to the process thinker, free will is essential and inherent to the universe.

Whitehead enunciated the more comprehensive process model of reality, but he stayed with the cogito, albeit a much amplified, process version of it. One must turn to Bergson's notion of duree for a closer approximation of process time to that obtaining in volition [52]. Bergson applied it to free will rather than to will per se. The present model takes the next step, and applies it to will, qua will. Volition, most importantly in its middle, cerebellar, bottom-up stage, relates temporally, first and foremost, to the future. That future, however, is dual. It consists in the future, qua future, and the future-in-the-present.

For the person, time is mobile. It may speed up or slow down. Personal duration is ineffable. It can only be demonstrated indirectly through intuitions of the imagination and through metaphor [54]. At the core of duree is its indivisibility. Space is divisible, but time operates seamlessly in its domain. Both physical and metaphysical, psychological and metapsychological notions of time, including Minkowski's space-time, must take this indivisibility into account.

The essence of time cannot be captured by the scalar model. For that it would have to cease being time. Time would have to stand still. Bergson's theory of time as duration addressed this matter. It was a response to Kant's, static, geometrical notions of space and time. Bergson recognised that Kant adhered to the philosophical and scientific tendency to prioritise space over time by spatialising time. Kant conflated time with its spatial representation. Bergson argued that duration is unextended. It is heterogeneous. Its parts cannot be juxtaposed as a succession of distinct parts, with one causing the other. They are not distinct, but continuously run into each other. They can be subjectively intuited rather than objectified. Bergsonian consciousness closely approximated to James' notion of the stream of consciousness. Causality anticipating that consciousness was located in free will. The present model located it a step further back, in will qua will.

Discussion

Old scientific theories die hard. The primacy of the large brain over the small brain, and of cerebrum-based conscious intention over cerebellum-based unconscious volition, is axiomatic in contemporary neuroscience. On the basis of neurophysiological studies, Libet (op cit 4) challenged received philosophical and psychological notions of the primacy of consciousness vis-a-vis free will. He discovered that the biological parameters of motor intention preceded the psychological. His findings remain controversial [55]. The present article, by arguing from philosophical and psychological grounds, extends Libet from motor intention, to intention and volition in general. It suggests that volition is based in based in primary, cerebellar, feedforward mechanisms, with secondary, cerebral feedback. The cerebellum demonstrates the philosophical adequacy, computational efficacy, and is linked with integrative brain systems necessary for the primary operation of volition and consequent control of conduct.

Having operationalized volition philosophically, and psychologically, it must be engineered, neurologically. The cerebellum is composed of a vast number of tripartite, anatomical, fibre modules each comprising mossy fibres and climbing fibres (which enter the cerebellum from outside), and parallel fibres (which are the axons of granule cells). The modules can be conceived as Hebbian cell assemblies [56]. They constitute a 3-layer, hierarchical, feed-forward, error-detection neural network. They synapse with the principal cells of the cerebellum, the Purkinje cells. These are the main output passing to deep cerebellar nuclei. They are inhibitory in nature, and are excited ('tuneable') by parallel fibre projections of granule cells, and by climbing fibre projections from the inferior olive.

James Olds suggested that the neurological architecture of the cerebellum is well suited to the task of temporal coding. In a lecture given in Australia under the auspices of the British Institution, in 1978, he suggested that the small brain is a set of CNS temporal-coding devices. These devices are essentially error-detectors. Time is dynamic, and essentially un-aprehensible. Hence systems of continuous error-detection in anticipation of the ever unfolding present, evolved to compensate for this.

The psychogenesis of will is encompassed by a temporal sequence of three stages. It commences in internal and/or external sub-conscious 'perception.' The former is based in instinct, appetite, memory, and imagination; and, the latter is based in outer external events. In the psychopathology of will, perception is of stressful phenomena, again generated either internally or externally.

The middle stage in the genesis of volition consists in the sub-conscious mediation of the expected, future course of effort by the cerebellar lobe executive. It centres on cerebellar feed-forward mechanisms, and supervised learning. These inferential data combine with data from the past, albeit centering on the continuously surrendered present, from the cerebellar, procedural memory store, and from cortical and subcortical centres.

The final operation, which is top-down, additionally consists in large brain, feed-back processes, and in associative learning and working memory. It consists in the generation and elaboration of consciousness of effort, and the sense of agency. The final stage in the genesis of volition is action, itself hypostasised as a 'volition'. We are now in a position to detail the psychobiological and neurobiological parameters of each of the constituents of the volitional, cerebellar lobe executive.

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