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How the Cerebellum and Cerebral Cortex Collaborate to Compose Fractal Patterns Underlying Transpersonal Experience

(Commentary on Marks-Tarlow's "A Fractal Epistemology for Transpersonal Psychology")

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I offer supportive neurophysiological evidence for Marks-Tarlow's (2020, this issue—all subsequent citations to her refer to this paper) fractal epistemology upon which she provides a foundation for an *inclusive* approach to transpersonal psychology. The contention made in this commentary is as follows: A fractal epistemology for transpersonal events clearly comports with the fractal evolution of the tightly collaborative fractal relationship between the human cerebellum and the cerebral cortex. Before going on, it will be helpful to appraise the reader with background on the recent (last million years) evolution of the collaboration between the cerebellum and the cerebral cortex.

A Cognitive-Neuroscience Breakthrough

Three decades ago, Leiner, Leiner, and Dow (1986, 1989) published two landmark articles on how evolution has made human thought processes uniquely fast, complex, and efficient. Citing the fact that the small *cerebellum* at the back of the brain (see Figure 1 for the location) had increased in size three- to four-fold in the last million years of evolution, they proposed that the connections between the cerebellum and the cerebral cortex (cerebro-cerebellar connections) had evolved not only to increase the speed and skill of bodily movements but the speed and skill of *mental processes*:

> Because the cerebellum is traditionally regarded as a motor mechanism (Holmes, 1939), these cerebrocerebellar interactions are usually thought to confer [only] a motor benefit on humans, such as increased dexterity of the hand (Tilney, 1928). But... a detailed examination of cerebellar circuitry suggests that its phylogenetically newest parts may serve as *a fast information-processing adjunct of the association cortex and could assist this cortex in the performance of a variety of manipulative skills, including the skill that is characteristic of anthropoid apes and humans: the skillful manipulation of ideas* [italics added]. (1986, p. 444)

These two articles were the beginning of a sudden and unexpected breakthrough in the cognitive neurosciences. Leiner, Leiner and Dow's watershed proposal spurred a huge amount of brain imaging research on the cognitive functions of the cerebellum and the cerebellum's massive two-way connections throughout the cerebral cortex—the 40 million nerve tracts between the cerebellum and the cerebral cortex are the most numerous in the brain. This is 20 times more than the two million that connect the eyes with the visual cortex (Leiner, Leiner, & Dow, 1993; Ramnani et al., 2006). Moreover, the human cerebellum contains 69 billion neurons compared to a mere16 billion neurons in the cerebral cortex!

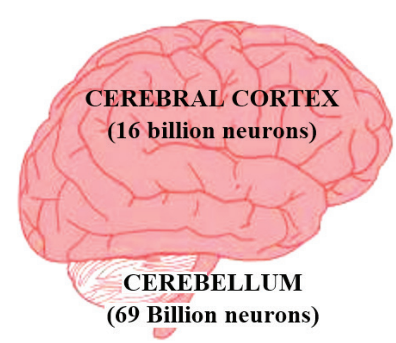

Figure 1. Illustration of the cerebellum in relation to the cerebral cortex along with their respective neuron counts. The neuron counts are based on Lent, Azevedo, Andrade-Moraes and Pinto (2012).

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The Cerebellum and the Rise of Homo Sapiens

During the last million years the *lateral cognitive areas* of the cerebellum seen in Figure 2 expanded greatly. (Note in Figure 2 that the cerebellum is mapped onto *both* the motor-sensory areas of the cerebral cortex, and its cognitive areas as well.) Through the forty million nerve tracts mentioned, these cognitive areas of the cerebellum are connected richly with language, mathematics, working memory, and planning areas of the cerebral cortex (Balsters, Whelan, Robertson & Ramnani, 2013; Hayter, Langdon, & Ramnani, 2007; Marvel & Desmond, 2010a, 2010b, 2012; Vandervert, 2015, 2016a, 2017a, 2017b). This million years of cerebro-cerebellar evolution saw the rise of Homo sapiens and the origins and rise of culture (Vandervert, 2016a). Within the context of this million years of evolution, Homo sapiens are seen not so much about survival in cerebral cortex-driven pitched battles of the moment as they are seen as the product of thousands of generations of repetitive and thus cerebellum-driven cognitive-emotional refinements toward prediction, optimization, and automaticity (Vandervert, 2016a, 2017a, 2017b). These refinements are produced predominantly by computations in the 69 billion neurons of the cerebellum, and they are experienced not only in the automaticity of patterns of culture but in sudden new blendings of experience toward optimized cognition and feeling in creative transpersonal moments. As culture develops, these refinements are progressively shared with other cerebro-cerebellar systems wherein positive feedback loops of transpersonally inspired innovation can leap-frog forward and thus often rapidly and endlessly be further refined.

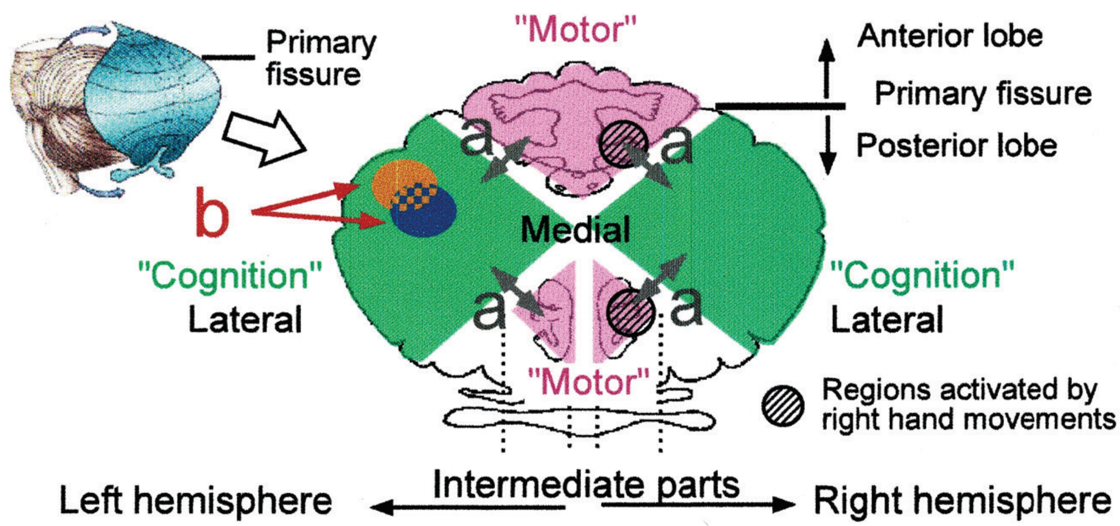

Figure 2. Flattened view of cerebellar surface illustrating that the anterior lobe and intermediate parts of the posterior lobe are related to the prediction, anticipation, and streamlining of "motor and somatosensory functions," whereas the lateral posterior cerebellum is related to the prediction, anticipation, and streamlining of "cognitive functions." To orient properly to the anterior/posterior axis of the flattened view, the viewer should keep in mind that anterior/posterior refer to what is actually a substantially convex cerebellar surface (see smaller drawing to left). Arrows at (a) indicate difference between "motor" (note modularity of somatotopic maps at top and bottom) and "cognition" found in previous neuroimaging studies. Arrows at (b) indicate modularity within the lateral posterior cerebellum for, for example, two different cognitive functions—*many more cognitive areas have been found (see text)*. These motor and cognitive areas are often blended to produce new, creative forms of experience (Vandervert, 2015). .From "Modular Organization of Internal Models of Tools in the Human Cerebellum" (Imamizu, Kuroda, Miyauchi, Yoshioka, & Kawato (2003, pp. 5461–5466). Copyright 2003 National Academy of Sciences, U.S.A. Reprinted with permission.

It is important to note in regard to the sensory-motor homunculi in Figure 2 that, just as the homunculi are completely mapped onto the motor-sensory homunculi in the cerebral cortex, the cognitive functions of the lateral areas of the cerebellum are also mapped completely onto areas of the cerebral cortex only in a much more complex fashion depending on the experiential history or the individual.

To illustrate the analogous point-by-point parallel mapping of cognitive functions between the cerebellum and cerebral cortex it is necessary to briefly discuss the cerebellum's *dentate nucleus*. Most people reading this journal will not have heard of the cerebellum's dentate nucleus. The dentate nucleus provides massive output from the cerebellum to both motor and cognitive areas of the cerebral cortex. The cognitive portion of the dentate evolved directly from the motor portion, and Vandervert (2017b) has argued in detail how this absolutely foundational motor-cognitive connection led the cerebellum to be behind the embodiment of mathematics. The embodiment of mathematics is a major premise of Marks-Tarlow's fractal epistemology. In regard to mathematics, a huge number of nerve tracts going *from* the cerebellum's *dentate nucleus* to the cerebral cortex, includes those going *to* the parietal and prefrontal areas for planning, language and associated high-level functions of working memory (Bostan, Dum, & Strick, 2013; Leiner, Leiner, & Dow, 1989; Marvel & Desmond, 2010a, 2010b, 2012). Based on extensive research studies, Bostan, Dum and Strick (2013) put it this way: "It is likely the signal from the dentate to the prefrontal and posterior parietal areas of the cortex [working memory, executive functions and rule-based learning] is as important to their function as the signal the nucleus sends to motor areas of the cerebral cortex" (p. 3). In sum, the cerebellum plays a predominant role in the refinement and blending of literally all repeated movements, thoughts and emotions (Adamaszek, D'Agata, Ferrucci, et al. 2016; Bostan, Dum, & Strick, 2013; Ito, 1997, 2008; Leiner, Leiner & Dow, 1986,1989)—mathematics is their generalized, collective optimization (see Vandervert, 2017b).

The Evidence for a Fractal Relationship Between the Cerebellum and the Cerebral Cortex

Supportive evidence for the contention of this commentary of a tightly collaborative fractal relationship between the human cerebellum and the cerebral cortex comes from a strong research history of evidence on how fractal processing in the *cerebellum* (which occurs below the level of conscious awareness) is involved in the constant *optimization and automation of* movement and cognitive-emotional processing. *Automation* produced by the computation of constantly optimized or streamlined internal models in the cerebellum (cerebellar internal models are models of what is going on inside the rest of the brain) is in no way robotic; rather it is an integral part of rapid and creative working memory as seen in chess masters, sports super stars (especially in their signature moves), concert pianists, and so forth, all of whom retain the capacity to freely improvise. The whole evolutionary adaptive point of these cerebellar internal models is to constantly error-correct what the cerebral cortex is doing so that it gets faster, better, more automatic, and innovative at whatever it does—see Vandervert (2015) and Vandervert, Schimpf and Liu (2007) for the prominent role of the cerebellum in creativity.

The Cerebellum and Creativity

It may seem that automaticity and creativity would be contradictory processes, but they have been shown to be two intermingled cerebellar strategies toward goal optimization. Vandervert, Schimpf and Liu (2007) first proposed the cerebellum as a source of creativity. Their proposal was based on Imamizu, Higuchi, Toda and Kawato's (2007) findings that the cerebellum is critically involved in the error-correction of blended of internal models. World-renowned cerebellum expert Masao Ito (2007, 2008) expressed agreement with Vandervert et al.'s suggested role of the cerebellum in creativity. I contend that of the more optimized, automated and blended patterns of behavior and cognition-emotion come to underlie the development of all manner of Maslow's (1971) "the farther reaches of human nature" and Csikszentmihalyi's (1975) "flow." More will be said of this below.

Strong Evidence That the Cerebellum Optimizes and Automates as a *Fractally Structured* Sequence Generator

For background on the cerebellum as a *fractal sequence generator of optimization-automaticity*, readers can consult an impressive group of expert findings and varied areas of application in Anderson (2000) and Schmahmann, Anderson, Newton, and Ellis (2001), Pellionisz, Graham, Pellionisz, and Perez (2013) and Rankin, Fink, and Large (2014). And, in general, Pellionisz et al. (2013) quite convincingly argued that, "The cerebellum serves as the best [fractal] platform for unification of neuroscience and genomics" (p. 1381).[1]

In supporting Marks-Tarlow's inclusive fractal epistemology, I will now provide the reader with brief background notes on (1) how the cerebellum learns self-similar internal models to *optimize* and automate prediction of future states of cognitive-emotional affairs, and (2) how, specifically, peak experiences (Maslow, 1971) and flow (Csikszentmihalyi, 1975) can be seen as products of cerebellar optimization and automaticity.

How the Cerebellum Optimizes and Automates the Prediction of Future Cognitive-Emotional States of Affairs

In my own research on the mechanisms behind the development of movement and cognitive-emotional processes, I have described how the cerebellum's *detection of sequences* in movement and thought is, through its participation in working memory, behind the development of high-level genius, child prodigies, culture, and mathematics (Vandervert, 2015, 2016a, 2016b, 2017a, 2017b, 2018). *Sequence detection* in the cerebellum is a key brain mechanism by which the brain *optimizes and automates* the *prediction* of what is coming next *before* it occurs, thus allowing progressively faster, more consistent and more appropriate behavioral and mental prediction, anticipation, and error-corrected models to be sent to appropriate areas of the cerebral cortex. This cerebellar mechanism of sequence detection toward optimized and automated prediction (through constant error-correction) has been described in very similar ways (but independently) by leading cerebellum researchers (namely, Akshoomoff, Courchesne & Townsend, 1997; Ito, 1997, 2008; Leggio & Molinari, 2015) over the last 20 years.

Because I believe there is strong emerging evidence (and I will provide that evidence for in a moment) that this sequence detection toward prediction in the cerebellum may consist of *fractal prediction trajectories*, I provide the earlier team's (Akshoomoff, Courchesne, & Townsend, 1997) description of cerebellar sequence detection in some detail. Before going to that description, it is important to understand that (1) with each repeated iteration of any movement or thought-emotion a new round of cerebellar sequence detection occurs *below the level of conscious awareness*, and (2) this cerebellar sequence detection provides the constantly *error-corrected predictive* power behind cerebellar *internal models* that are sent to the cerebral cortex toward the optimization/automation of performance. (Recall that cerebellar *internal models* are so named because they are models of the internal world of processes going on in the cerebral cortex.)

In brief, with each repeated iteration (or practice) toward achieving a particular goal, the cerebellum detects system sequences and uses them to predict errors in attention, working memory (thought), and movement -- and corrects or adjusts these movement/mental-emotional systems toward achieving the required skill or desired performance level of that goal. Akshoomoff, Courchesne, and Townsend (1997) phrased this cerebellar sequence detection and adjustment process as follows:

> The cerebellum does this [sequence detection] by encoding ("learning") temporally ordered sequences of multi-dimensional information about the external and internal events (effector, sensory, affective, mental, autonomic), and, as *similar sequence*s [italics added] of external and internal events unfold, they elicit a readout of the full sequence in advance of the real-time events. This readout is sent to and alters, in advance, the state of each motor, sensory, autonomic, attentional, memory, or affective system which, according to the "previous learning" of this sequence, will soon be actively involved in

> the current real-time events. So, in contrast to conscious, longer time-scale anticipatory processes mediated by cerebral systems, output of the cerebellum provides moment-to-moment, *unconscious* [italics added], very short time-scale, anticipatory information [which it feeds forward to both motor and nonmotor areas of the cerebral cortex]. (p. 592)

Ito (1997, 2008) has shown how such repetitious, practice-driven processes produce adaptive cerebellar microcomplex circuits which constantly error-correct toward the regulation of "the speed, consistency, and appropriateness" (1997, p. 486) of all motor and mental-emotional processes. In other words, Ito has shown how the cerebellum achieves the regulation of *optimization* and skillful automation toward the achievement of any and all goals! For example, in each practice session during learning to play the piano, shooting baskets, or even fine-tuning drafts of a novel or scientific manuscript, the cerebellum anticipates errors toward the overall goal(s) involved and adjusts each outcome accordingly. Soon, the entire piano piece, for example, is played rapidly and errorlessly as cerebellar internal models are fed forward to motor/cognitive-emotional areas of the cerebral cortex while, at the same time, the pianist may carry on a conversation of any sort paying little mind to what his fingers are doing (see Vandervert, 2016b, 2016c).

Does Cerebellar Sequence Detection Toward Optimization/Automation (a la Akshoomoff, Courchesne & Townsend, 1997) Occur Within an Overall Fractal Structure?

Do the above *temporally ordered sequences that the cerebellum encodes* (Akshoomoff, Courchesne, & Townsend, 1997) have a *fractal* structure? The answer to this question is not definitively known at this time. However, in this regard, Pellionisz, Graham, Pellionisz, and Perez's (2013) theoretical modeling of the fractal computational structure of the cerebellum concluded in part that, "*coordination by the cerebellum is to be characterized by generalized coordinates as in non-Euclidean tensor and fractal geometry*" (p. 1406). Moreover, Anderson (2000) and Schmahmann, Anderson, Newton, and Ellis (2001) argued that the cerebellum provided an overall integrative framework for conscious, emotion, and cognitive processes.

Further, Rankin, Fink, and Large (2014) found that the brain uses fractal structure to predict the unfolding of sequences in music: "[our] results demonstrate that participants use fractal temporal structure to predict tempo fluctuations and temporal structure alone is sufficient to anticipate changes in tempo" (p. 6). Since fractal temporal structure in music is modeled in the cerebellum (Rauschecker, 2014), it is reasonable to hypothesize that cerebellar sequence detection may indeed use fractal structure in modeling the prediction and anticipation of future events in many other (or all) repetitive learning and performance regimes. Examples of such other learning regimes would include, for example, learning and excelling in the execution of skilled expert piano performance, sports skills, chess, and so forth.

Are the Prediction Trajectories in the Cerebellum *Fractal* Trajectories?

Would the foregoing cerebellar mechanisms of selective attention, anticipation, and prediction be *fractal* trajectories?

A preliminary but quite solid answer to this question begins with the considerable work (over three decades) on developmental physiology and evolutionary physiology of John S. Torday. Torday (2016) proposed a detailed fractal model of evolutionary physiology from the single cell to the human brain. He proposed that: "*The reason why physiology exhibits holistic, unitary behavior is because it is fractal. That is to say, it is self-similar at every scale, due to the underlying, integrative mechanisms of cellular ontogeny, phylogeny and homeostasis*" (p. 5). For a directly related, broader discussion of a fractal basis of evolution see Blaisdell, Pottenger, and Torday (2013).

It is important to note here that within this model fractal integrative functions from cell to brain was the basis of life's origin and its adaptive survival, and the evolving functions of the evolution of the cerebellum would of course have been and continue to be critical to that survival. I will return to this important point in a moment.

Directly within the context of Torday's (2016) quote that *physiology is fractal*, he provided a description of the iterative fractal mechanism:

> The organism can evolve in response to the ever-changing environmental conditions, the genes of the germline cells *"remembering" previous iterations under which they (by definition) successfully mounted an adaptive response* [italics added]. Then, by recapitulating the germline-specific GRNs [Gene Regulatory Networks] under newly-encountered conditions, they may form novel, phenotypically-adaptive structures and functions by recombining and permuting the old GRNs. This process is conventionally referred to as "emergent and contingent". It explains how and why the same GRN can be exploited to generate different phenotypes as a function of the history of the organism, both as ontogeny (short-term history) and phylogeny (short-term history), the germlines orienting and adapting the internal environment to the external environment by expressing specific genetic traits. (p. 7)

A way to understand the italicized memory portion of the above quote in fractal terms is that *fractal iterations contain the most information about the future from the past on all time scales* (see, for example, Anderson & Mandell, 1996, pp. 77-86).

Is Sequence Detection in the Cerebellum a *Part and Parcel* of Torday's Model of Fractal Physiology?

Today's (2016) quoted fractal progression of the evolution of physiology quite closely parallels Akshoomoff, Courchesne, and Townsend's (1997) adaptive-predictive sequence detection process described in their earlier quote. The reader is asked to take a moment to note the parallel iterative memory mechanism of the cerebellum (lines 1-3, Akshoomoff, Courchesne, & Townsend quote) and that of the genes of the germline cells (lines 2-5, Torday quote). Torday refers to this process as fractal iterations; sequence detection in the cerebellum can reasonably be interpreted in the same way. One might speculate along with Vandervert's (1990, 1996) fractally based neurological positivism that Torday's model of fractal physiology is a product of Torday's own, personal adaptive, fractally-driven cerebellum—in other words, "it takes a fractal to know a fractal" (Anderson & Mandell, 1996, p. 115). Or, more directly pertinent here, it takes a fractal cerebellum (a la, Pellionisz, Graham, Pellionisz, &Perez, 2013), to know a fractal mathematics (a la, Vandervert, 2017b)—as cited earlier, Pellionisz et al. quite convincingly argued that, "The cerebellum serves as the best [fractal] platform for unification of neuroscience and genomics" (2013, p. 1381).

The Origins of the Transpersonal Experience of "Flow" (á la Mihaly Csikszentmihalyi's Example) in Internal Models Learned in the Cerebellum

The experience of "flow" in Csikszentmihalyi (1975) was described as beginning with play and as an *enjoyable* experience that accrues from a focused development of high levels of skill (in for example, mountain climbers, chess masters, composers of music, modern dancers, inveterate gamblers), and it is experienced as:

> …the state in which *action follows upon action according to an internal logic* [italics added] which seems to need *no conscious intervention* [italics added] on our part. We experience it as a unified flowing from one moment to the next, in which we feel in control of our actions, and in which there is little distinction between self and environment; between stimulus and response; or between past, present, and future. (p. 43)

Here is the essence of the cerebellar connection between play, flow and creativity: «Flow» in my scheme (like play and creativity; Vandervert, 2015, 2016, 2017a, 2018) is produced through cerebellar *inverse dynamics models* which are learned from focused repetitious movement and mental experience starting in infancy and continuing throughout life in, for example, Csikszentmihalyi's mountain climbers, chess masters, and so forth. See Vandervert (2017a) for discussion of cerebellar inverse dynamics models. Once learned through focused repetitive effort, cerebellar *inverse dynamics models* automatically (and below the level of conscious awareness) flow to and though the cerebral cortex unconsciously tripping optimal (including creative movement and thought-emotion) and automatic response patterns in movement, thought and feeling—this, I argue, is how the TRANSPERSONAL experience of FLOW is propagated (see http://blogs.biomedcentral.com/on-biology/2017/05/25/the-cerebellum-a-new-horizon-for-brain-studies-of-the-genius-of-albert-einstein/).

Concluding Comments

I end this supportive commentary for Marks-Tarlow's fractal epistemology with a quote from where I began: "A fractal epistemology for transpersonal events clearly comports with the fractal evolution of the tightly collaborative relationship between the 69 billion neurons of the human cerebellum and the cerebral cortex (which contains a mere 16 billion neurons)."

We can hypothesize that transpersonal experience is solidly based in the fractal anatomy and physiology of the brain (Pellionisz, Graham, Pellionisz, and Perez's (2013); Torday, 2016) and proceeds in a self-similar manner finally reaching a fractal pattern that optimizes a bodily/mental sync (via the earlier-mentioned motor/cognitive dentate nucleus) that thereby, feeds forward within that system—it "flows."

That this hypothesized fractal cerebellum is predominately behind these highest of experiences can be seen in what happens *both* when things in the cerebellum go right, for example in child prodigies (Vandervert, 2016b, 2016c) and when things in the cerebellum go wrong. The latter case of cerebellar processing going wrong has been well established in leading cerebellum researcher Schmahmann's (2004) cerebellar cognitive affective syndrome:

> It [the cerebellar cognitive affective syndrome] is characterized by (1) disturbances of executive function, which includes deficient planning, set-shifting, abstract reasoning, working memory, and decreased verbal fluency; (2) impaired spatial cognition, including visual-spatial disorganization and impaired visual-spatial memory; (3) personality change characterized by *flattening or blunting of affect and disinhibited or inappropriate behavior*; and (4) linguistic difficulties, including dysprosodia, agrammatism and mild anomia. *The net effect of these disturbances in cognitive functioning was a general lowering of overall intellectual function* [italics added]. (p. 371)

Notes

1 While not specifically germane to this commentary, for a general corroborative fractal analysis of the overall evolutionary branching of species, see Nottale, Chaline, and Grou (2002).

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