

# Hand, Eye, Brain: The Neuroscience of Blind Contour Drawing

Gary R. Peterson

As an artist/scientist, I've often practiced the following exercise: I draw a picture of some object while looking only at that target object and *not* at the pen hand or the drawing itself until it is done (see Teacup example). It's called blind-contour drawing. The finished drawing does not match up very well with the overall form of the original object. Unlike tracing the borders of an object through a transparent overlay, there's no visual comparison allowed to help my unseen pen emulate on a remote sheet of paper the path that my eye follows around the isolated target object. My earlier investigations into the disfigured character of blind contour drawings pointed to the basal ganglia as the area of the brain where hand-eye coordination goes astray but I will now examine the role that the cerebellum (CB) plays in hand-eye coordination—or in this case, disconnection.

I've never directly examined a human brain, never held one in my hand or poked my fingers in the ventricles. My interest is in systems analysis and computational neuroscience. Still, that involves some knowledge of cytoarchitecture and maybe even gross anatomy. I do have a friend, a PhD in neurobiology, that I'm pretty sure—for a steak and a beer and maybe a side of horseradish peroxidase—could get me into the lab for some hands-on with a brain specimen. I might even audit a class in neurophysiology. But thanks to the library and the internet, I already know more about the brain than a boy scout knows about knots.

There are hundreds of types of brain cells, each a discrete little unit of conditioned behavior. Some are inhibitory and others excitatory to their cellmates. Neurons are special nerve cells that connect us to the outside world through our five physical senses. The list of electro-chemicals—hormones and neurotransmitters (like, say, dopamine just for fun) that fuels them is extensive and more are being discovered all the time. Considering all the possible connections, combos and configurations of cells that affect our behavior and constitute subjective reality, those that conjure instincts or execute formal strategies allowing me to orchestrate even a simple line drawing, it is an amazingly concerted effort. That brain's neural networks are like cascading gates of logic that can read nuances as subtle as a flared nostril, a slightly flat musical tone, or some stilted artifice such as liking something as opposed to not disliking it. Looking at marks on paper, what you see is what you get, a drawing, whereas marks on sheet music may tell the band to give it a rest, but for lack of compliance—or a lesion in the cerebellum—one might hear snapping gum and cell phones instead of pure silence. If our perceptions were as simple as a “you are here” pointer on a tangled schematic of a trillion brain cells that form the structural embodiment of cognition and gives rise to processes that even the most ardent researchers and theorists are hard-pressed to describe let alone explain, then the insights provided in a single essay by some high-minded blogger (yep truly) might suggest that consciousness emerges like verticality from a spinning top much like the vestibulo-ocular reflex and the cerebellum keeps us on our toes (with an eye on the ball). As another point of interest, research has linked the posterior cerebellum to happiness. I'm serious.

The basal ganglia (BG), a conglomerate of cell groupings in the mid-brain, promote intuitive thinking needed when planning a strategy to reduce the cumulative drift of my unseen pen hand while I blindly trace a visible curve. Prediction enhances perception. I recently felt a buzz in my basal ganglia as I was solving a Tower of Hanoi puzzle, vaguely sensing a pattern of alternating steps needed to move five disks in proper order from one of three columns to another—but I digress. Early on in a blind drawing exercise, the BG defers to the cerebellum for coordinating motor commands, both hand and eyeball. The striatum area of the BG receives signals from the motor cortex about whatever action it is trying to do, and forwards this hand-eye movement info via the thalamus to the vermis, a worm-shaped structure of cells mid cerebellum. The BG is also well-connected to the premotor cortex but in this case might send it more intuitively biased signals than if the drawing hand was visible to the eye. So the discrepancy between the actual and rendered object does indeed register in BG. Both the basal ganglia and the cerebellum exert control over proprioceptive (joint and muscle) feedback. Nerve cells in the muscles, skin, and joints send info about limb position and movement—which now becomes a critical proxy for visual feedback—up to the precuneus that straddles the central brain crevice towards the back of the medial intra-parietal cortex. This is near the occipital junction where the saccading eyeballs also report their directional status for integration with motor commands to the hand. The precuneus and Brodmann area 7 will figure largely, shortly.

Blind contour drawing is an example of a feed-forward control process; it doesn't look for discrepancies between the target object and the tracing, it just keeps the pen plowing ahead. Not so coincidentally, the cerebellum is also a feed forward neural network that aligns visuomotor data as supporting evidence to the preconceived notions formed in the premotor cortex when visual stimulation is put into the loop. The cerebellum has a learned repertoire of motor skills that provide guidance for adaptive behavior in the motor cortex as needed. Each neuron in the cerebellum's hierarchical network fires according to its natural function of simplifying the net configuration of cells in subsequent layers until the viewed object is "recognized," then a final output neuron disinhibits a paired cell in the motor cortex, giving it the "go-ahead" to let the drawing hand do its thing. The cerebellum continuously models pen-to-target projections to estimate the results of the motor commands and predict errors even without visual feedback. This retrograde regulatory mechanism (think ice strainer) allows electrochemicals stored in brain cells (not unlike gin or vodka) to modify the synaptic strength and firing rates of other receptively attuned cells (add vermouth) into a state that induces premotor intentions (shaken, not stirred) towards a desired result—a lame cocktail metaphor (martini) or the actual drawing task at hand. Any visual error signals returned to the cerebellum are normally transmitted via climbing fibers from the inferior olivary nuclei in the medulla oblongata, but due to the hand being hidden those signals don't exist. FYI, the cerebellum is attached to the brainstem just under the forebrain. It reminds me of a power steering unit clamped to the engine of a car except the mounting bracket isn't a brainstem and fan belts are not neural loops. But speaking of the brain stem, that's where the aforementioned medulla and its olive are located. Please don't drink and drive. Drawing is permitted.

The feed-forward structure of the cerebellum lends itself to so-called "supervised" or adaptive learning; Input data about direction and magnitude of hand force reduces to an accurate approximation of the desired output signal. This sounds like the neural substrate for inductive reasoning to me—but again, another discussion. In contrast, "unsupervised" learning is a deductive process by cells acting as logic gates in the high-minded cerebral cortices for tasks like the synthesis and expression of abstract concepts (but deeper meaning isn't our objective here). The basal ganglia are well-suited for "reinforcement" learning where a strategy is tested to minimize drifting errors that nevertheless culminate in floating heads and wall-eyed facial expressions—the often amusing but unintentional symptoms of blind contour drawings. It helps to compartmentalize the developing drawing into localities through which the pen need travel but once thereby reducing the cumulative effect of errors in scale and position that otherwise become more exaggerated with each saccade of the eyeball as it advances along the object's borderlines. Regional tracking cobbles together successive parts rather than outlining the whole and then spiraling inward. This seems to distribute the blind error factor more equitably across the overall picture. Meanwhile, the anterior cingulate (AC) area of the brain is likely involved in any drawing exercise that requires me to focus my attention. This inner cortex also detects whenever strategies—like those conjured in the basal ganglia, go wrong. But without the normal cues of visual feedback, it doesn't send up any red flags—at least until after this drawing is done, at which point the AC might go a little nuts.

When I want to draw a line, an impulse from the premotor cortex signals my intention ("free-will" implications entailing yet more philosophy) to the cerebellum for estimations and calibration of the kinematic parameters—the pen trajectory and muscle force required for said action, including gripping the pen, so that it can report to the primary motor cortex and perhaps convey some commands directly to the spinal neurons that actually conduct the movement. Interestingly, some cells in cerebellar nuclei (CN) fire in advance of the hand movement while others lag behind time wise suggesting that, despite its feed-forward nature, both impulse *and* feedback signals are in play in the cerebellum; It sets the drawing hand in motion and *then* adjusts motor commands based on feedback, visual or otherwise, from the recurrent networks of which the cerebellum is a part.

The cerebellar cortex contains Purkinje cells (PC) after a guy named Purkyne. These big cells are triggered by parallel fibers (axons) from the tiny but plentiful granule cells—about a half-million fibers for each PC. Parallel fibers get their mojo via mossy fibers and then, along with potent and excitatory climbing fibers from the medulla (which keeps a running dialog with premotor cells) they hook up with Purkinje dendrites. These dense oak-treelike arbors branching out from each one of the P-cells are all flattened out and layered to form a matrix with said fibers running perpendicularly through them forming excitatory synapses at each of the mega-multitudes of dendrite connections. Then, like cascading logic gates in a computer, the PCs transduce the data and funnel the info, encoded as inhibitory signals, down to the deep cerebellar nuclei for output to the motor cortex. (By "signal" I generally mean the chain reaction of electrical impulses propelled along brain cell axons due to a voltage differential between sodium and potassium on either side of a myelinated membrane thereby bumping a molecule into an appropriate

receptor across each synaptic gap in the chain.) On a microscopic level, the distinctive mass of the cerebellum seems somewhere between vast and infinite but probably isn't much bigger than a toadstool. I calculate that if each Purkinje cell actually was the size of an oak tree, then your head would be about seventy-two miles wide (not five million miles as originally noted). Nevertheless, layered P-cells and the parallel fibers running through them form the neural grid of a super calculator.

Most Purkinje cells release the neurotransmitter GABA (gamma-aminobutyric acid), which is inhibitory as opposed to the excitatory action of glutamate in the various other fibers. With vector data from the firing rates of eye, hand, and target cells, simple voltage spikes cascade down through the array of PCs and the output signal, now represented in a single cell, disinhibits the CB interposed nuclei to allow, say, wrist movement. However, evidence suggests that this might only occur for complex motions involving more than one joint, say, the elbow *and* the wrist. Simpler tasks may default to some other brain area altogether. Any visuomotor commands will correlated to feature detector cells that fired in the visual cortex when the eye met the external target object. Yet if the target was seen but the hand was hidden, I can't blame the cerebellum for the telltale symptoms of insufficient visual feedback, e.g. scrawling pen syndrome. Terms like "blind," "estimate," "predict," and "error" suggests why the fidelity of blind rendering is laughably low. It seems like pyramidal type brain cells would be more suitable for fine motor control. They have graduated inputs and outputs to actuate variably subtle or forceful signals and indeed they're found in certain cortical loops, particularly the frontal cortex (headquarters for short-term memory and executive function) but it is the size, density, and monotonous uniformity of the Purkinje cells and their all-or-nothing disposition that make the cerebellum such a robust device for the fine computing involved in both motor and, surprisingly, cognitive tasks. The cerebellum, while making up about only ten percent of the total area of the brain, contains about half of the sum total of all neurons.

Back to the exercise, I start a new drawing by first sizing up the blank paper as a frame of reference, gauging a starting position by the touch and reach of my soon-to-be-unseen hand that will guide the pen based only on the implicit perceptions of my motor impulses, blindly hoping its path will accurately transcribe the contours of the target, a teacup and spoon for example, on which my eyes are focused. Without seeing the pen's trajectory, the impulses from my hand and eye muscles translate into a visual proxy by which I emulate the outlines of the target. Beyond the retinas in my eyeballs (and past the lateral geniculate nuclei that mainly sorts out color signals), increasingly complex arrays of feature detector cells in Brodmann area 17 at the back of the head—each attuned to a specific angle, contour, and location of the teacup in my visual field—spark accordingly. The dialog between my motor cortex and my hand informs the parietal lobe of my brain about the orientation and scale of the invisible trace. That mental representation of my unseen hand is concurrent with a different internalized image of the target object that forms in the medial temporal lobe. These two visual aspects are experienced as one and also resonate in the cerebellum where it is synchronized in part by the varying speeds at which data is propelled along pathways of differing cell types (magno or parvo) during the initial feed-forward sweep through my brain.

Soon after the light patterns from the external object stimulate my retinas, Brodmann area 17 (in the occipital lobe, a.k.a. visual cortex) not only detects edges but sorts out border ownership on the boundaries of light and dark that entered my eye. The orientation of the object's angles and curves determine the frequency and firing order of the feature cells which are in cortical columns that traverse the six layers of pyramidal, granular, and ganglion cells comprising the striate cortex. Tallying the total of cell firings across this internal visual field is what determines edges. These formal properties of the target object continue downstream on two different signal paths towards the prefrontal cortex via the temporal and parietal lobes respectively. Info relayed to visual area V1 is already reduced to outlines but it sends progressively non-linear info to subsequent regions. The ventral stream—the “what” pathway—starts in V1 and heads for areas V2 and V4 and is associated with form recognition and object representation while the dorsal stream, the “how” or “where” path, is another likely area of discrepancy between the object and the idealized trace that projects to V3 in the parietal lobe before the two paths hook up again in the temporal lobe. The prefrontal cortex helps determine whether or not any visual feedback from my pen hand is available for fine-tuning the trace. In this case it's not.

The parietal lobe attends to spatial organization and integrates the information, synthesizing a master plan: the *egocentric* map located in the precuneus on the inner faces of the central brain fissure in Brodmann area 7. It solicits the memory-reconstruction apparatus of the temporal lobe which returns its objective view of things back to the staging area V1 where both sensory and mental imagery can coexist while keeping the motor cortex and cerebellum in the loop for interacting with the external object. Not only the hand, but the eyeball needs a coding scheme to rotate its view from one point of interest to the next. This movement is directed by a little hump of cells deep in the midbrain between the cerebellum and corpus callosum (the bridge connecting east and west hemispheres of brain world). This steering wheel for the eyeballs is called the superior colliculus. Impulses from that wheelhouse not only tell the eyeballs where to move but also inform the viewer, me, that it is indeed my eyes that are moving and not the world around me. This involves the frontal eye field, another node of cells in the frontal lobe that specialize in voluntary eye movement around a stationary object as opposed to the more instinctive reaction of tracking a moving target in which case the vestibulo-ocular reflex would kick in to coordinate eye and head movement with the target. Yet, when monitoring a stationary object—but no view of the drawing hand—predicting the state of the hand is blindly inferred by the motor commands regarding position and trajectory. It's like drawing a picture based on a conversation between the muscles and joints—gossip overheard in the temporal lobe. But then, motivating the hand on verbal instructions instead of visual cues is not such a far-fetched notion considering that the temporal lobe is also the seat of language processing. Nevertheless, the script is actuated in the precuneus and the cerebellum dutifully accepts that fabricated scenario (phantom hand and all) as authentic. With each saccade of the eyeball, the kinematic parameters for the tracing hand are continuously re-estimated relative to the benchmark of the wrist-anchored pen hand.

I'd like to compare two scans of my brain, one recorded while I was tracing the outline of an object with a pen on a transparent overlay, and a second scan generated while viewing

the same object but drawing it on an isolated sheet of paper obscured from my view. Up to ninety percent (90%) of the same brain areas that are activated during the normal line tracking are also active during the blind contour exercise. But when both brain scans are compared, where in the brain circuitry would the small ten percent (10%) discrepancy lie? I'm beginning to think it might be in the *allocentric* map described below.

Multiple internal representations underlie the normal experience of vision but I have infused additional multi-sensory data with the imaginary, i.e. self-generated, view of my hand in order to elicit the desired motor impulses to guide the pen along the path. The internal representation of the external target object, which normally includes a view of my drawing hand, is called the allocentric map: an extrinsic representation of objects based on the spatial relationships between the hand, eye, and target but with no sense of self. This is evidenced by the increased firing rates of a certain populations of brain cells including those in the medial temporal lobe, of all places, because it involves spatial *memory*. That means the hippocampus—a mid-brain distribution center to the memory bank, is probably involved too. Timing is critical factor and the allocentric map arrives via the magno path which means it gets there fast and early in the vision process allowing it to compare notes with the *egocentric* view—the first-person perspective which is found in the parietal lobe, a topographically shorter but slower route.

The egocentric map is based on a person-to-target relationship—that is, a self-referential, eye-centered representation that forms on the precuneus in the parietal lobe. This map is the so-called “mind’s eye,” a mental worksheet for spatial and temporal scaling of hand, eye, and target that heeds proprioceptive input from muscles and joints as well as visual feedback. The precuneus is also a seat of consciousness and self-awareness. Curiously, it is like some other identity sensitive brain areas such as the insula and fusiform gyrus, in that it is hidden in a deep, dark crevice. The fact that the precuneus also serves to decipher musical melodies is an interesting trait beyond the scope of this discussion except to say it has a lot on its plate. It’s also linked to the retinas which project to opposite sides of the brain from their respective eyeballs. For the record, I’m right-handed but I’ll ignore the contra-lateral effects of the dominant side of my brain that may figure into the equation. It has been suggested that “blind” drawing tilts the process from the logical left hemisphere to artistic right half of the brain that favors spatial and relational input. Regardless, the nuances of motor activity can hinge on disparate parts of the brain. Drawing a single straight line in one direction may activate either the right dorsal premotor area or the left cerebellar cortex depending simply on whether the pen speed is increasing or decreasing.

The brain cells underlying both the objective allocentric view in the temporal lobe and the subjective egocentric view in the parietal lobe each project to and from the retrosplenial cortex (RC), a small region deep in the cingulate cortex and at the end of a tongue-like extension that sticks down from the parietal lobe and licks the cerebellum. It is an important crossroad through which visual info passes but doesn’t linger. The RC is a critical node for aspects of attention and tracking that also links Brodmann area 5 to area 17 (first stop for all visual input). This area is also well-connected to the hippocampus and implicated with many functions including memory, navigation, imagination, and

planning. It can even spark an emotional charge (not unlike the sparks I recently got while wiring a three-way switch in my home) which may lend visual emphasis by over-sizing certain details in the developing line drawing. Plasticity and synaptic scaling in feed-forward circuits provide the attention-focusing component to said emotional charge perhaps explaining why the more interesting aspects of anatomy in my figurative drawings, e.g. heads, hands, faces, boobs etc., often end up appearing ten percent bigger in scale than the rest of a depicted body. Meanwhile, the retrosplenial cortex also projects to the lateral cerebellar nuclei via the slower parvocellular pathway through the thalamus. Most everything goes through the thalamus.

Neural gain fields are an important concept to mention: The amplitude of action potentials in brain cells can combine like constructive interference does in wave theory, allowing multiple reference frames to add up or boil down to a single motor command. Unlike feed-forward controls, they use internal feedback to fine-tune output signals. The egocentric map is such a gain field construction. It fills in the blanks left for want of a visible hand in the allocentric map by giving added weight to proprioceptive input. This too could account for the exaggerated details and general character of my pen and ink drawings, the cartoonish transmogrifications that the art world has yet to embrace. In another wildly indulgent anecdote, I'm reminded of once having completely rebuilt my motorcycle gearbox only to find a small internal part left on the workbench. Fortunately, it had no operational effect on the bike when I took it for a spin, unlike my blind contour drawings in which there is definitely a screw loose.

To summarize the purpose of this visual exercise, my drawing hand is monitored only by my mind's eye, a mental image based on proprioceptive feedback, not by what my real eye would see if it looked at the drawing while it was developing. It's like flying by instruments versus visual flight regulations. Yet, it's mostly the same set of brain cells that fire up whether I use a fabricated view of my drawing hand, or actual visual input. That small discrepancy in cell activity between the two wiring configurations—sensory vs. guesstimated, is what I'm about to identify.

The precuneus is now encoded with a self-generated “view” of the hand interacting with the target object. Studies indicate that to achieve this type of visual integration—and here's the discrepancy I've been searching for—the *egocentric image moves slightly forward* and forms its gain-modulated representation onto the anterior portion of the precuneus whenever, as in this case, the hand is obscured from eye! From there it projects to the nearby motor and dorsal premotor cortex. The discrepancy is not in the cerebellum after all. Imagination, preparation, and execution of movements have all been found to overlap and activate ventrally in the brain from BA 7 to BA 5 when integrating proprioceptive input (hand coordinates) to the visual aspects otherwise found dorsally in the precuneus. The downstream coordination of hand commands can now project to the cerebellum from the premotor area (the precuneus has no direct projections to the cerebellum). So it's Brodmann Area 5, a lateral swath of brain situated near the top center of the head immediately forward of the medial intra-parietal cortex and just behind the somatosensory area—i.e. “touchy-feely” gyrus across the gap from the motor cortex—

that receives any eye-centered reference frame built on gut feelings in lieu of normal visual feedback.

So, if comparing two brain scans—one taken while hand-tracing some target object compared to blindly drawing the same—the biggest discrepancies between them are some atrophic idling found in the medial temporal lobe where the allocentric map is starved for visual feedback from the hand, but even more so in the neural traces of the egocentric map, where a noticeably whack rendition results from the distorted signals of cumulative best-guesstimates that coalesce *slightly forward* from a normally dorsal location in the precuneus of the parietal lobe. Talk about “lost in translation!”