Laterality of Motor Control and its Robotic Applications: A Paper and Pencil Method for Lateralizing the Major (Action, Thought) Hemisphere.

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Iraj Derakhshan

Laterality of Motor Control and its Robotic Applications: A Paper and Pencil Method for Lateralizing the Major (Action, Thought) Hemisphere

Iraj Derakhshan M.D.[1,2]
[1]Comprehensive Neurology Inc., Charleston, West Virginia, USA
[2]Mimicking Man Manually Inc., Charleston, West Virginia, USA

Abstract – *In making use of movement related cortical potentials (MRCPs) to facilitate movements of a cursor or that of a robot it is important to determine the laterality of the action hemisphere in the individual concerned. The hemisphere of action is the hemisphere from which all commands are issued regardless of the laterality of the effector that carries out the said command. The action hemisphere lies on the left in ~ 80 percent of the people and on the right in the remainder. In this article I review further evidence for such an arrangement in humans and discuss a paper and pencil test that allows the lateralization of the action hemisphere in normal circumstances. This is based on the fact that the side contralateral to the action hemisphere makes wider excursions than the other side, since moving the nondominant side of the body requires participation of the corpus callosum in order to convey the necessary command from the action (major) hemisphere to the minor hemisphere.*

Keywords: command center, action hemisphere, motor control, decision maker, robotics

Introduction

Although observations concerning asymmetrical performances of the two hands in bimanual simultaneous drawing tasks date back to the nineteen century (Carter, 1876; Hall and Hartwell, 1884), the reason for this asymmetry has not been elucidated. Recently, it has been shown that central control for all commands (irrespective of the laterality of the side that carries them out) lies in the left hemisphere in ~ 80 % of the population and in the right in the remaining population (Derakhshan, 2003a, b; Derakhshan, 2004; Derakhshan, 2005 a, b, c; Derakhshan, 2006a, b, c; Derakhshan, 2007). Since the command for moving the nondominant side must first travel through the bridge connecting the hemispheres (called corpus callosum) before reaching the minor hemisphere (dedicated to the affairs related to the nondominant side of the body) the nondominant side always lag behind the dominant by an interval commensurate to the interhemispheric transfer time (IHTT). Neurally, the dominant side of the body is on the opposite side of the action (major) hemisphere and the nondominant side of the body lies beneath the same (ipsilateral). It has been shown that behavioural handedness is a rough estimation of the abovementioned arrangement (i.e. neural wiring). It is well known that the two handedness groups are nonhomogenous and that this aspect is more pronounced among the left handers (Goodglass and Quadfasel, 1954; Mohr et al, 1980).

Material and Methods

In this article I provide further evidence, obtained in the course of routine neurological examination of patients, concerning the circuitry underpinning brainedness (i.e. laterality of command center, major hemisphere) by providing illustrative cases of my own, in addition to those reported in the literature that were overlooked or ignored by the authors of those studies. In administrating the test care was taken so that only the pens were contacting the paper, to avoid friction as a confounding factor. It is well known that when administering such tests the subject must not be engaged an another activity, such as speaking or humming, as double tasking will affect the performance of the dominant hand disproportionately to that of the nondominant (Hiscock et al, 2006). Finally, on occasion the test was done with the eyes closed to improve performance by reducing distraction (Hall and Hartwell, 1884).

A Review of the Newly Discovered Circuitry

Contrary of the common sense, expressed in the statement that "there is no a priori reason to expect one hand to consistently lead the other," in bimanual exercises (Helmuth et al, 1996), overwhelming evidence indicates that it takes more time to move the nondominant side of the body under any circumstances. As stated earlier, this is because moving the left side in right handed subjects involves activation of both hemispheres (see below for the explanation of exceptions) as opposed to moving the right side which is handled entirely by the contra-lateral (left) hemisphere (Derakhshan, 2005b, Derakhshan, 2006b; Babiloni et al, 2003; Urbano et al, 1996). Thus, commands for all movements are issued by one hemisphere irrespective of the moving hand, the left in 90 % of right handers (Johansson et al, 2006; Derakhshan, 2005a, b; Derakhshan, 2006a, b). Thus lesions affecting the major hemisphere affect movements of both sides of the body whereas those of the minor hemisphere affect the opposite side only (Wyke, 1967). Clinically, this consists of paralysis of the side opposite to the injury and of the inability to perform properly with limbs on the same side as the lesion (apraxia, in neurological parlance). The exceptions to this rule occur in those whose behavioral handedness and neural wiring (see above) does not match; a group which had been wreaking havoc in our complete understanding of the hemispheric functions until recently. To this day, large numbers of candidate for seizure surgery undergo un-necessary ablative operations (including hemispherectomy) on the wrong side of the brain. This is significant since data indicate that only the action (major) hemisphere can initiate seizures; the nondominant (minor) hemisphere being bereft of any motor ability of its own (Derakhshan, 2005c, Derakhshan, 2006a).

This callosum-mediated-lag of nondominant side of the body, for example, is represented as a wider excursion of the right diaphragm compared to the left when breathing quietly or with force; a finding repeatedly made in ultrasonographic and magneto-encephalographic measurements of movements of the diaphragm (Houston et al, 1992; Fedullo et al, 1992; Gierada et al, 1995; Raichra et al, 2001; Kiryu et al, 2006; Yoshioka et al, 2007).

The same asymmetry is evident when moving the hands in the vertical meridian (up-down or reverse). In activities of daily life, the first documented instance of laterality of motor control in this dimension, i.e. the melody lead of the right hand in piano players, was made by using piano role music of classical pianists of the nineteen century (Derakhshan, 2003b). Prior to the discovery of the circuitry which underpins this asynchrony when strict simultaneity was intended by the player the phenomenon was ascribed to mechanical causes in piano making or was explained away as an artistic expression (Goebl, 2001).

I do not know of a quotidian expression of the laterality of motor control in the horizontal meridian except one displayed in playing string instruments, i.e. the earlier activation of the bowing hand (right) compared to the fingering hand (left) in violin playing by ~ 70 milliseconds (Baader et al, 2005). Evidently, this will provide for the readiness (vibration) of the string before the actual sound is made by fingering, permitting flowing production of the next note. Another example in the same gendre is the drum player's "flam," an onomatopoeic expression of what is heard when the drum is hit "simultaneously" with both hands (producing a grace note appearance).

That while drawing simultaneously with both hands "the left hand will lag behind the write and will move with less freedom, so as to draw a small curve and draw it more slowly" was noted by Sir Robert Brudenell Carter (1876), an ophthalmic surgeon who wrote concerning the importance of bimanual coordination in cataract surgery. He also noted that attempts to remedy the delay of left hand are achieved only by manipulating the force applied to the paper by the right hand, impeding its progress. A few years later, in 1884, Hall and Hartwell formally examined the issue by asking right and left handed subjects to move their index fingers along a graduated yardstick. They recorded that in moving the fingers from the opposite ends of the same stick the fingers met to the left of the midline in the right handed subject (and to the right in the left hander); also because of the differential speed of the two hands when moved "simultaneously". The neural underpinning of the above two observations was alluded to earlier with details provided elsewhere (Derakhshan, 2006a, b).

Following Poffenberger's experiments in 1912, it was known that, in responding to a lateralized stimuli, the response of the two sides of the body was asymmetrical (one side responds faster than the other). Mistakenly, however, this had since been ascribed to presumed sensory transfer from one hemisphere to another in the posterior aspect of the corpus callosum (i.e. from the hemisphere "receiving" to the hemisphere "responding" to the visual signal, to which the subject responded by one or the other hand by pressing a button). It turned out that callosum had no role in vision (Derakhshan, 2004; Derakhshan, 2007) because the asymmetry remained unchanged even if the subject responded with his/her eyes closed (Derakhshan, 2006b; Savage et al, 1993).

According to one-way callosal traffic circuitry, the larger excursion of the dominant side in bimanual drawing tasks is due to the fact that the left side of the body remains stationary until the commands issued for such movements passed across the anterior callosum to reach the minor hemisphere (responsible for implementing such commands). This is clearly seen the larger diameter of the circle drawn by the right hand of a right handed subject depicted in Fig. 1 of Kennerley et al (2002) and in the length of line and diameters of circles in experiment 1 of Robertson et al (1999, table 2). Kennerley and colleagues also documented the slight lead of the right hand in circle drawing test they conducted on their subjects. Neither of aforementioned authors, however, commented on such glaring laterality indexed differentials (asymmetry) revealed in their experiments. In another article on the same subject, the same authors took the behavioral handedness of a left handed subject at face value (patient V.J.) only to express puzzlement at their own finding of the lesser variability in the performance of the ostensibly nondominant (right) hand of their left handed callosotomy patient (Ivry et al, 1999 p. 360). According to the new understandings derived from one-way callosal traffic circuitry, this patient was a neural right hander who adopted the left hand as her favorite at an early age (Derakhshan, 2006b). The reverse of this situation occurred in subject # 7 in the article by Viviani et al (1998) from which Table 1 is reproduced. Cases TM, CG, and ST in the present article all fall in the same category.

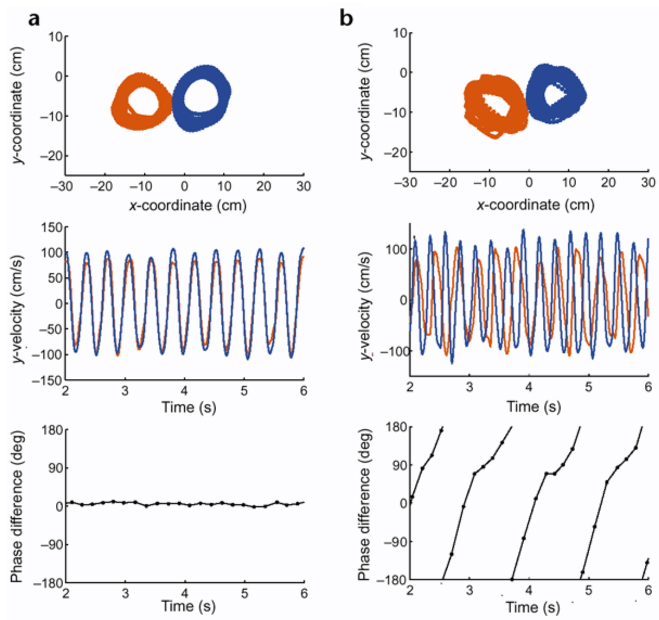


Figure 1. Temporal uncoupling during a single trial of symmetric, maximum rate circling in a patient. See text for explanation. (**a**) Control subject. (**b**) Callosotomy patient VP. Position (top) and velocity along the *y*-axis (middle) of all the cycles within a single trial for the left (red) and right (blue) hands. Bottom, relative phase relationship between the two hands. Point estimates of relative phase were calculated by determining the time of occurrence of every North/South point of the non-dominant hand relative to two successive North/South points of the other hand. Negative values indicate a left-hand lead. The control participant shows synchronous movements with a stable phase relationship. For the patient, the right hand cycles at a higher frequency, causing a continuous drift in the phase relationship (that is, phase wrapping). From: Kennerley et al. Callosotomy Patients Exhibit Temporal Uncoupling During Continuous Bimanual Movements. Nature Neuroscience 5: 376-381, 2002, Fig. 1. Reproduced with permission.

Relationship of Bimanual Drawing Asymmetry to the Simple Reaction Time

Just by observing the performance of people as they draw the lines or geometrical shapes, the mobilization of the nondominant hand for sometime after the start of movement by the dominant side is readily noticeable. Subjects themselves notice the same with amazement when performing the testing maneuvers in the open space with the eyes open. This lag of the left hand in real right handers is translated into widening of the space between the two hands as the subjects move their arms (flexed at the elbows) toward their dominant side and in the opposite as the arms swing to the nondominant side of the hemispace. Clearly, is reasonable to suggest the side contralateral to the major hemisphere moves faster that the side ipsilateral to the same; probably because of the synaptic delays in the major hemisphere in the neuronal aggregates representing the nondominant side of the body within the left hemisphere, in addition to the interhemispheric transfer of same commands for implementing those commands by the right hemisphere. Given the fact that lesions affecting the callosum are associated with slowing of the nondominant side of the body (Preilowski, 1972; Kennerley et al, 2002), it becomes obvious that the faster reaction time of the dominant hand is a reflection of the abovementioned circuitry (Derakhshan, 2003a; Derakhshan, 2005b, Derakhshan, 2006b). Examples to the contrary (Goble, 2007) are based to the lack of awareness of the investigators cited by Goble as to the distinction of neural and behavioral handedness in the group studies cited (2007). At any rate, the faster speed of the right hand in right handed subjects was recently reported by the same laboratory that in the past had reported many of those instances showing faster reaction times in the left hand of right handed subjects (Mieschke et al, 2001; Tremblay et al, 2005). Thus, the speed differential depicted in the present article and the reaction time differential of the two hands refer to the same phenomenon, i.e. marching of the nondominant side of the body to a drummer located a callosum-width farther away from the action (major) hemisphere, i.e. by an IHTT.

Discussion

The pivotal role of the corpus callosum in bimanual coordination has been recognized by clinicians for a long time, witnessed by their discovery that lesions affecting the action hemisphere (hemisphere of speech) affected movements on both sides of the body whereas those of the minor hemisphere only affected the contralateral side (Wyke 1967; Fisk et al, 1985; Fisk et al, 1988). Surgically, such a role for callosum as well as presence of directionality in callosal traffic after callosotomy (i.e. laterality of symptoms) after callosotomy was documented early in callosal sections for treatment of epilepsy (Preilowski, 1972).

That bimanual coordination (i.e. the consistent leading of one hand when strict simultaneity was intended) is not related to sensory feedback has been corroborated recently by the demonstration of persistence of bimanual advantage in stability of intertap intervals in a person whose was insensate because of sensory neuropathy affecting both arms (Drewing et al, 2004).

In brain computer interface (BCI) arena, recognition that moving the left side in right handed subjects is associated with the activation of both hemispheres is a more recent “surprising” phenomenon and its foundation has remained unrecognized (Blankertz et al, 2006, Figs. 1 and 2; Babiloni et al, 2003). However, Blankertz et al (2006) did identify “the huge intersubject variability” with respect to spatial and temporal characteristics of brain signals as a major challenge in BCI research. Clearly, based on what was presented above, this variability is based on the dichotomy of cerebral dominance as it relates to avowed (behavioral) handedness at the public at large. Thus, the new understanding that one in five people displays a handedness ipsilateral to the command center is of importance to the application of movement related cortical potentials (MRCP) in EEG based BCI systems (Millan et al 2004). On the other hand, the new understanding could provide the basis of manufacturing robots possessing of handedness, imitating humans in a more perfect way.

Neurological evidence against the dogma of contralateral innervation (i.e. right controls the left side, left controls right side) abounds and has been reviewed elsewhere (Derakhshan, 2006d). The evidence also indicates that consciousness, imagination and thought all lie in the hemisphere of action (major hemisphere), and that the role of the minor hemisphere is to handle the affairs related to nondominant hemispace including those related to the body; on the behest of action hemisphere in that very person (Derakhshan, 2003a, 2003b; Derakhshan, 2004; Derakhshan, 2005a, b). Clinically, it has been frequently observed that the distribution of lesions associated with disturbances of consciousness (coma) is heavily biased to the left hemisphere, with or without occurrences of epilepsy at the outset (Lyden et al, 2004). Specifically, in two separate prospective studies each consisting of nine cases of stroke associated with loss of consciousness from the start, the left-right distribution of hemispheric involvement was seven to two (Melo et al, 1992 pp. 94, 99; Sylaja et al, 2006, see table). Of these studies, only Melo and colleagues recognized the lopsided distribution of such lesions among their unconscious patients (i.e. a ratio of ~ 80/ 20 %, similar to that of the laterality of motor control mentioned above).

Since disturbances of motor control in humans are commonly bilateral because of the directionality in callosal connection between the two hemispheres, the new understanding will eliminate the need for bilateral placement of deep brain stimulators in surgical treatment of those entities responding to such interventions as deep brain stimulation; i.e. by lateralizing the source of pathological oscillations in the action (major) hemisphere (Hellwig et al, 2003; Derakhshan, 2006e). An example of this bilaterality of the effect of thalamic stimulation in the major hemisphere in a patient with essential tremor is documented in Fig. 20.

The noninvasive nature of this diagnostic method in lateralizing action hemisphere obviates the need for any surgery or expensive diagnostic endeavors for such determinations. It will also allow the possibility of using a "blue-tooth-like receiver for sampling EEG signals arising from the hemisphere of action in a particular individual and the wireless transfer of those signals to a robot made for such purposes (For example see Millan et al, 2004), or to operate machinery while bypassing the use of the extremity of the operator.

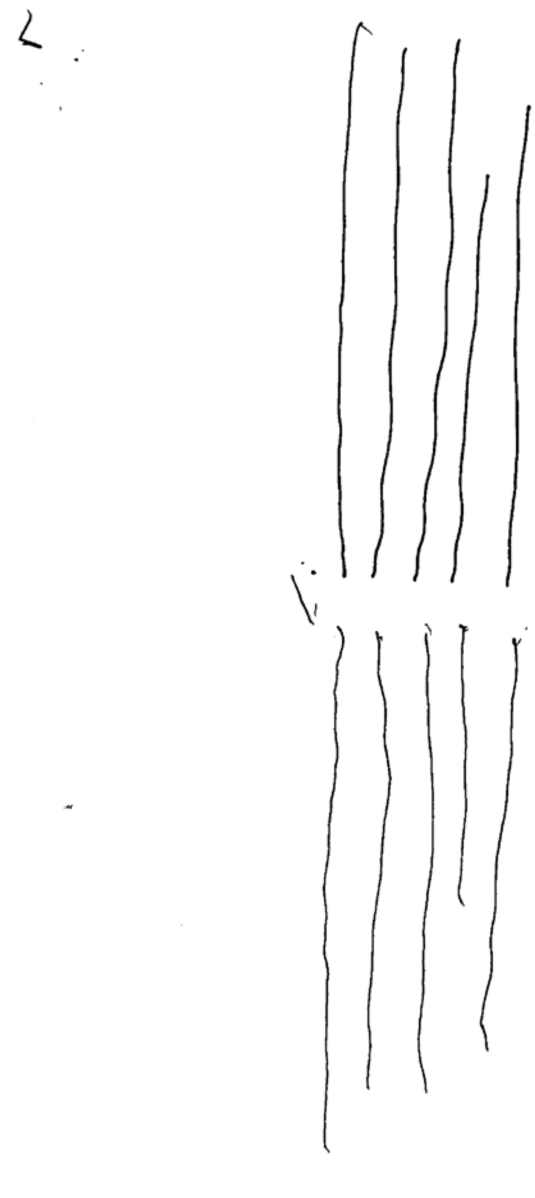


Fig. 2. LF, a neural and behavioral right hander. Note longer lines on the right (r) side.

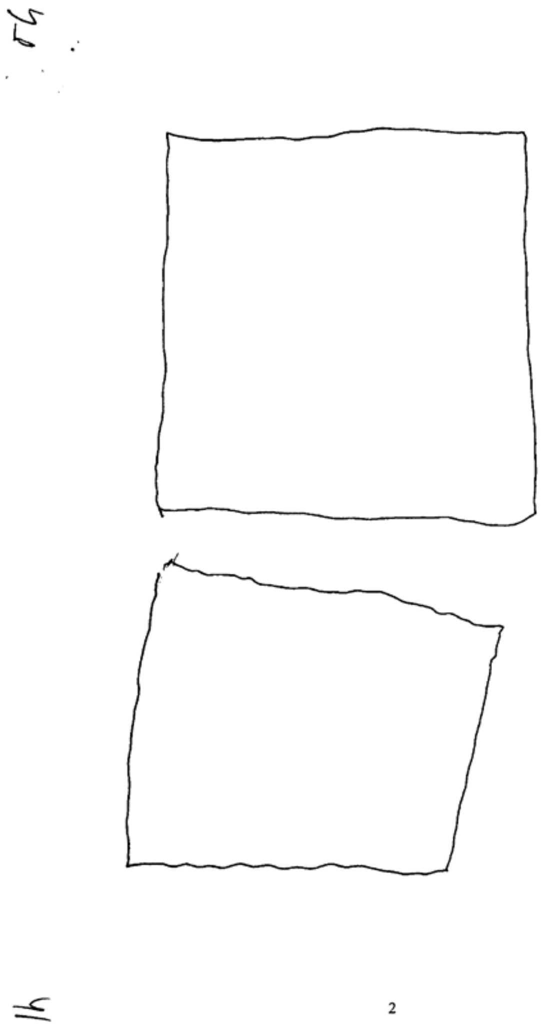


Fig. 3. LF, behavioral and neural right hander. Note larger squares on the right. See Table 2 for reaction time correlations.

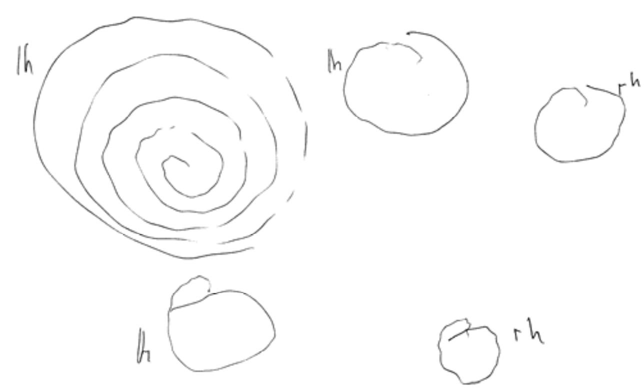
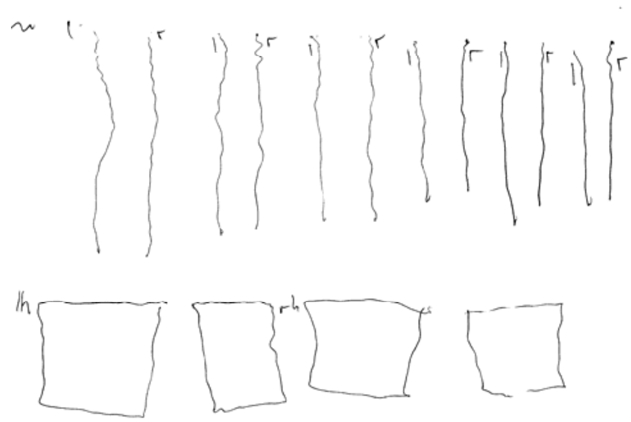


Fig. 4. See fig. 5 for explanation



Figs, 4 & 5. EB, a behavioral right and neural left hander. Compare consistent performances in drawing test with the inconsistency of reaction time (due to tremor). The upper frames are drawings in vertical dimension. r = right hand, l = left hand, in all figures.

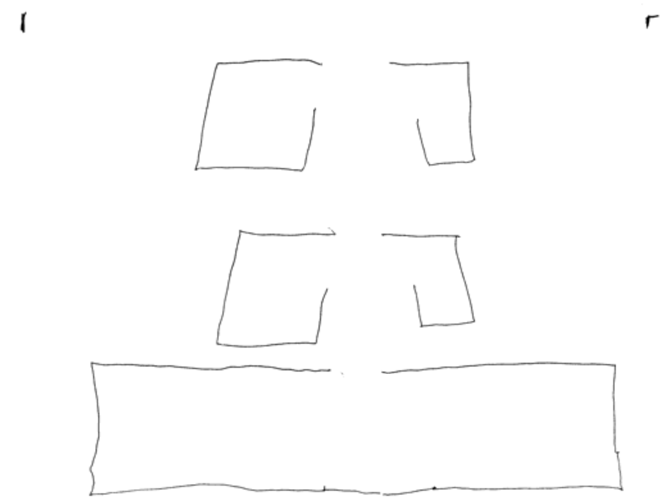


Fig. 6. See Fig. 8 caption.

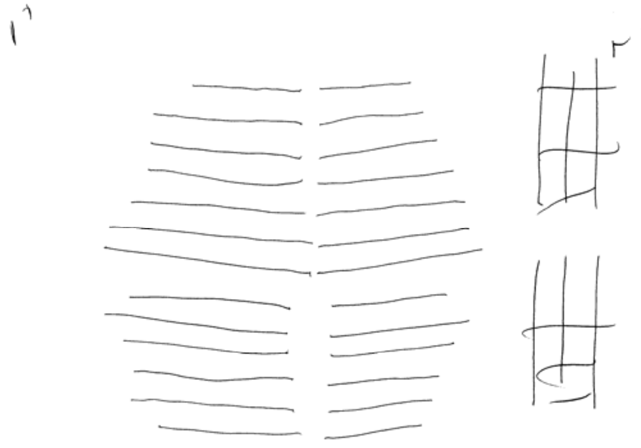
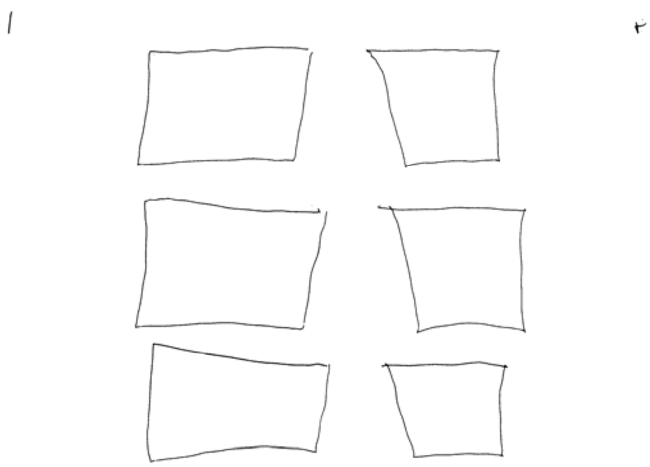


Fig. 7. See Fig. 8 caption.



Figs. 6-8. DN, a behavioral right and neural left hander. Note the consistency of performances, with drawings all larger on the left, and compare with the inconsistency of performance in reaction time study.

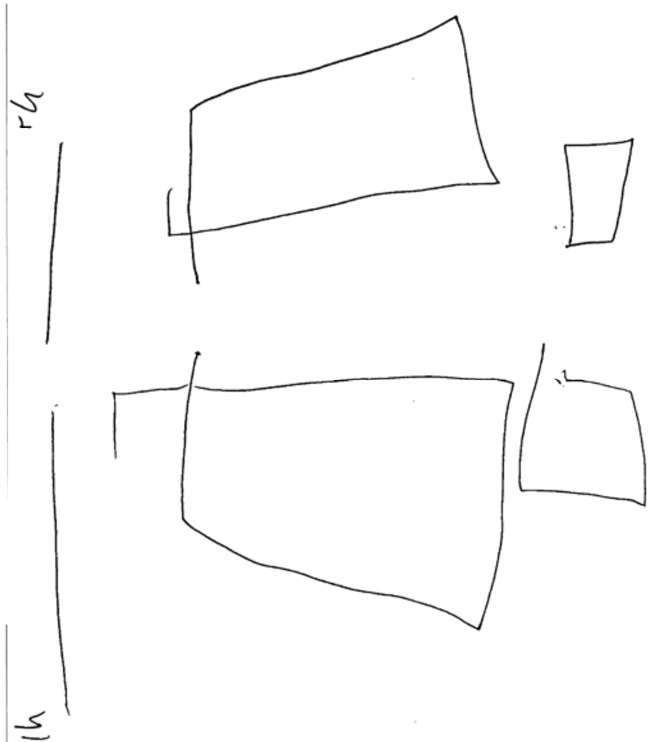


Fig. 9. ST, a behavioral left and neural right hander. These drawings were done with eyes closed.

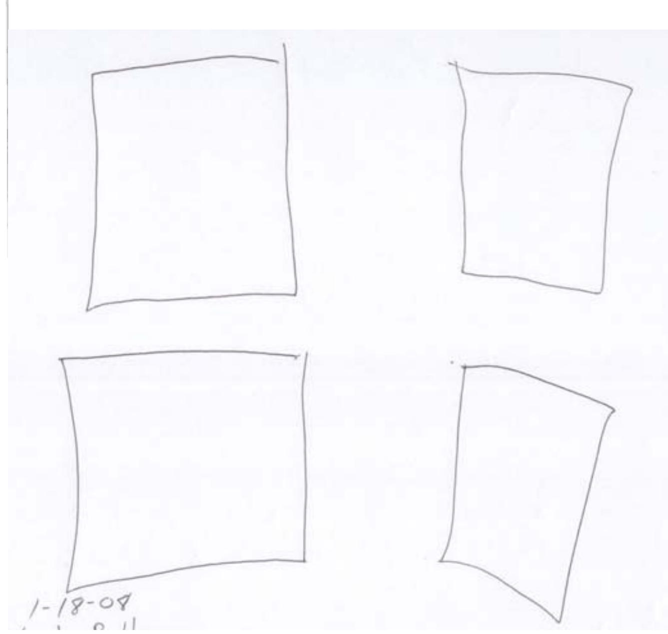


Fig. 10. CH, a neural and behavioral left hander, with larger excursions on the left side.

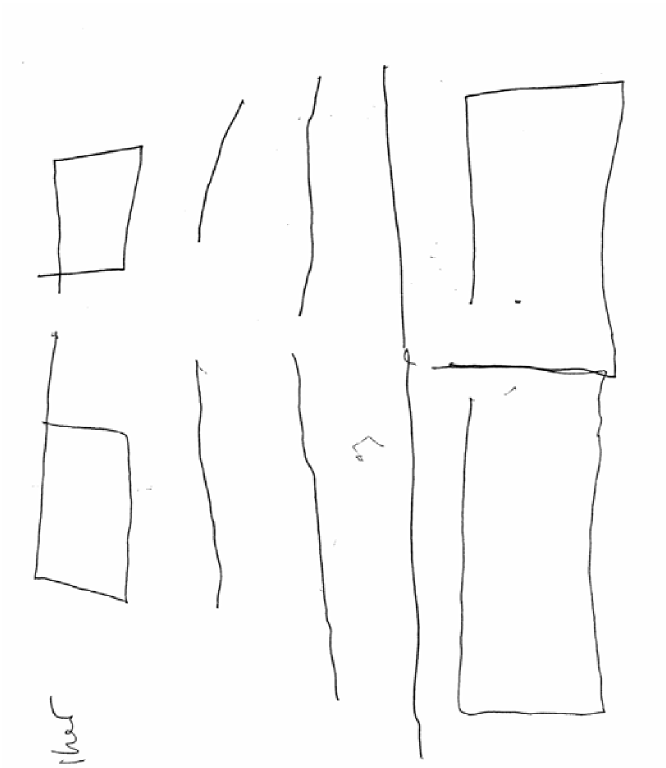


Fig. 11. MC, a neural and behavioral left hander. All drawings on the left are larger. Compare with performance in reaction time test which demonstrate effect of training.

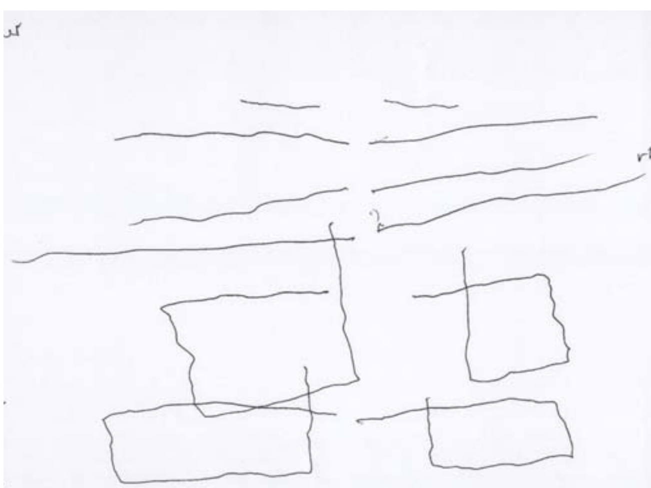
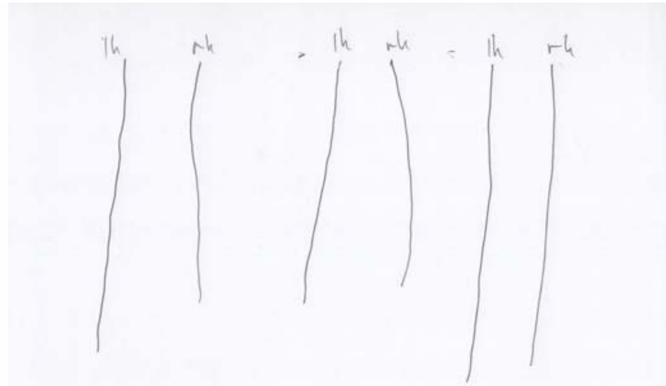


Fig. 12. See Fig. 13 caption.



Figs. 12, 13. PE, a neural and behavioral left hander. Left hands larger excursions are seen in horizontal and vertical dimensions.

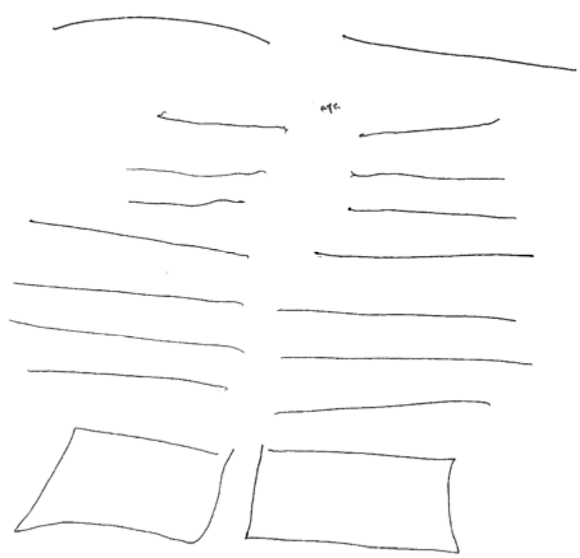


Fig. 14. CG, a behavioral left hander except for writing. Compare the relative consistency of the drawing test with lack of the same in reaction time study. Note, however, that the lowest reaction time belonged to the right hand which drew the longer lines and the larger square.

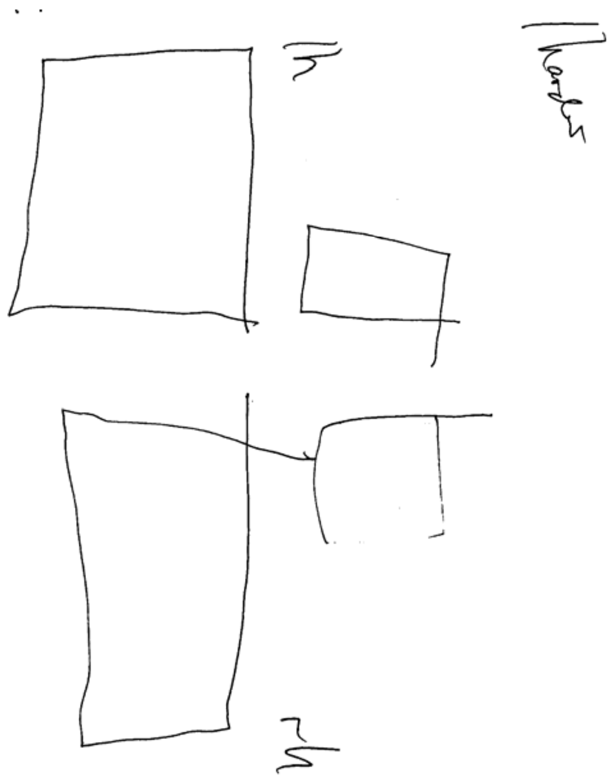


Fig. 15. TM, a behavioral left and neural right hander. Note the straightness of the lines drawn by the (ostensibly) dominant left hand (with eyes closed). See table for reaction time data.

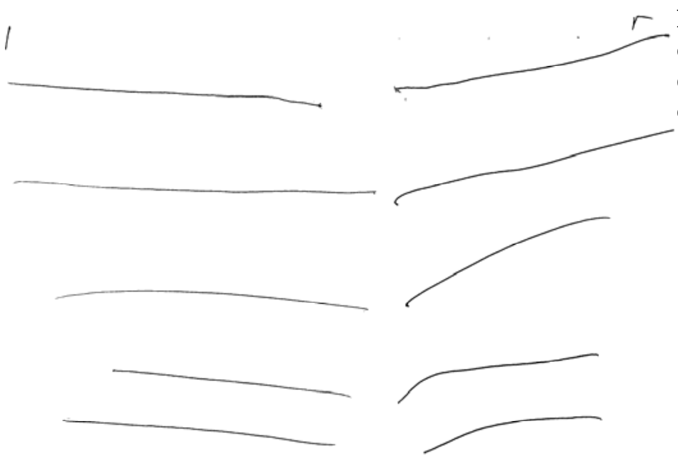


Fig. 16. EM, a neural and behavioral left hander. Note the consistency of hand performance in the drawing test and the inconsistency in the reaction time study.

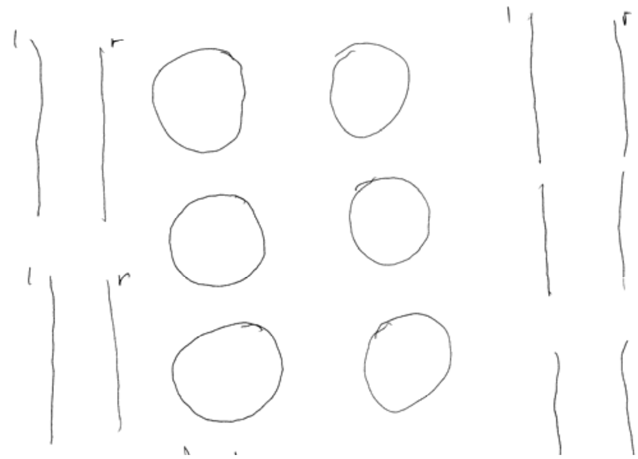
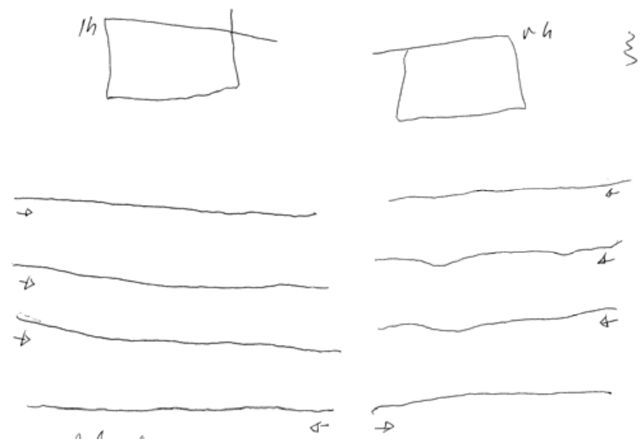


Fig. 17. See legend for Fig. 18.



Figs. 17, 18. DS, a neural and behavioral left hander. Note the consistency with which the dominant hand displays larger excursions in bimanual drawings regardless of directionality of hand movements in relation to the midline.

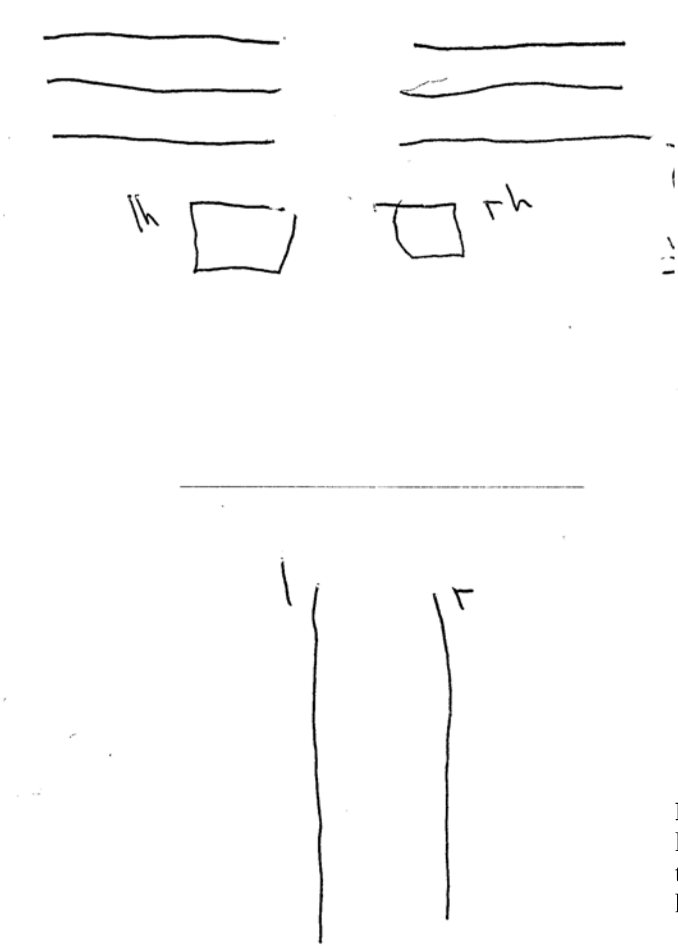


Fig. 19. Notice that the asymmetric performance is more clearly evident on drawing a square and in vertical drawing task. It may be noted in the latter that the right hand starts later and stops sooner the process than the left hand. The subject was a behavioral left hander.

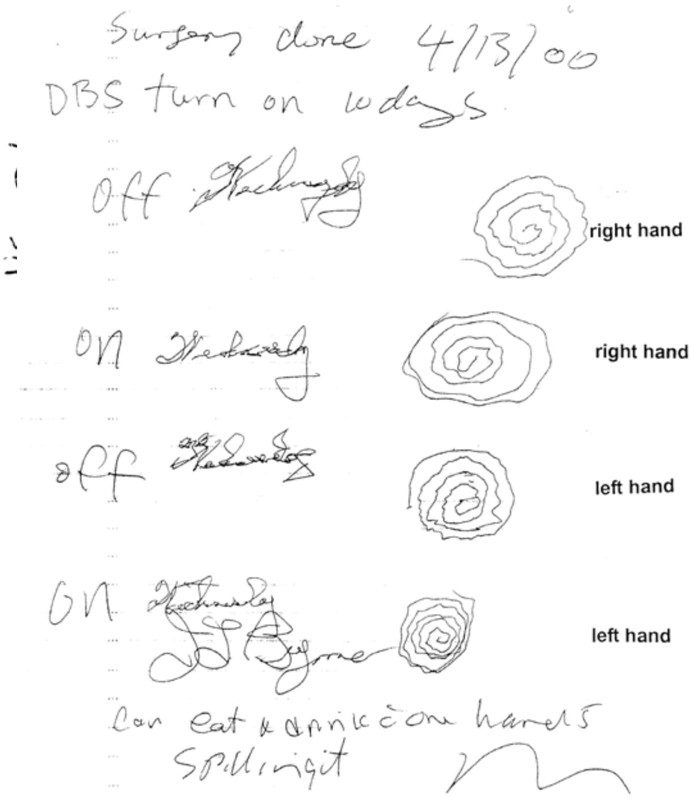


Fig. 20. Illustrating the effect of deep brain stimulation of the left thalamus in a patient with sever bilateral tremor. Notice that turning on the stimulator ameliorated the tremor in both hands, making the handwriting with the right legible.

Table 1 Kinematics of the movement. For each subject are indicated the eccentricity (Σ) and the inclination of the major axis (a) of th trajectory for left and right hand (mean values computed over al movement cycles and all trials). Also reported are the mean velocit (V) and the mean and standard deviation of the asynchrony (∂).

Subject no.	Σ_L	Σ_R	a_L	a_R	V (cm/s)	∂ (ms)
Right-handed subjects						
1	0.78	0.71	–16	6	63.18	35±18
2	0.49	0.46	–18	5	56.34	49±24
3	0.87	0.84	–29	20	59.21	17±19
4	0.71	0.74	–33	19	52.37	73±33
5	0.81	0.78	–13	9	62.24	17±15
6	0.84	0.84	–8	–1	79.35	25±15
Average	0.75	0.73	–19	10	62.11	36.0
Left-handed subjects						
7	0.84	0.85	–7	–2	60.04	24±13
8	0.79	0.83	–2	10	70.90	–24±10
9	0.76	0.84	–2	5	68.17	–6±10
10	0.76	0.71	–4	18	75.56	–48±18
Average	0.79	0.81	–4	8	68.67	–13.5

From Viviani et al, Hemispheric asymmetries and bimanual asynchrony in left- and right-handers. Exp. Brain Res, 120: 531-536, 1998. Note. According to one-way callosal traffic circuitry, patient #7 was a behavioral left and neural right hander. Thus, he moving his right hand ahead of the left (like all behavioral and neural right handers under "right handed subjects." See Viviani et al for details (p. 533). Patient 7 is similar to cases TM, CG and ST in this report.

Table 2

Initials, Behavioral Handedness;
Neural Handedness (reaction times)

LF, right hander;
left hand 324ms, right hand 367ms; larger drawings right hand
left hand 302ms, right hand 254ms; larger drawings right hand

EB, right hander;
left hand 318ms, right hand 185ms; larger drawings left hand
left hand 197ms, right hand 190ms

DN, right hander;
left hand 285ms, right hand 263ms; larger drawings left hand
left hand 257ms, right hand 250ms
left hand 224ms

ST, right hander;
left hand 364ms, right hand 472ms; larger drawings left hand

CH, left hander;
left hand 537ms, right hand 190ms; larger drawings left hand
left hand 210ms, right hand 210ms
left hand 216ms

MC, left hander;
left hand 436ms, right hand 374ms; larger drawings left hand
left hand 322ms

PE, left hander;
left hand 423ms, right hand 206ms; larger drawings left hand
left hand 185ms

CG, left hander;
left hand 543ms, right hand 270ms; larger drawings right hand
writes with right left hand 251ms, right hand 253ms

TM, left hander;
left hand 265ms, right hand 242ms; larger drawings right hand

EM, left hander;
left hand 539ms, right hand 332ms; larger drawings left hand
left hand 329ms, right hand 326ms
left hand 417ms

DS, left hander;
left hand 237ms, right hand 238ms; larger drawings left hand
left hand 212ms, right hand 223ms

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