The Slower Side Marches to a Distant Drummer: A Fresh Look at the Results of a Paper and Pencil Test for Laterality of Motor Control

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Abstract - *This historical review is based on three articles on pseudoneglect and anosognosia. Method: I provide a fresh interpretation of the quantitative data in "a pencil and paper test" utilized by Friedlander (1964) and Graff-Radford, Crucian and Heilman (2006), based a new understanding in laterality of motor and sensory control. The latter proposes that the command center is always located in one hemisphere and that the non-dominant side of the body is not activated until the said commands reach the minor hemisphere via the callosum. Results: Evidence is reviewed indicating that laterality aspects of numerical data in the two articles is based on the delay of the nondominant side by an amount equal to the interhemispheric transfer time (IHTT). Hence, the nondominant side is marching to a distant drummer located a callosal width farther away compared to those effectors located on the dominant side of the body (which are thus in direct communication with the major hemisphere). Conversely, the directionality of the sensory signals arising from the non-dominant side is from the minor to the major hemisphere. This is the basis of the laterality of anosognosia in lesions affecting the minor hemisphere. It is concluded that pseudoneglect, i.e. the systematic erring to the left in a right hander when demarcating the middle of an object, is related to speedier transfer of motor signals to the right hand by an IHTT (due to the anatomy described above). Thus, crossed aphasia and crossed nonaphasia denote instances in which behavioral handedness is different from the neural handedness of the subject studied (i.e. his/her brainedness, laterality of the command center). These occurrences indicate that while we have a choice in adopting a hand as our favorite at an early childhood, we have no choice as to the laterality of the hemisphere with which we speak (major hemisphere, hemisphere of action).*

Keywords: Pseudoneglect, Anosognosia, Handedness, Brainedness, Command Center

Introduction

In 1884, in an article in Mind, Hall and Hartwell documented the faster speed of the dominant hand than the nondominant if the two hands were moved simultaneously from the opposite ends of a yard-stick (Hall and Hartwell, 1884). Therefore, in a right hander, the two fingers met to the left of the midline. This observation has since been replicated twice, once by Friedlander in 1964 (Friedlander, 1964) and more recently by Heilman and associates in 2006 (Graff-Radford, Crucian and Heilman, 2006).

Many different permutations of this readily verifiable finding come to mind, all replicating "asymmetrical excursion" of the two hands when moved simultaneously; the right hand moving faster than the left in a right handed person (see below for occasional exceptions to the rule and the explanation thereof according to a new insight now under scrutiny). One would be to slide the closely held index fingers from the left to the right end of the yardstick (preferably with the eyes closed, as suggested by Hall and Hartwell) and witness the widening distance between the two fingers as they approach the right end. The other is to close the eyes and move back the widely separated fingers, this time to the extreme left end of the yard-stick, witnessing narrowing of the distance between the two fingers as they reach that end. This wider excursion of the right hand may also be witnessed as ones own out-stretched arms (flexed at the elbows) are allowed to sweep the horizon simultaneously from side to side. Invariably, one notes that the distance between the two hands increase when the arms are swung from the left to the right and decrease when swung to the left (in a real right hander). In a similar fashion, the lead of the dominant hand is observable when sliding the fingers along the edges of the yard-stick from upside down or from downside up (vertical dimension). This latter version is identical to that already known to musicologists for more than a century; i.e. the melody lead of the right hand in piano players, documented first by L.N. Vernon in 1936 (Palmer, 1997). Clearly, all these observations bespeak of the faster speed of the right hand in normal right handed people when moving the hands simultaneously or separately, resulting in the systematic erring of the right hand to the left of midline as they perform tactile or visual estimation of the middle of an object (i.e. Pseudoneglect) (Sampaio and Chokron, 1992).

The purpose of the present article is to provide these three accounts with a newly described understanding, i.e. the presence of directionality in callosal traffic in both sensory and motor domains. According to the data reviewed elsewhere, callosal traffic consists of two loops that run in opposite directions. The first loop (which runs anteriorly) connects the motor areas of the two hemispheres, with signals running from the left to the right hemisphere (in neural right handers, i.e. those who are left hemispheric for speech). These signals run in the opposite direction in neural left handers. The second loop (which runs posteriorly) pertains to the sensory impulses arising from the non-dominant side of the body (as just defined). It runs in the opposite direction from the first loop, i.e. from the right hemisphere to the left in neural right handers. Thus, the anterior loop relates to the laterality of motor control and the posterior loop relates to conscious appreciation of the non-dominant side of the body which also occurs in the major hemisphere (Derakhshan, 2003a, b; 2004, 2005a, b, c; 2006a, b). It will be shown below that the anterior loop gives rise to "pseudo-neglect" described above while the posterior loop is relevant to anosognosia encountered in lesions affecting the minor hemisphere or its connection to the major hemisphere (via the posterior aspect of the corpus callosum). It must be noted here that diaschisis is the principal physiological mechanism for the laterality of symptoms observed in lesions affecting the anterior callosum (Derakhshan, 2003a, 2005a, b).

To my knowledge, Friedlander was the first to utilize Hall and Hartwell's method in investigating "bilateral asymmetry of function" and explaining the laterality of a clinical finding (anosognosia). He also realized the role of handedness in overestimating distances on the non-dominant side of the body. However, because of his belief in the "canonical" wisdom (the law of contralateral innervation, now being revised), and because of lack of insight as to the meaning of crossed aphasias and crossed non-aphasias (indicating unreliability of avowed handedness as to the neural wiring of any individual) he failed to provide a satisfactory answer for laterality of anosognosia. (See below for Friedlander's findings as to the laterality of his subjects.) There have been recent calls for revising the classical teachings of contra-laterality of motor control based on bilaterality of event related desynchronization on moving the left hand (Crone et al, 1998). This latter finding, indicating that moving the nondominant side requires the transfer of signals initially arising in the major hemisphere and then transferred to the minor hemisphere (right) via the callosum for moving the left hand has been confirmed more recently by Bestelmeyer and Carey, 2004 (page 1164), Saarinen et al, 2005 and Spironelli et al, 2006).

As indicated above, the command center lies on one side. Thus, the overestimation of space on the nondominant side of the body as seen in the abovementioned articles must reflect the onset of the initial command for moving the left hand in the mind of Friedlander subjects. In other words, the time taken for the command initiated in the major hemisphere to traverse the callosum and reach the minor (right) hemisphere (dedicated to events occurring on or towards the nondominant side of the body) appeared to the subject as a distance traveled by the left limb without a movement having occurred outside. According to the above interpretation, it is the interhemispheric transfer time (IHTT) that is the source of the lagging of left hand in all of the permutations described earlier. The same principle applies to the phenomenon of oculomotor "pseudoneglect," i.e. the left deviation seen in line bisection by a right hander, this time the eyes replacing the hands in making the movement while performing the task. To repeat, in estimating the length of the line to be cut in half the subject overestimates the left half since it takes more time to move the eyes to the non-dominant side, due to obligatory mediation of callosum for the purpose of moving the eyes to the left (Derakhshan, 2005c). It is known that the left-ward deviation occurs even if a person's voice is used to signal the middle as estimated by the subject (Lavanchy et al, 2004).

Clinically, the callosal nature of this delay is evident from the fact that lesions of the callosum affect only the nondominant side of the body while those of the major hemisphere affect moving both sides (i.e. paresis on the dominant and apraxia on the non-dominant side). Experimental evidence in favor of the above scheme is legion (Derakhshan, 2003a, b, c; Grafton et al, 2002). For example, in performing tasks of comparable difficulty, the simple reaction time and the movement time of the neurally dominant side of the body (i.e. the side contralateral to the command center) is always faster than those on the non-dominant side and the said discrepancy increases in lesions affecting the anterior callosum or the minor hemisphere (Bestelmeyer and Carey, 2004; Saarinen et al, 2005; Spironelli et al, 2006) (see discussion for further details). Returning to Friedlander's findings, only two of the 10 left handers he examined over-reached the semicircular "white guide line" on the left of the subjects (subjects Ros. and Co., table ii) and eight under-reached the said benchmark. This corresponds to a 1/5 ratio in neural to behavioral mismatch among the left handed subjects he examined. Conversely, three of 10 right handers tested under-reached the left semicircular white guide line, thus declaring themselves as neural right handers (subjects Kal, Gl, Fu, table ii). According to the sign (plus or minus) of the cumulative quantitative data provided by Friedlander, the remaining subjects over-reached the semicircular guide line on the left, declaring themselves to be neural left handers (i.e. with the command center on the right side). Admittedly, this ratio is the reverse of what is usually the case among the right handers, but rare occurrences like this do happen in small samples from time to time (Derakhshan et al, 2004). Here, the possibility of a selection bias (i.e. including only those who responded according to author's expectation) or of a book keeping error as to recording the handedness of the participants, cannot be entirely dismissed.

In contrast to Friedlander approach which required moving the arms away from the midline, Graff-Radford et al's (2006) experiment required simultaneously moving the hands towards each other. The authors recorded the earlier reaching to the midline by the right hand in a total of sixteen right handed subjects. (In actuality, the authors measured the angle of each line beginning at the point of origin to the end point. The participants reliably drew a steeper angle toward themselves with their right hand; the angles of the line drawn with the left hand were most usually flatter) In this respect, except for the choice of the trajectory studied (line drawing versus circle drawing), the study of Graff-Radford et al is similar to that of Lewis and Byblow (2004), who measured the relative tangential angle (RTA) of right hand left hands in bimanual exercises in right handed controls. Similar to Graff-Radford et al's finding (see above), Lewis and Byblow's participants "demonstrated an average RTA of ~ 20 degrees, "representing dominant hand lead during circling." They also found that the RTA increased progressively as the movement frequency increased, "representing greater asynchrony between the hands at higher circling rates."

Most significantly for the purpose at hand, the comparison of data from the control subjects with those of poststroke hemiparetics documented the dependence of the above finding on the integrity of the major hemisphere (left). Incidentally, the reverse of this experiment may be performed by holding a pen in each hand and moving them apart from a central position. It will be noted that the line drawn by one of the hands (i.e. the neurally non-dominant) is invariably shorter than that drawn by the other, by an amount/interval equal to IHTT (see above for explanation).

Discussion

Musicologist had long noted earlier arrival of the right hand on the target key than that of the left hand despite the intention of the player for simultaneous delivery of notes involved (melody is played by the right hand and harmony by the left). They designated this unintentional delay of the left hand as the melody lead of the right hand in piano players, which averaged ~ 80 msecs (palmer et al, 1997).

Given the above account, the following question arises: How does laterality of motor control in society (almost ninety percent right handed) correspond to the observations at the bedside? Contrary to the intuition, the correspondence of behavioral handedness to hemispheric dominance (brainedness) is a statistical one (not biological), i.e. the hemisphere of speech (the command center) lies opposite to the dominant hand in ~ 80 percent of people. The remainder of people displays a mismatch, i.e. the major hemisphere lies ipsilateral to their avowed dominant hand. Specifically, ~ 10-20 percent of right-handers and 50 percent of sinistrals display such a mismatch. Clinically, this is manifested as occurrences of crossed aphasia and crossed nonaphasia (failure to display the expected aphasia) in lesions affecting the hemisphere contralateral to the behaviorally dominant hand (or the reverse in nonoccurrence). A similar proportion of right and left handers fail to display neglect or anosognosia with lesions affecting the hemisphere contralateral to their avowed non-dominant hand (Goodglass and Quadfasel, 1954; Mohr et al, 1980; Hu et al, 1990; Marchetti and Della Sala, 2005). That speech is only a marker of the command center has been known for a long time, as revealed in the result of different modalities of investigation (Efron, 1963; Grafton et al, 2002; Saarinen et al, 2005). For example, anesthetizing the major hemisphere with intracarotid phenobarbital affected the motor function of the right hemisphere in the form of "loss of deftness" on the left (with no similar effect the other way around) (Heilman et al, 2000; Hanna-Pladdy et al, 2002). These facts together with the observation that many youngsters have yet to decide as to their handedness well into their teen-years (Derakhshan, unpublished data), reflect the fact that humans exercise a choice as to laterality of its favorite hands (right and left) but have no choice as to the laterality of their major hemispheres (right or left).

The lead of the right hand in right handers in simultaneous drawing of a circle or ellipse with both hands has been well documented and the role of callosum in genesis of this lead has been acknowledged by other authors (Viviani et al, 1998). However, the fact that it is the laterality of the command center (the hemisphere of action, including the act of speech) that matters as to which of the two hands of a subject takes the lead in performing such bimanual tasks (not necessarily the behavioral handedness) is a recent understanding. In the past this callosally mediated delay of the left hand has often been attributed to synaptic inefficiency of the right hemisphere or was simply ignored despite its ubiquitous appearances in data obtained (Swinnen et al, 1996; Swinnen et al, 1998; Tarkka and Hallett, 1990; Viviani et al, 1998). In a recent investigation Bestelmeyer and Carey concluded that "the right hand (mean median 291 msec) always completed a movement faster than the left" (mean median 301 msec) ($p< 0.003$) (page 1164). These authors also reviewed data indicating that choice reaction times of the right hand was faster that that of the left. More to the point was their conclusion that while moving the left hand was a bi-hemispherical event moving the right hand involved only the left hemisphere. Similarly, bilateral hemispheric EEG activation (first the left then right motor cortex activation) on moving the left hand, was documented recently by Spironelli et al (2006). As seen with regard to the hands, this study found symmetrical activation of right and left hemispheres with visual stimuli arising from the left hemispace (Simon task), thus documenting activation of the left hemisphere prior to that of the right by 120 msec (when looking to the left).

Similar temporal and topographical (hemispheric) asymmetries were found by Saarinen et al (2005) in an EEG study measuring the suppression of 20 Hz activity of motor stripes on both sides (Fig. 6 of the authors). Clinically, the crucial role of callosum in generating the nondominant lag of the left hand is best demonstrated in the necessity of an extant callosum (anteriorly) for the amelioration of neglect of the left side when such patients attempt moving the nondominant side of the body (Derakhshan, 2004). In the same vein, complete severance of callosal connection is associated with paralysis of the nondominant side of the body (Sakai et al, 1998). Similarly, sharing of resources within the left hemisphere is also manifested at the bedside by the demonstration of sudden loss of tone (down-ward drift) of the outstretched left arm when the outstretched right arm is bent to allow for the patient to touch his nose with the right index finger while the outstretched right arm remains steady when the left arm makes a similar maneuver (Derakhshan, 2004).

Anosognosia

Clinically, the posterior callosal loop plays a role in the laterality of anosognosia the incidence of which occurs far more frequently on the left. While it is known that improvement of anosognosia and neglect upon moving the left side of the body requires an extant callosum anteriorly, the role of posterior callosum in mediating awareness of events that occur on the non-dominant side of the body is revealed in the longer reaction time of the left hand to stimulation of that hand compared to that of the right hand when stimulated that side (Efron, 1963). For the same reason, ipsilateral and bi-hemispheric occurrences of somatosensory evoked potentials occur only with stimulation of the non-dominant side of the body. Furthermore, absence of any role for the splenium of corpus callosum in primary vision has been documented long ago (Derakhshan, 2007).

More recently, preservation of Stroop effect in complete absence of the callosum was documented by Brown et al (2001) confirming the same. Thus, the common belief in the role of callosum in primary vision is based on the authority of Sir Isaac Newton who first suggested such a hypothetical role for the callosum in 1704 (Query no. 15). Nevertheless, the fact that easy-to-remember diagrams of visual field defects in text-books are “misleading,” and “have little basis in fact,” has not been lost to some of the modern writers on the subject (Slamovits, 1998, pp 91, 98).

Friedlander sought an explanation of the lopsided occurrences of anosognosia (heavily skewed to the left) by envisioning a much larger representation of the right side of the body in the left hemisphere of right handers than that of the left side in the right hemisphere of the same group (making the right side less liable to exhibiting anosognosia). The most pertinent observations refuting that suggestion are the occurrences of anosognosia in the right hand of behavioral right handers (i.e. neural left handers see above). In one such report, Marchetti and Della Sala reported the occurrence of anosognosia (denial of hemiplegia) in 6 of the sixteen patients they reviewed. Neglect of the right side occurred in 14 of the sixteen patients and aphasia was absent in all cases. The authors correctly called the syndrome “crossed right hemisphere syndrome.” According to the circuitry under review, cases similar to those described by the said authors are examples of behavioral/neural mismatching, i.e. neural left handers who had adopted the right hand as their favorite hand with no change as to the laterality of command center as the result of the choice they had made earlier in their life. In short, cases described were left handers who had self-converted to the way of life of right handers. The immutability of the wiring underpinning (neural) handedness (the laterality of command center) was recently confirmed by Kloppel et al (2007) using functional MRI. In a group of converted left handers they documented bilateral activation of the motor cortices when the cohort of converted left handers they investigated moved their right hands.

By far, the most convincing evidence for the role of corpus callosum and the directionality of callosal traffic underpinning the laterality of denial of hemiplegia was presented by Green and Hamilton (1976). In averaging somatosensory potentials evoked by stimulation of right and left median nerves in 50 patients (all presumably right handed) with verified lesions in right or left hemisphere, 10 of which displaying “anosognosia for hemiplegia and other features of the parietal lobe syndrome including hemisomatognosia,” the following data were obtained:

Nine of 10 patients displaying anosognosia for left hemiplegia had acute lesion affecting the right hemisphere and in the remaining case the lesion was on the left (with right hemiplegia). In the nine left hemiplegics, the somatosensory potentials were absent over both hemispheres when stimulating the left medial nerve at the wrist. Thus, in 10 patients in whom the contra-lateral evoke potentials were absent the ipsilateral potentials were absent as well (pointing to a role played by the corpus callosum as mentioned earlier). Stimulation of the right median nerve resulted in appearance of the potentials contralaterally alone. In the single case with anosognosia for right hemiplegia (in a patient with left thalamic hemorrhage) absence of somatosensory evoked potentials on both hemispheres was noted when stimulating the right median nerve. These findings related to the distribution and laterality of somatosensory evoked potentials is identical to data in another study related to the subject under review. Goff and colleagues (1962), in a study of normal populations consisting of right and left handers, documented bilateral occurrences of such potentials on stimulating the nerves on the nondominant side of the body, with an ipsilateral delay amounting to an IHTT. Similar to the case of Friedlander and due to the conventional belief in contralaterality of motor and sensory control, Green and Hamilton were at a loss as to the explanation of the laterality aspects of their findings in an otherwise excellent study. However, according to the data presented above, the exceptional case of anosognosia of the right hemiplegia occurred in a neurally left handed (right brained) patient who may or may not have been a behavioral left hander (no information was provided as to the handedness of the subjects).

At any rate, the absence of aphasia and sensory evoked potential over both hemispheres upon stimulation of the right hand in that case are confirmatory evidence that the affected hemisphere was the minor hemisphere.

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