

# An Exchange on Franz, Rowse, and Ballantine (2002)

## Handedness, Neural Versus Behavioral: Is There a Measurable Callosal Difference?

*Comments of I. Derakhshan*

Handedness has been characterized as the clearest example of human behavioral lateralization (Dassonville, Zhu, Ugurbil, Kim, & Ashe, 1997). In the study of Dassonville and colleagues, the volume of activation in the contralateral motor cortex was consistently greater during movements of the dominant hand than during those of the nondominant hand (in both right- and left-handers). In another study, White et al. (1997) performed a detailed light-microscopic morphological evaluation and found "that the preferred use of the right hand in humans occurs without a gross lateral asymmetry in the primary sensory motor system" (p. 1047). Furthermore, in a pertinent review of the issue, Beltramello et al. (1998) correctly suggested that the bilateral cortical activation that occurs when individuals move the nondominant side, which has been demonstrated in emission imaging studies, "has something to do with the use of the nondominant left hand" (pp 282–283), although they offered no explanation for that statement. The question is whether the three classes of observations just exemplified can be reconciled.

With the anatomy of handedness now securely at hand, the answer is affirmative (Derakhshan, 2003e). Thus, when the main structural characteristic of handedness, that is, the temporal precedence of the dominant hand in simultaneous bimanual activity, is questioned (Franz, Rowse, & Ballantine, 2002), it is noteworthy. I therefore welcome the opportunity to explore the laterality aspects of the observations of Franz and her colleagues in light of the new discovery. Removing the doubts they have raised will provide further support for the validity of my claim that it is the vectorial nature of callosal traffic that underpins lateralities of movement control in humans (i.e., the one-way callosal traffic theory).

After a brief overview of the novel scheme, and using the insights gained from it, I will provide an explanation for the negative findings of Franz et al. (2002) concerning the precedence of the dominant hand, reconciling their data (to the extent possible) with the earlier observations they had set out to examine. Furthermore, I present data here indicating that their use of self-declared or inventory-driven methods for determining laterality in their participants partly accounts for the results they obtained. At the same time, I examine the role of the callosum in the inferior performance of the nondominant hand documented in their study.

Then, I briefly point out that the same one-way scheme seems to be operative in the sensory realm, although in the opposite direction. The directionality of callosal traffic underpins the unity of experience we all have in our seamless appreciation of the world and in our reacting to it as individuals who possess one brain with two hemispheres.

According to the theory under scrutiny, handedness is a reflection of (a code for) the proximity of all effectors on the dominant side of the body to the command center in the major hemisphere, by a callosum length. The neuronal aggregate devoted to voluntary actions is divided between the two hemispheres. The nature of the controlling influence exerted by the moiety (of that devoted ensemble) housed in the major hemisphere on its counterpart housed in the minor hemisphere is excitatory. Any interruption of that callosally mediated influence (e.g., whether chemical as in the Wada test, iatrogenic, traumatic, electrical, or vascular; Loring, Meador, & Lee 1994) will result in diaschitic symptoms, crystallized in the following clinical syndromes: (a) the garden-variety syndrome of contralateral paresis and ipsilateral apraxia (with or without aphasia) in lesions of the motor cortex of the major hemisphere; (b) laterality-indexed weakness or apraxia of nondominant limbs in lesions affecting the callosum (e.g. in Marchiafava-Bignami disease); (c) ipsilateral paresis affecting the limbs located beneath the cortical lesion involving the major hemisphere; (d) callosally mediated temporal improvement of the functioning of the nondominant hand in supracapsular lesions of the major hemisphere as the lesion heals, as was quantified recently (Derakhshan, 2003f); and (e) the callosally mediated improvement of the effects of neglect of the left side in right parietal lesions upon moving any of the effectors on the left side—improvement brought about by the activation of the minor cortex that results in turn from the activating influences of the command center on the left hemisphere and that is transferred to the right hemisphere via an extant callosum. The last two syndromes have come to light only recently as a result of the theory under examination (Derakhshan, 2003a, 2003d, 2003f). By now it should be quite clear that it is the anatomy just described, that is, the topology (the linking of left and right) of the major and minor moieties of the neuronal aggregate devoted to voluntary activity, that underpins the laterality of movement control in humans, with the laterality of the dominant hand being a code for the directionality just summarized. Some very able clinicians are apparently unable to grasp that fact, obviously because of the difficulty of overcoming the didactic and

everyday prejudices we all share (Hund-Georgiadis & Von Cramon, 2002; Ishai & Furuya, 2003; Jang, Byun, Chang, Han, & Ahn, 2002; Marien, Engelborghs, Vignolo, & DeDeyn, 2002; Riestra, 2003).

One of the everyday expressions of that scheme is the so-called melody lead of the right hand in piano players, which musicologists have long ascribed to artistic expression. Varying in length by the tempo (Vernon, 1936), that gap (asynchrony, spread) is easily demonstrated when one lowers one's hands onto a surface at different speeds while holding in each hand a stick of a different material (in order to produce sounds of different timbre and thus to better appreciate the sequencing of those two sounds). Inevitably two sounds will be heard. The first is from the dominant hand and the second from the nondominant, as defined earlier (Derakhshan, 2001). The spread represents the interhemispheric transfer time (IHTT), that is, the time taken by the signal from the command center on the left (in right-handers) to reach the motor apparatus on the right hemisphere, which is exclusively dedicated to the affairs of all effectors on the left side, including those of the face, diaphragm, and vocal cords, and those used for swallowing and gazing (Derakhshan, 2003a, 2003d). The literature is replete with data showing the callosally mediated delay, both peripheral and cortical, of the nondominant side obtained with appropriate modalities of investigation (Dassonville et al, 1997; Kristeva, Keller, Deecke, & Kornhuber, 1979).

The Stucchi and Viviani (1993) experiments and others to which the respected authors properly refer, are among such laterality-indexed demonstrations of callosal travel of the motor command from the major to the minor hemisphere that are obtained when individuals draw a spiral or a circle while using a visual template. The callosally mediated, laterality-indexed "synchronization error" is a natural and mandatory event. The flexibility and task dependence of the latter interval has long been known, and its physiology is being (needlessly) debated (Cardoso de Oliveira, 2002). Action onset asymmetries of 10 to several hundred milliseconds, with the dominant hand leading the nondominant, have been recorded (Vernon, 1936; Weiss, Jeannerod, Paulignan, & Freund, 2000). Using the cortical event-related desynchronization method, Pfurtscheller (1992, p. 63, Figure 2) recorded a 1-s asynchrony (reaction time differential) in an electroencephalography (EEG) experiment; that is the longest IHTT measurement that I have encountered in the published literature. Others have documented EEG-related asynchronies of 250 ms, with the dominant hand leading the nondominant (Defebvre et al., 1994). I have commented on the probable role of callosal fibers of different caliber and myelination status in sustaining such task-dependent variability of IHTT (Derakhshan, 2003b) and on the role of the callosum in mediating the improvement in the functioning of the (nondominant) hand on the same side as the site of a stroke (involving the major motor cortex) as the healing of the lesion was translated into improvement of

function of the minor hemisphere controlling the left side (Derakhshan, 2003e, 2003f). The point, of course, is that the doctrine of contralaterality of movement control (that is, the left hemisphere controls the right side of the body, whereas the right hemisphere controls the left) is a simplistic half-truth and is in need of modification if it is to become a scientific theory and be subject to experimental refutation.

Thus, the observations of Franz et al. (2002) were made in a situation in which participants had no template from which to copy; the absence of such a template prevented the dominant hand from showing its expertise, which is usually revealed as a shorter reaction time when that hand follows such cues. Nevertheless, the dominant hand did make its mark in a different way, that is, in increased stability and in a lower coefficient of variation than that of the other hand. Others (e.g., Johnson et al., 1998) have performed experiments similar to that of Franz and her colleagues but involving a bimanual cranking task at two different speeds with and without auditory cues. In the study of Johnson and colleagues, the phase histograms of the 16 right-handed controls who practiced mirror-symmetrical movements showed that occasions in which the left hand was leading the right occurred slightly more often than the other way around. Neither the variation in coordination pattern nor the accuracy of coordination was affected by the auditory cue in in-phase movements. In the case of antiphase (but still mirror symmetrical) movements, however, the group was able to perform more accurately with the cue turned off than with the cue turned on.

Therefore two quite different questions arise: (a) What is the structural reason for better technical performance by the dominant hand in the experiments reported by Franz et al. (2002) and (b) why was the previously reported leadership of the dominant hand absent in the circumstances described in Franz's experiments?

According to the one-way callosal traffic theory just depicted, the reason for the better and faster performance of the dominant hand is its callosum-length proximity to the command center located on the contralateral side, which is also reflected in the better performance of the motor units of the muscles on the dominant hand (Adams, De Luca, & Erim, 1998). The inferior performance of the nondominant hand results from the loss of sharpness of the signal exacted on the command as it trails the length of the callosum (see p. 532, Figure 1 and Table 1, in Schulte-Mattler, Muller, Georgiadis, Kornhuber, & Zierz, 2001); it does not result from any synaptic inferiority of the minor hemisphere itself, which is a position subscribed to by those who still accept the doctrine of contralaterality of movement control in humans (Derakhshan, 2003g). That decay is again encountered in the performance of the two hands in manual-aiming paradigms, where it reveals itself (uniformly) regardless of the degree of the tasks' indices of difficulty (Bryden, 2002). In the sensory realm, the decay is once again encountered as an increase in the threshold of simultaneity (measuring 3.6 ms) in bimanual versus

unimanual stimulation, in favor of the dominant hand (Geffen, Rosa, & Luciano, 2000).

Addressing the second question now, it is critically important to be aware of the arbitrariness of all inventory methods of determining a person's handedness and of the distinction between neural and behavioral handedness. The two measures statistically coincide in the overwhelming majority of people (approximately 90% of whom are right-handed), although not on an individual basis, particularly among left-handers, 70% of whom are left-hemispheric for speech. It is a considered claim of the one-way callosal traffic theory that speech is a marker for the laterality of movement control in man (Schluter, Krams, Rushworth, & Passingham, 2001). Whereas humans have a choice in adopting a preferred hand, they have no choice as to the hemisphere with which they speak, hear, or sense (see the following).

Thus, with respect to the cortex, all movements are bilateral in a significant anatomical sense depicted at the outset, and as shown in EEG and in the functional magnetic resonance imaging (f-MRI) studies thus far cited. Franz et al. (2002) referred to the discussions of classical neurologists on bilateral representation of speech (or any other functions, for that matter). Those representations have often been based on results from the Wada test (Loring et al., 1994, an unreliable and misleading method for the purposes under discussion because of the vicissitudes of the procedure itself (Derakhshan, 2003c, in press). What is critical to our understanding, however, is the temporal sequencing of cortical activation when the nondominant hand is moved voluntarily (see the preceding discussion). Moving the left side demands sequential activation of both hemispheres (the left hemisphere first in right-handers; see, e.g., Defebvre et al., 1994; Kristeva et al., 1979).

The occurrences of crossed aphasia and crossed non-aphasia (respectively, instances in which, on the basis of the self-declared handedness of the patient, one does not expect either the presence or the absence of a language deficit) represent a total failure of self-reported or inventory methods of laterality determination. The sobering event and the message of those experiments of nature are hidden in the presence of apraxia in the nonparalyzed hand, ipsilateral to the major hemisphere, as defined earlier (for the occurrence of apraxia and difficulty in writing in the not paralyzed [neurally nondominant] right hand of all crossed aphasic individuals, see Tables 1 and 2 in Marien, Engelborghs, Vignolo, & De Dyne, 2001). Such incongruities between self-declared handedness and how a person is neurally wired occur in no fewer than 1 in 6 people, a vast majority of whom are ostensible left-handers (Derakhshan, 2002; Drager & Knecht, 2002).

Statistically, in the situation reported by Franz et al. (2002), only 5 of the 16 behavioral left-handers (and 2 of the 16 right-handers) were authentic sinistrals; the remainder were ostensible left-handers, in whom one would expect no temporal lead of the left hand. There are ample examples in the laterality literature in which the presence of such

inauthenticities among the participants wrought chaos on the whole scene until the investigators removed those "impurities" by abandoning the dictum of the inventory (see Tables 1 and 3 in Savage & Thomas, 1993) or by other means (see Tables 1 and 3 in Efron, 1963). I believe that the same such incongruities occurred among Franz's participants, causing the obliteration of onset asymmetry among the behaviorally left-handed group, making the comparison with the right-handed cohort difficult, and frustrating the stated aim in an enquiry with a singular temporal dimension. The same kind of error occurred in the study of Dassonville et al. (1997): The significance of a 16-ms differential in reaction time (in favor of the dominant hand) was missed. The actual value was underestimated because of the impurity of the left-handed cohort in that study. The fact that Dassonville and colleagues tracked the handedness of their participants in another (cortical) dimension, however, rescued the occasion, and they arrived at a correct conclusion. Yet, although Dassonville and colleagues were the first to discover the imaging differential of handedness, their belief in the existence of an (imaginary) ipsilateral corticospinal pathway as the anatomy behind their findings prevented them from drawing proper conclusions from their finding (Derakhshan, 2003d).

In the case of Franz and her colleagues' study, however, all is not lost. Determining the neural handedness of each participant by any of the modalities mentioned and reappraising the data afterward is a remedy that seems achievable.

*Correspondence address: I. Derakhshan, 415 Morris Street, Suite 401, Charleston, WV 25301, USA. E-mail address: idneuro@hotmail.com*

## **Handedness Is Not the Only Factor That Determines Hand Lead in Bimanual Tasks**

*Response of E. A. Franz and A. Rowse*

We enjoyed reading the commentary by Derakhshan, and we agree with him on a number of issues. He seems, however, to have misunderstood our data and interpretations. In this response, we first attempt to clarify his confusion, and then we consider some of the points he raises about handedness and the role of the corpus callosum.

In our study (Franz, Rowse, & Ballantine, 2002), we sought to examine whether handedness determines which hand leads in bimanual tasks generally or whether other factors might also come into play. We operationally defined handedness as "where a person falls on a continuum that ranges from strongly left-handed to strongly right-handed, on the basis of a battery of tasks" (Franz et al., 2002, p. 408; see also Oldfield, 1971). Preference assessments such as that include a battery of commonly performed tasks and are readily used in studies as a first approximation of handedness.

The motivation for our study came from our interest in the spatial properties involved in the planning of bimanual tasks



(Franz, 1997, 2003; Franz, Eliassen, Ivry, & Gazzaniga, 1996; Franz & Ramachandran, 1998). We hypothesized that in addition to handedness, other factors might come into play that influence hand lead in bimanual tasks such as circle drawing in different directions. In particular, we suspected that cognitive planning processes associated with selecting the appropriate directions in space to draw might also influence hand lead. In the case of mirror-symmetrical circle drawing, those additional factors might not be necessary, given that the two hands move with respect to one another rather than to a real or an imagined external reference.

Consistent with our predictions and with other published reports, mirror-symmetrical drawing tended to be characterized by a right hand lead, on average, in right-handers. In left-handers, there was a left hand lead, but the average magnitude of that lead was not as large as that found in right-handers (see the two rightmost columns of Figure 3, p. 407, of Franz et al., 2002). To further assess that effect, we counted the number of trials that were led by the right hand (or the left hand) and computed a frequency for each. That analysis revealed that approximately 75% of trials from the right-handed group were led by the right hand, whereas approximately 56% of trials from the left-handed group were led by the left hand (see the two rightmost columns of Figure 4, p. 408, of Franz et al., 2002). We concluded that the dominant-hand lead was more pronounced in right-handers than in left-handers, and we referred to the left-handers' lead effects as more "mixed," indicating that a large proportion of trials were led by each hand in those individuals.

The novel finding (not emphasized in earlier studies) was that parallel drawing tasks did not show the same patterns of results as did mirror-symmetrical tasks. When both hands were required to draw in a clockwise direction, the right hand led on nearly 80% of trials in both the left- and the right-handed groups. In the counterclockwise drawing condition, the left hand led on approximately 80% of trials in both groups (see the two leftmost columns of Figure 3 of Franz et al., 2002, for the magnitude of the lead and Figure 4 for the frequency data). Interestingly, the phase difference was even larger on parallel drawing tasks than on mirror-symmetrical tasks (as can be seen by comparing the columns in Figure 3).

We concluded the following: "The similarity of findings between groups [left- and right-handers] indicates that handedness does not determine which hand leads in parallel tasks. Rather, coordination mode and movement direction appear to be the determining factors. The second finding of importance was that the right hand tended to lead in both conditions of mirror-symmetrical drawing in right-handers, whereas a mixed hand lead was the tendency in left-handers on mirror-symmetrical tasks. Accordingly, handedness might play a role in determining hand lead in mirror-symmetrical tasks" (Franz et al., 2002, pp. 408–409). Thus, we feel our primary results are consistent with Derakhshan's expectations for mirror-symmetrical bimanual drawing. With parallel bimanual drawing, other

spatial planning properties might come into play that strongly bias hand-lead effects. In our research, we continue to explore the nature of those effects.

With respect to Derakhshan's claims, we agree that the basic notion of a one-way traffic flow of callosal information transfer might account for findings obtained on mirror-symmetrical tasks in those individuals who are strongly lateralized. In fact, in the first instance, we used hand lead in our model to infer the dominant hemisphere of processing. Our qualifier is that those effects, which are most readily observed in simple bimanual reaction times and in a host of bimanual tasks, are actually quite small relative to the strong directional biases that influence hand lead in more spatially demanding types of bimanual tasks. For that reason, our model of parallel drawing movements incorporates additional spatial planning modules that also appear to be lateralized on the basis of the direction of drawing.

One motivation for revisiting those issues in neurologically normal participants came from our earlier findings on two small groups of individuals who lack a corpus callosum (callosal agenesis or callosotomy). Our initial finding was that without vision of the hands, only one coordination mode could be performed by each group (Franz, 2000a, 2000b, 2003—described on p. 410 of Franz et al., 2002). We inferred from those findings that the corpus callosum is necessary for the flexible control of dominance on such tasks. Although the group with callosal agenesis learned to perform the mirror-symmetrical tasks after considerable training with vision, the group who had had a callosotomy continued to show problems in the performance of parallel circle drawing even after such training. Given that the individuals from the two groups showed opposite patterns of cerebral dominance on our other assessments, another inference from those findings is that each cerebral hemisphere might be dominant for a different type of bimanual organization.

With respect to parallel circle drawing, some effects of lateralized computations might also be apparent. The hand-lead patterns shown in both patient groups mentioned earlier and in the control subjects of Franz et al. (2002) were suggestive of the possibility that the two hemispheres might be differentially equipped to guide movements in different directions. We considered that argument on p. 410. Those computations, which are posited to occur upstream from those involved in command initiation, ultimately have a strong influence on hand lead, perhaps because each hemisphere might be differentially equipped for the computations that underlie the specification of each direction.

We agree that in people who are strongly right-handed, movement-related signals from the left hemisphere will arrive at the (contralateral) right hand before arriving at the (ipsilateral) left hand, given that the signals would take some time to traverse the callosum in order to reach the right cerebral hemisphere and, in turn, the left hand. It is possible that people with strong left-handedness are characterized by precisely the opposite direction of traffic. As

implied by our findings, however, numerous people might fall in between those extremes of handedness. It is not clear how the one-way traffic idea would account for the effects found in those people, and most likely, the idea is too simplistic on its own.

A related issue concerns the excessively long delays that have been purported to reflect callosal transfer, as was pointed out in Derakhshan's comments. It seems that delays as long as hundreds of milliseconds might not be caused solely by callosal transfer. Thus, the factors that underlie those long delays also require further examination. As implied by our earlier examples, one possibility is that the processing within a hemisphere takes a finite length of time, but one hemisphere's speed (and ability) of processing different tasks (or different task components) might differ from that of the other hemisphere. In the case of a complex bimanual task, a large between-hand lag found in a presumably left-hemisphere-dominant task could be explained by the summed contribution of callosal transfer and a slow right hemisphere module responsible for some processes that are crucial in the formation of the left hand's trajectory. We must also keep in mind that the tasks we presently examined are continuous and as such might reflect delays associated with more than the simple transfer of information from one hemisphere to the other. Those considerations are indeed what have motivated us to further explore complex bimanual tasks in people who demonstrate different handedness preferences.

We thank Derakhshan for his input, but we feel that the issues he raised concerning our study are unlikely to have adversely affected our results and conclusions. However, we will keep in mind those considerations while pursuing our ongoing empirical studies on those issues.

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Correspondence address: Elizabeth A. Franz, Action, Brain, and Cognition Laboratory, Department of Psychology, University of Otago, Dunedin, New Zealand. E-mail address: Lfranz@psy.otago.ac.nz

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