

# Laterality of the Alien Hand: Directionality of Callosal Traffic Underpins Neural Handedness

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## Abstract

Whereas the relationship of handedness to the ability to talk has been known to the ancients (Psalm 137, for example) the exact knowledge of anatomical underpinnings of this relationship at the public level is a new understanding.

This article pursues another corollary of the anatomy sustaining laterality of motor control, i.e. the variability of the alien/unruly hand in patients who have suffered injury to the largest tract connecting the two hemispheres, i.e. the corpus callosum.

It is shown that the lateralities of the command center (major hemisphere) and that of the alien hand always coincide, despite the apparent variability of the affected hand in such events (i.e. right hand of left hand in different right handed patients). According to the newly discovered circuitry, the hard-wired directionality in callosal traffic (neural handedness) determines the laterality of the alien/unruly hand after callosal injury, rather than the avowed handedness of the subject (behavioral handedness). The discrepancy between neural and behavioral handedness is explained clinically and physiologically. The latter provides for a noninvasive and inexpensive determination of neural handedness of the subject, i.e. the simple reaction time of two symmetrically located effectors in the body. The side with the longer reaction time is seated below the major hemisphere.

## Introduction

Since first described by Brion and Jedynak in 1972, there have been several reviews on the subject of alienation of one hand after callosal injury; with or without concomitant involvement of cortical regions and the patient's acknowledgement of the ownership of the unruly hand.<sup>1-4</sup> Among these the reviews by Tanaka et al and C.M. Fisher are the most comprehensive. None of these however, have addressed the variable laterality of the alien/unruly hand among the right handed subjects (i.e. whether the alienation involved the left or the right hand, and why).

The purpose of the present article is to build upon the work of Tanaka et al and Fisher by presenting clinical and time-resolved data in support of the distinction between behavioral (ostensible, avowed) and neural handedness, thereby providing an explanation of the above-mentioned discrepancy (variability) in laterality of alien/unruly hand as reported in the literature.

The distinction of neural from behavioral handedness has been glossed over in the past under different designations<sup>5-8</sup> without recognition of the anatomical meaning of handedness as recently discovered (i.e. a code for the laterality of motor control). The latter insight, i.e. the existence of directionality in callosal traffic, has resolved a number of existing controversies in neurology by providing verifiable explanation for the facts sustaining those controversies. Among these are the issue of "dissociability" of the faculty of speech from "praxis," crossed aphasia and crossed nonaphasia,<sup>9, 10</sup> and weakness ipsilateral to expanding hemispheric lesions; hitherto ascribed to an **irrelevant artifact**, the Kernohan's notch.<sup>11, 12</sup> As the overarching issue is the concept of speech as a maker of the major hemisphere, further confirmation of the new anatomical understanding in motor control, by demonstrating its explanatory power regarding the laterality of the alien hand in callosal injury, seemed appropriate.

## Materials and Methods

Using clinical and time resolved data from personal cases and the literature, it will be shown that the laterality of the alien/unruly hand is yet another manifestation of a not mismatch between neural and behavioral handedness in a certain segment of population at large in lesions affecting the corpus callosum.

An overview of the Anatomy of Handedness and Directionality in Callosal Traffic

1. It has been conclusively shown that sensory and motor signals traveling between the two hemispheres have directionality (i.e. they travel 1-way; from the left to the right hemisphere for motor and in the opposite direction for sensory events (in right handers)). Thus, the neurally

dominant side of the body is the side closer to the command center (major hemisphere, the hemisphere of action) by a callosum width. Therefore, activation of the nondominant side of the body is delayed by an interhemispheric transfer time (IHTT). Stated differently, evidence shows that the minor hemisphere is devoted to the affairs of the nondominant side of the body/space and has no motor capability that is of its own; all motor signals for moving the nondominant side arise from the major hemisphere and are transmitted to the minor hemisphere via the corpus callosum for implementation of such commands (see below for further explanation).

For example, in a time-resolved study of a right handed patient with ischemic lesion of the minor hemisphere, sharing of resources in the major hemisphere was revealed by demonstration of an involuntary drift of the left arm upon performing finger to nose movements with the right hand. No similar movement of the right arm when performing the same maneuver with the left was observed, indicating the existence of directionality in callosal traffic in the motor realm.<sup>5, 6, 12</sup>

A similar interpretation of the way-ward movement of the left hand during tasks performed by the right in three callosal injury cases was given by Tanaka et al: "The motor control system of the left hemisphere seems to have been well preserved and stable, since at no time did our patients exhibited abnormal behavior of the right hand, which indicates that the left hemisphere in our patients was dominant for volitional control of movement. Thus, the dissociative behavior of the left hand in our patients appears to have been produced by **a failure in transfer of motor control information from the left hemisphere to the right** during tasks requiring the left hemisphere volitional motor control."<sup>1</sup> Callosally-mediated control of the left hand by the left hemisphere have been amply documented in simple reaction time studies, all indicating a delay of activating the left hand commensurate to IHTT.<sup>12-14</sup>

Thut et al documented sequential activation of motor cortices (left then right hemisphere) when moving the left hand in time resolved mapping of event-related potentials in a group of right handed subjects.<sup>15</sup> Bilateral activation of hemispheres upon moving the left hand was also documented by Salmelin et al.<sup>16</sup> Furthermore, interference with the functioning of the left hand has been documented in reaction time studies when right handed subjects with aphasia performed the test while counting aloud.<sup>17</sup>

2. Similarly, it has been shown that the major hemisphere is the final destination of all somatosensory signals from the nondominant as well as the dominant side of the body.<sup>14, 18</sup> In the words of Schwartz et al: "tactile information from the left hand, after reaching the somatosensory zone in the right hemisphere, is transmitted to the left hemisphere ..... This anatomical arrangement renders left-hand information more vulnerable to chance lesions than right-hand information, which has direct access to the response mechanism via a more compact projection system."<sup>18</sup> Thus, sensing from the nondominant side of the body, which is callosally mediated, is delayed by an IHTT.<sup>13, 14, 18-20</sup> Because of the excitatory nature of signals arising from the major hemisphere,<sup>21</sup> moving the nondominant side awakens the dormant (injured) right hemisphere temporarily lessening the neglect in such patients.<sup>6, 22</sup> For example, turning the eyes to the left in a right hander with right sided frontoparietal lesion resulted in a 50 percent improvement of extinction in visual confrontation testing; gazing to the left diminished the rate of extinction in double simultaneous stimulation from 93 percent to 47 percent, according to a detailed study by Rapcsak et al.<sup>23</sup> More recently the same group of investigators made similar observation on the effect of left lateral gaze in line bisection test in patients with cortical neglect.<sup>24, 25</sup>

To sum, the above data confirm that moving and sensing the nondominant side of the body are bi-hemispherical events requiring callosal participation and that the events involving the dominant side occur within the contralateral hemisphere alone.<sup>6, 12-14, 26</sup> This arrangement is readily demonstrated by attempting to snap the fingers of both hands at the same time. Invariably two clicks will be heard (instead of one). The second click belongs to the nondominant side of the body for being farther from the command center by an IHTT. Musicologists have recognized this nondominant delay for well over a century and a half calling it the melody lead of the right hand in piano players; as the melody is written for the right hand and the harmony for the left, although they are notated for simultaneous delivery.<sup>27-28</sup> More recently, measurements

of the onset latency of fingering and bowing hands in violin players showed earlier onset of activity in the bowing hand compared to the fingering, despite implicit (notational) requirement of simultaneous movement of both hands.<sup>29</sup>

Further evidence supporting the dichotomy of the command structure at society at large comes from the studies of readiness potential in normals by showing earlier onset of these potentials on the dominant hemisphere when moving the nondominant (left) hand either simultaneously with the right<sup>30</sup> or alternately;<sup>31</sup> by an amount commensurate to IHTT. Still others have shown the similarity of electromagnetic fields generated by moving the nondominant hand to that of bimanual activity, emphasizing bihemispheric nature of cortical activation in moving the nondominant hand.<sup>32</sup> Finally, reaction time studies have shown earlier response to various stimuli by the dominant hand compared to the nondominant (Steel et al, 2002,  $p < .0001$ ).<sup>20, 33</sup> To sum: it is evident that self-declared and neural handedness is not necessarily one and the same in an individual and that the relationship of the two is statistical rather than biological. In short, it is the comparative proximity of one side of the body to the command center that determines the laterality of symptoms following disruption of brain's unity as one organ (following callosal damage), not the laterality of the affected limb per se.

According to the anatomical criteria for dominance detailed above, i.e. the callosum-width proximity of the dominant side to the command center, the following are examples of alien/unruly hands occurring in patients whose neural and behavioral handedness were incongruous, the first two examples celebrated in the classical literature on the subject:

1. The Imperial Counselor reported by Liepmann, whose inability to control movements of his right hand with preserved connectivity of the left to the command center became evident only after Liepmann forced him to use his left hand to carry out verbal commands, to draw and to write.<sup>34, 35</sup> He displayed another commonly observed sign of partial callosal disruption, i.e. enabling synkinesis,<sup>10, 36</sup> i.e. moving the (neurally dominant) left hand in order to guide the wayward right hand closer to the intended target (seen in Figs. 3 & 4 of Liepmann's article).<sup>36</sup> Similar cases manifesting as switching of the favorite hand from one side to the other after iatrogenic or natural injury to the corpus callosum have been reviewed elsewhere.<sup>12</sup>
2. The case of the renowned neuroanatomist Alf Brodal, self-described after the author's stroke.<sup>37</sup> Brodal was a behavioral right hander. He sustained a severe stroke on the left side of the body, affecting his speech in the form of severe dysarthria and apraxia in writing (with the right hand). Referring to his own hand writing Brodal wrote: "while the former phenomena [that the lines were uneven and oblique] clearly indicate a defective control of motor function of the right hand, the skipping and doubling of letters, etc, is scarcely a pure motor phenomenon, but suggests some kind of apractic disturbance related to language function." Although memorializing this unusual feature of left sided stroke in a right hander was the purpose behind writing his experience, because of his belief in the conventional wisdom (i.e. the contralaterality of motor control), Brodal never arrived at the root of the problem he was keen to understand (i.e. the distinction between neural and behavioral handedness) leaving his questions regarding the anatomical underpinning of his apractic symptoms unanswered. The latter were similar to those displayed by Imperial Counselor outlined earlier (albeit less severe).
3. Less well-known but just as well documented cases of reversed laterality of the alien/disowned hand were described by Denny Brown and Banker, Nishikawa and colleagues (case 3) and Carrilho and colleagues (case 3), all emphasizing the floating (levitation) of the alienated right hand as hallmark of the syndrome in behaviorally right (but neurally left) handed individuals subsequent to lesions of the left hemisphere or the corpus callosum.<sup>38-40</sup> Instances of reversed laterality of motor control without the presence of alien/unruly hand were reviewed recently by Marchetti et al under the suggestive title of "crossed right hemisphere syndrome,"<sup>41</sup> insinuating the notion of geographic replacement of one hemisphere by the other in the affected subjects; a notion consistent with presence of directionality in callosal traffic as a verifiable basis for such an analysis. Roberts provided an earlier review of the same subject going back to classical cases reported in the nineteenth century.<sup>42</sup> Within this category, Rapcsak et al came closest to understanding the role of callosal directionality in rendering right handers a "nonhomogenous group in terms of cerebral motor dominance," whence their suspicion that the right handed patient with apraxia of the right hand "was using a transcalsal route when performing skilled

movements with his right hand.”<sup>43</sup> This is the closest affirmation of the 1-way callosal traffic circuitry in the older literature. Time resolved data reviewed here and elsewhere provide incontrovertible evidence to the same effect.<sup>6, 12, 15, 19, 20</sup>

4. As mentioned earlier, electrophysiological hallmark of the dominant side of the body is the faster reaction time of the effectors on that side compared to the nondominant side of the body. Similarly, earlier emergence of readiness potential over the major hemisphere declares the nondominant status of the limb ipsilateral to the major hemisphere.<sup>30-31</sup>

The first of these two conditions were met in the case of the patient V.J., a behavioral left hander described by Frey et al<sup>10</sup> and Eliassen et al.<sup>44</sup> As seen in Fig.1 of Eliassen et al, VJ's reaction time on the right was faster than that of the left by an IHTT of 15 ms, making her a neural right hander according to the new scheme. This interpretation obviates the need for postulating “dissociation” between the representation of tool- use skill and hand dominance as suggested by Frey et al<sup>10</sup> as well as the need for refuting “neurological models that maintain that bimanual coupling arises from a common control signal isolated in one hemisphere” as advocated by Gazzaniga.<sup>45</sup> On the contrary, the new understanding restores the classical model, i.e the principle of constant conjunction of brainedness and neural handedness as documented above and elsewhere.<sup>5</sup> The second of the above-mentioned physiological conditions occurred in a right handed patient described by McNabb et al (1988).<sup>46</sup> CT scan showed extensive destruction of the left medial frontal and parietal cortex and corpus callosum after left anterior cerebral artery occlusion. As seen in Fig.1, there is bi-lateral occurrence of movement related potentials when the subject moved her neurally nondominant right hand, and unilateral as she moved her dominant left. Clinically, this is consistent with the fact that this patient did not have aphasia as would be expected in a patient with a lesion of the major hemisphere. Thus, the finding in McNabb's patient is similar to that depicted in Figs. 2 and 3 from a normal subject reported by Salmelin et al,<sup>16</sup> except for reversed laterality of the potentials due to neural-behavioral mismatching in the case of McNabb et al.

## Discussion

The above review indicates that the circuitry underpinning laterality of motor control in humans is more complicated than hitherto envisaged, i.e. belief in contralateral innervation in its current form. It also indicates that confidence in behavioral handedness is subject to statistical considerations. An important aspect of the laterality of sensory and motor control is the temporary improvement of visual and tactual neglect upon moving the nondominant side of the body;<sup>6, 22, 47</sup> a feature never observed without an extant callosum at the genu.<sup>13</sup> This is also the case in seizure related callosotomies wherein there have been several instances in which a repeat MRI has revealed the existence of callosal connectivity, forcing reappraisal of the earlier speculations by the authors regarding the subject under discussion.<sup>48-50</sup>

Another important practical result of the above understanding is that seizures may not start in the minor hemisphere unless the lesion in that hemisphere raises the intracranial pressure, thus affecting the major hemisphere as well.<sup>12, 51</sup>

Another corollary of the anatomy sustaining neural handedness is in the methodology it provides for lateralizing the major hemisphere safely and inexpensively; i.e. the determination of the reaction times of two symmetrically placed effectors in the body. Except in the case of sterno-cleido-mastoid, the side with the shorter reaction time is located contralateral to the major hemisphere.<sup>52</sup> The explanation of this reassuring exception to the rule governed by directionality in callosal traffic is presented elsewhere.<sup>13</sup>

## Conclusion

Based on the data presented above, the laterality of the alien/unruly hand is the same as that of the motor control if occurrences of neural and behavioral mis-matches are kept into consideration. This latter occurs in no less than 15-20 percent of the population at large, a source of confusion in cortical neurology since Paul Broca's contribution to the subject. This article reviews evidence that behavioral handedness may not be taken at face value for indication the laterality of motor control in humans. The relationship between neural and behavioral handedness is stochastic, not biological.

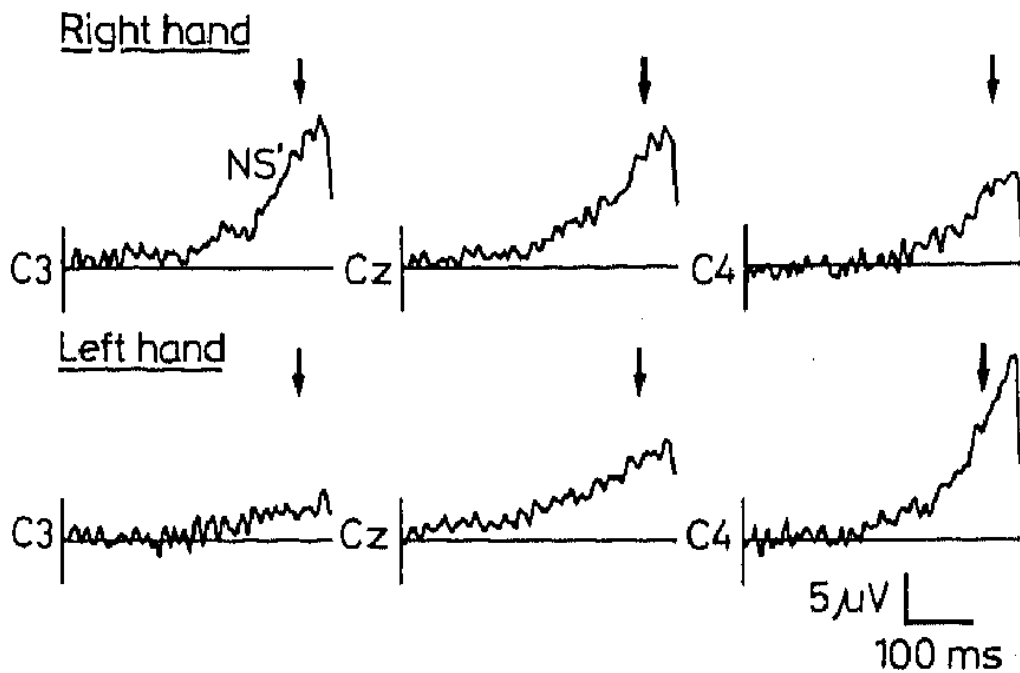


Fig 2 *Movement-related potentials associated with right and left finger extension. Note the wider (bilateral) distribution of the NS' component of the premotor negativity with right-sided movements than with left-sided movement, and the attenuation of the preceding Bereitschaftspotential (BP) for both right and left-sided movement. The arrows indicate movement onset which was detected using an infra-red system.*<sup>6</sup>

**Figure 1.** In this patient with right sided alien hand moving the neurally nondominant right hand is associated with bi-hemispheric activity at C3 and C4. Moving the dominant left hand, however, is associated with activity at C4 only. The figure also provides an estimate of onset latency of movement potential (NS') on both sides; ~ 200 ms on the left (C3) and 300 ms on the right (C4), resulting in an estimate of interhemispheric transfer time of ~ 100 ms. (From McNabb et al, 1988, *J Neurol Neurosurg Psychiatry*, 1988. See text for further details. Reproduced with permission.

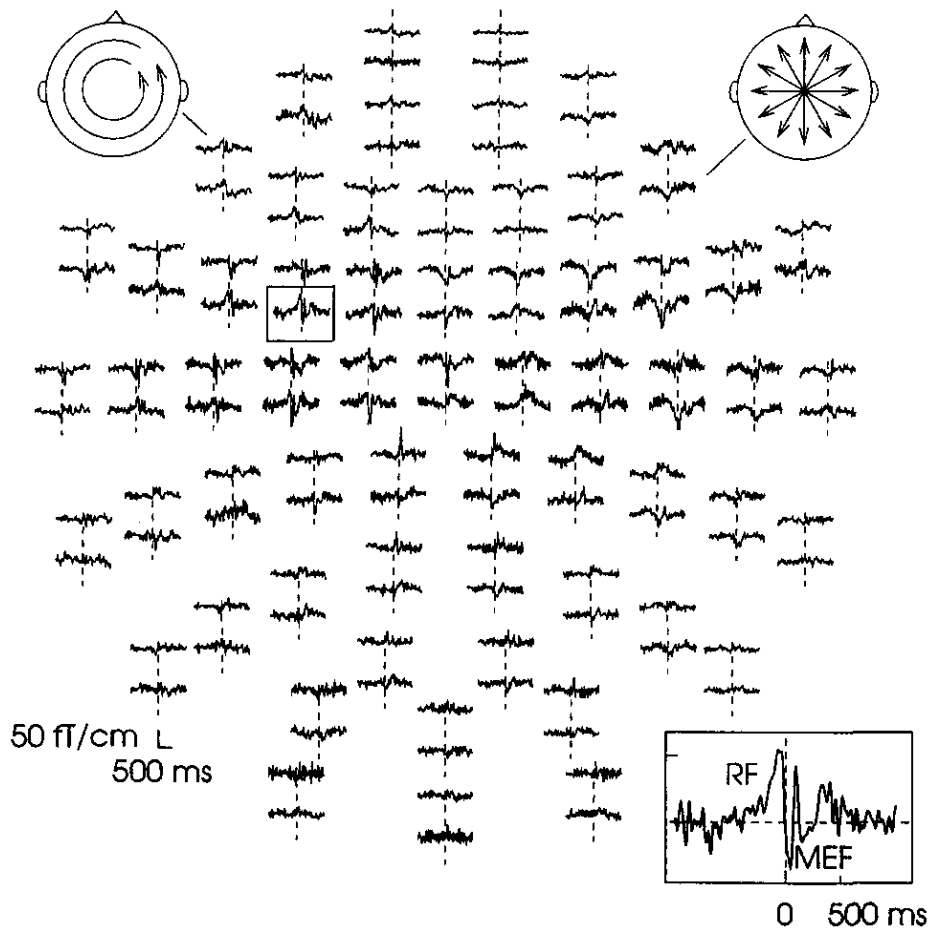
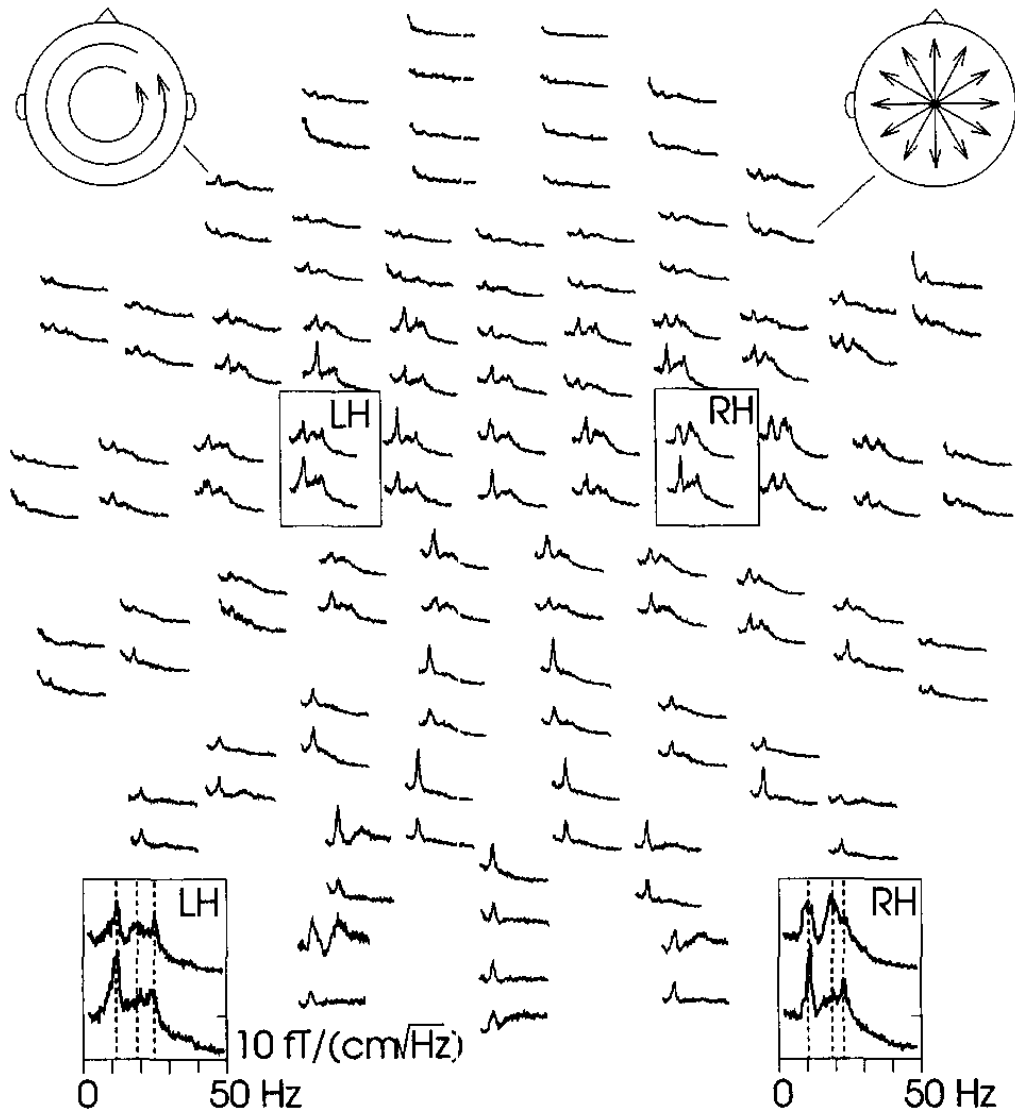


Fig. 1. Distribution of magnetic signals from 1 sec before to 1 sec after button press (dashed vertical lines) when subject SA moved his right index finger. The maximum signal, measured over the left Sml, is plotted as insert. The latitudinal and longitudinal derivatives of the magnetic field (upper and lower curves in each pair, respectively) are shown at each measurement site. RF and MEF denote readiness and movement-evoked fields, respectively.

Figure 2. Note contralaterality of the MEF with movement of the right side. Compare to Fig. 3. (From Salmelin et al, *Electroencephalograph Clin Neurol* 1995; 95: 444-452. Reproduced with permission).



**Fig. 5.** Spectral distribution (amplitude versus frequency) of the signals measured over the whole head when subject SA was moving his left index finger. The inserts in the lower corners show expanded views of the selected signals over the SmI hand areas of the left (LH) and right (RH) hemispheres; the dashed vertical lines denote the 3 distinct spectral peaks. The upper and lower curves of each sensor pair represent the latitudinal and longitudinal records, respectively, at each measurement site.

**Figure 3.** Notice bilaterality of MEF when the subject moved his left index finger; compare to Fig. 2. (From Salmelin et al, *Electroencephalogr Clin Neurophysiol*, 1995. Reproduced with permission).

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