RESEARCH ARTICLE ABSTRACTS

Left parietal activation related to planning, executing and suppressing praxis hand movements

Lewis A. Wheaton, Esteban Fridman, Stephan Bohlhalter, Sherry Vorbach, Mark Hallett
Clin Neurophysiol; 2009; 120: 980–986

Objective: We sought to investigate the activity of bilateral parietal and premotor areas during a Go/NoGo paradigm involving praxis movements of the dominant hand.

Methods: A sentence was presented which instructed subjects on what movement to make (S1; for example, “Show me how to use a hammer.”). After an 8-s delay, “Go” or “No Go” (S2) was presented. If Go, they were instructed to make the movement described in the S1 instruction sentence as quickly as possible, and continuously until the “Rest” cue was presented 3 s later. If No Go, subjects were to simply relax until the next instruction sentence. Event-related potentials (ERP) and event-related desynchronization (ERD) in the beta band (18–22 Hz) were evaluated for three time bins: after S1, after S2, and from -2.5 to -1.5 s before the S2 period.

Results: Bilateral premotor ERP was greater than bilateral parietal ERP after the S2 Go compared with the No Go. Additionally, left premotor ERP was greater than that from the right premotor area. There was predominant left parietal ERD immediately after S1 for both Go and No Go, which was sustained for the duration of the interval between S1 and S2. For both S2 stimuli, predominant left parietal ERD was again seen when compared to that from the left premotor or right parietal area. However, the left parietal ERD was greater for Go than No Go.

Conclusion: The results suggest a dominant role in the left parietal cortex for planning, executing, and suppressing praxis movements. The ERP and ERD show different patterns of activation and may reflect distinct neural movement-related activities.

Significance: The data can guide further studies to determine the neurophysiological changes occurring in apraxia patients and help explain the unique error profiles seen in patients with left parietal damage.

Discrete parieto-frontal functional connectivity related to grasping

Noriaki Hattori, Hiroshi Shibasaki, Lewis Wheaton, Tao Wu, Masao Matsuhashi and Mark Hallett
J Neurophysiol; 2009; 101: 1267-82

The human inferior parietal lobule (IPL) is known to have neuronal connections with the frontal lobe, and these connections have been shown to be associated with sensorimotor integration to perform various types of movement such as grasping. The function of these anatomical connections has not been fully investigated. We studied the judgment of graspability of objects in an event-related functional MRI study in healthy subjects, and found activation in two different regions within IPL; one in the left dorsal IPL extending to the intraparietal sulcus and the other in the left ventral IPL. The former region was activated only in the judgment of graspable objects while the latter was activated in the judgment of both graspable and non-graspable objects although the activation was greater for the graspable objects. Psychophysiological interaction analysis showed that these regions had similar, but discrete functional connectivity to the lateral and medial frontal cortices. In relation to this particular task, the left dorsal IPL had functional connectivity to the left ventral premotor cortex, supplementary motor area (SMA) and right cerebellar cortex, whereas the left ventral IPL had functional connectivity to the left dorsolateral prefrontal cortex and pre-SMA. These findings suggest that the connection from the left dorsal IPL is associated specifically with automatic flow of information about grasping behavior. By contrast, the connection from the left ventral IPL might be related to motor imagination or enhanced external attention to the presented stimuli.
Gesture-subtype dependent left lateralization of praxis planning: An event-related functional MRI study

S. Bohlhalter, N. Hattori, L. Wheaton, E. Fridman, E.A. Shamim, G. Garraux and M. Hallett
Cerebral Cortex; 2009; 19: 1256-62

Ideomotor apraxia is a disorder mainly of praxis planning and the deficit is typically more evident in pantomiming transitive (tool-related) than intransitive (communicative) gestures. The goal of the present study was to assess differential hemispheric lateralization of praxis production using event-related fMRI. Voxel based analysis demonstrated significant activations in posterior parietal (PPC) and premotor association (PMC) areas, which were predominantly left-hemispheric, regardless of whether planning occurred for right or left hand transitive or intransitive pantomimes. Furthermore, region of interest based calculation of mean laterality index (LI) revealed a significantly stronger left lateralization in PPC/PMC clusters for planning intransitive (LI = -0.49 ± 0.10, mean ± SD) than transitive gestures (-0.37 ± 0.08, p = 0.02, paired t-tests) irrespective of the hand involved. This differential left lateralization for planning remained significant in PMC (LI = -0.47 ± 0.14 and -0.36 ± 0.13, mean ± SD, p = 0.04), but not in PPC (-0.56 ± 0.11 and -0.45 ± 0.12, p = 0.11), when both regions were analyzed separately. In conclusion, the findings point to a left hemispheric specialization for praxis planning, being more pronounced for intransitive gestures in premotor cortex, possibly due to their communicative nature.

Reliability of TMS Motor Evoked Potentials in Quadriceps of Subjects with Chronic Hemiparesis after Stroke

Lewis Wheaton; Federico Villagra; Daniel F Hanley; Richard F Macko; Larry W Forrester
J Neurol Sci; 2009; 15: 115-7

Transcranial magnetic stimulation (TMS) non-invasively measures excitability of central motor pathways in humans and is used to characterize neuroplasticity after stroke. Using TMS to index lower extremity neuroplasticity after gait rehabilitation requires test-retest reliability. This study assesses the reliability of TMS-derived variables measured at bilateral quadriceps of chronic hemiparetic stroke survivors. Results support using measures of both paretic and nonparetic motor threshold, MEP latencies; and nonparetic MEP amplitudes. Implications for longitudinal research are discussed.

Cortico-cortical networks in patients with ideomotor apraxia as revealed by EEG coherence analysis

Lewis A. Wheaton, Stephan Bohlhalter, Guido Nolte, Hiroshi Shibasaki, Noriaki Hattori, Esteban Fridman, Sherry Vorbach, Jordan Grafman, Mark Hallett
Neurosci Lett; 2008: 87-92

We sought to determine whether coherent networks which circumvent lesioned cortex are seen in patients with ideomotor apraxia (IMA) while performing tool-use pantomimes. Five normal subjects and five patients with IMA (three patients with corticobasal degeneration and two with left hemisphere stroke) underwent 64-channel EEG recording while performing three tool-use pantomimes with their left hand in a self-paced manner. Beta band (20–22 Hz) coherence indicates that normal subjects have a dominant left hemisphere network responsible for praxis preparation, which was absent in patients. Corticobasal degeneration patients showed significant coherence increase between left parietal–right premotor areas. Left hemisphere stroke patients showed significant coherence increases in a right parietofrontal network. The right hemisphere appears to store useable praxis representations in IMA patients with left hemisphere damage.
Preparatory band specific premotor cortical activity differentiates upper and lower extremity movement

Lewis A. Wheaton, Mackenzie Carpenter, J. C. Mizelle, Larry Forrester
Exp Brain Res; 2008; 184: 121-126

Event related desynchronization (ERD) allows evaluation of brain signals in multiple frequency dimensions. The purpose of this study was to determine left hemispheric non-primary motor cortex differences at varying frequencies of premovement ERD for similar movements by end-effectors of the upper and lower extremities. We recorded 32-channel electroencephalography (EEG) while subjects performed self-paced right ankle dorsiflexion and wrist extension. Electromyography (EMG) was recorded over the vastus medialis and vastus lateralis muscles to determine onset of the movement. EEG was analyzed for premovement ERD within the alpha (8–12 Hz), low beta (13–18 Hz) and high beta (18–22 Hz) frequencies over the premotor, motor, and sensory areas of the left and mesial cortex from 1.5 to 0 s before movement. Within the alpha and high beta bands, wrist movements showed limited topography, but greater ERD over posterior premotor cortex areas. Alpha ERD was also significantly greater over the lateral motor cortex for wrist movements. In the low beta band, wrist movements provided extensive ERD differences to include the left motor and mesial/lateral premotor areas, whereas ankle movements showed only limited ERD activity. Overall, alpha and high beta activity demonstrated distinctions that are consistent with mapping of wrist and ankle representations over the sensorimotor strip, whereas the low beta representation demonstrated the clearest distinctions between the limbs over widespread brain areas, particularly the lateral premotor cortex. This suggests limited leg premovement activity at the dorsolateral premotor cortex. Low beta ERD may be reflective of joint or limb specific preparatory activity in the premotor area. Further work is required to better evaluate the extent of this low beta activity for multiple comparative joints.

How does the brain respond to unimodal and bimodal sensory demand in movement of the lower extremity?

Lewis A. Wheaton, J. C. Mizelle, Larry W. Forrester, Ou Bai, Hiroshi Shibasaki, Richard F. Macko

Numerous electroencephalography (EEG) studies have shown that neurophysiological signals change in response to visual and sensory adaptations in upper extremity tasks. However, this has not been clearly studied in the lower extremity. In this study, we evaluated how sensory loading affects brain activations related to knee movement. Thirty-two channel EEG was recorded while ten subjects performed knee extension in four different conditions: no weight and no visual target (NWNT), weight added to the ankle and no visual target (WNT), no weight and a visual target (NWT), and both weight and target (WT). Surface electromyography (EMG) was recorded from the vastus medialis and vastus lateralis muscles to determine onset of the movement. EEG was epoched from -4.5 s before to 1 s after EMG onset. Epochs were averaged to acquire movement-related cortical potentials (MRCPs) of each task condition. MRCP amplitude during the pre-movement period from -2 s to EMG onset was evaluated at electrodes over motor, sensory, frontal, and parietal areas. The amplitude of the pre-movement potentials for the conditions was different across areas of interest. Over the motor area, NWNT had lower amplitude than any other condition and WT had higher amplitude than any other condition. However, there was no difference between unimodal NWT and WNT conditions. Mesial frontal and parietal areas showed larger MRCP to the bimodal condition than either unimodal or NWT conditions. The parietal cortex was the only region that showed a difference between unimodal conditions with greater amplitude for NWT condition. Information concerning added sensory demand is processed by the motor cortex in a way that may be indifferent to the type of modality, but is influenced by the quantity of modalities at the level of the knee. Other brain structures such as parietal and premotor cortices respond based on the modality type to help plan appropriate strategies for motor control in response to sensory manipulations. This suggests that additional task demands in motor training may create a rich sensory environment that may be beneficial in promoting optimal neuromotor
The role of the dorsal stream for gesture production

Esteban A. Fridman, Ilka Immisch, Takashi Hanakawa, Stephan Bohlhalter, Daniel Waldvogel, Kenji Kansaku, Lewis Wheaton, Tao Wu, and Mark Hallet

Skilled gestures require the integrity of the neural networks involved in storage, retrieval, and execution of motor programs. Premotor cortex and/or parietal cortex lesions frequently produce deficits during performance of gestures, transitive more than intransitive. The dorsal stream links object information with object action, suggesting that mechanical knowledge of tool use is stored focally in the brain. Using event-related fMRI, we explored activity during instructed-delay transitive and intransitive hand gestures. The comparison between planning–preparation and execution of gestures demonstrated a temporal rostral to caudal gradient of activation in the ventral premotor cortex (PMv) and inferior to superior gradient of activation in the posterior parietal cortex (PPc). Comparison between transitive and intransitive gestures established a functional specificity within the dorsal stream for mechanical knowledge. Results demonstrate that not only PPc but also the PMv acts in the processing of sensorimotor information during gestures. This might be the substrate underlying selective deficits in ideomotor apraxia patients.

Posterior parietal negativity preceding self-paced praxis movements

Lewis A. Wheaton, Satoshi Yakota, Mark Hallett
Exp Brain Res 2005; 163: 535-539

Studies of movement-related cortical potentials (MRCPs) for simple movements have shown a slowly rising negativity (Bereitschaftspotential, or BP) about 2 s prior to movement onset, centered in the bilateral sensorimotor area. However, complex movements may elicit a different temporal and spatial distribution of this pre-movement activity. In this study, 64-channel electroencephalography (EEG) was recorded while normal volunteers were asked to perform a simple thumb adduction once every 10–15 s for three 10–15 min blocks. Following this, they were asked to make tool-use movements (hammer, scissor, and screwdriver pantomime) in the same manner. Surface electromyography (EMG) was recorded on the thumb adductor and forearm flexor. MRCP was analyzed for the beginning part of the epoch (from 3.5 s to 1.5 s before EMG onset, with 0.5 s time bins) for differences in the amplitude and spatial distribution of the BP. Significant differences were seen from 3.0 s to 2.0 s before EMG onset, where the amplitude was greater for the more complex movements. On average, negativity began at 3.0 s before onset for praxis movements, and only 1.7 s before onset for thumb adduction. Additionally, the negativity seen for the complex movements had a distribution beginning over the left hemisphere posterior parietal area, whereas, thumb adduction movements had a more anterior distribution, over the bilateral sensorimotor area. The posterior parietal negativity (PPN) suggests that early parietal activity is essential for tool-use movements and is not a part of preparing simple movements.

Synchronization of parietal and premotor areas during preparation and execution of praxis hand movements

Lewis A. Wheaton, Guido Nolte, Stephan Bohlhalter, Esteban Fridman, Mark Hallett

Objective: We sought to determine temporal patterns of functional connectivity between the parietal, premotor, and motor cortices during preparation and execution of praxis hand
movements.  

**Methods:** Normal subjects were instructed to perform six transitive (tool use) and intransitive (communicative gesture) self-paced pantomimes with the right hand while recording 64-channel electroencephalography (EEG) and electromyography (EMG) from right thumb and forearm flexors. Focusing on corticocortical coherence, we explored the time-course of synchronously active parietal and premotor circuits involved in these motor tasks. Trials were marked for EMG onset and averaged across subjects to determine changes in coherence relative to baseline between parietal, premotor, and motor areas.

**Results:** Coherence of homologous electrode pairs was similar when comparing transitive and intransitive movements. During preparation, beta band (18–22 Hz) coherence was maximal between electrodes over the left parietal lobe and left premotor electrodes. Additionally during preparation, the premotor area showed high coherence to the motor hand area and the parietal cortex. Electrodes over the supplementary motor area also showed coherence to the motor and parietal, but not the premotor area. Before and during execution, a second peak of high coherence increase was present in each area that demonstrated coherence increases during preparation. There was no coherence increase between parietal and motor areas. Coherence rapidly diminished 1.5–2.0 s after movement onset.

**Conclusions:** Patterns of increased corticocortical coupling within a parietal, premotor, and motor network are present during preparation and execution of praxis movements.

**Significance:** This study adds to evidence that parietofrontal networks may be critical for integrating preparatory and motor-related activity for praxis movements.

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**Temporal activation pattern of parietal and premotor areas related to praxis movements**

*Lewis A. Wheaton, Hiroshi Shibasaki, Mark Hallett*


**Objective:** We sought to determine the cortical physiology underlying praxis movements in normal subjects using electroencephalography (EEG).

**Methods:** Eight normal subjects were instructed to perform six types of self-paced tool-use pantomime and communicative gesture movements with the right hand. We recorded 64-channel EEG using a linked ear reference and electromyogram (EMG) from right thumb and forearm flexors.

**Results:** Data revealed early slow wave components of the movement-related cortical potential (MRCP) beginning over the left parietal area about 3 s before movement onset, similarly for both movement types. At movement onset, maximal amplitude was present over central and bilateral sensorimotor areas. Event-related desynchronization (ERD) in the beta band was seen over the left parietal and sensorimotor cortices during preparation, later spreading to the homologous area of the right hemisphere. Alpha ERD was mainly in the left sensorimotor cortex about 1.5 s before movement onset. Beta ERD in mesial frontal areas was greater during preparation for tool use compared to communicative gesture movements. Mesial frontal beta event-related synchronization (ERS) developed more rapidly after communicative gestures than tool-use.

**Conclusions:** The dynamics of parietal and frontal activities indicates the timing of these areas in the production of praxis. The posterior parietal cortex contributes to the early slow wave negativity of the MRCP.

**Significance:** Planning self-paced praxis movements begins as early as 3 s before movement in the left parietal area and subsequently engages frontal cortical regions.

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**Identifying true brain interaction from EEG data using the imaginary part of coherency**

*Guido Nolte, Ou Bai, Lewis Wheaton, Zoltan Mari, Sherry Vorbach, Mark Hallett*

Clin Neurophysiol 2004; 115: 2292-307

**Objective:** The main obstacle in interpreting EEG/MEG data in terms of brain connectivity is the
fact that because of volume conduction, the activity of a single brain source can be observed in many channels. Here, we present an approach which is insensitive to false connectivity arising from volume conduction.

Methods: We show that the (complex) coherency of non-interacting sources is necessarily real and, hence, the imaginary part of coherency provides an excellent candidate to study brain interactions. Although the usual magnitude and phase of coherency contain the same information as the real and imaginary parts, we argue that the Cartesian representation is far superior for studying brain interactions. The method is demonstrated for EEG measurements of voluntary finger movement.

Results: We found: (a) from 5 s before to movement onset a relatively weak interaction around 20 Hz between left and right motor areas where the contralateral side leads the ipsilateral side; and (b) approximately 2–4 s after movement, a stronger interaction also at 20 Hz in the opposite direction.

Conclusions: It is possible to reliably detect brain interaction during movement from EEG data. Significance: The method allows unambiguous detection of brain interaction from rhythmic EEG/MEG data.
**REVIEW ARTICLE ABSTRACTS**

**Ideomotor apraxia: A review**

Lewis A. Wheaton & Mark Hallett  
J Neurol Sci 2007; 260: 1-10

Ideomotor apraxia (IMA) is a disorder traditionally characterized by deficits in properly performing tool-use pantomimes (e.g., pretending to use a hammer) and communicative gestures (e.g., waving goodbye). These deficits are typically identified with movements made to verbal command or imitation. Questions about this disorder relate to its diagnosis, anatomical correlates, physiological mechanisms involved, and the patients in whom IMA is best characterized. In this review, utilizing information presented at an international workshop, we summarize the present state of knowledge about IMA. We include insights on how to distinguish IMA from the other motor apraxias and confounding disorders. We discuss testing for IMA and the need for more rigorous tests that examine more elements, such as imitation, actual use, task selection, and recognizing proper use. From neurophysiological insights, we propose hypotheses of the necessity of networks in praxis performance. We also point out that more neurophysiological knowledge in humans might lead to a better understanding of how different brain structures may aid in the rehabilitation of praxis. While little is known about exactly how rehabilitation may be pursued, biological evidence warrants the further exploration of this issue.

**Parietal Representations for Hand–Object Interactions**

*Lewis A. Wheaton*  
J. Neurosci. 2007; 27: 969-970

No abstract available. Contact law@gatech.edu for article.

**Treatment of Limb Apraxia: Moving Forward to Improved Action**

Am J Phys Med Rehabil 2008; 87(2): 149-161

Limb apraxia is a common disorder of skilled, purposive movement that is frequently associated with stroke and degenerative diseases such as Alzheimer’s disease. Despite evidence that several types of limb apraxia significantly impact functional abilities, surprisingly few studies have focused on development of treatment paradigms. Additionally, although the most disabling types of apraxia reflect damage to gesture and/or object memory systems, existing treatments have not fully taken advantage of principles of experience known to affect learning and neural plasticity. We review the current state of the art in the rehabilitation of limb apraxia, indicate possible points of contact with the learning literature, and generate suggestions for how translational principles might be applied to the development of future research on treatment of this disabling disorder.

**Exercise-mediated locomotor recovery and lower-limb neuroplasticity after stroke**

*Larry W. Forrester, PhD; Lewis A. Wheaton, PhD; Andreas R. Luft, MD*  

Assumptions that motor recovery plateaus within months after stroke are being challenged by advances in novel motor-learning-based rehabilitation therapies. The use of lower limb treadmill (TM) exercise has been effective in improving hemiparetic gait function. In this review, we provide a rationale for treadmill exercise as stimulus for locomotor relearning after stroke. Recent studies using neuroimaging and neurophysiological measures demonstrate central nervous system
(CNS) influences on lower-limb motor control and gait. As with studies of upper limbs, evidence shows that rapid transient CNS plasticity can be elicited in the lower limb. Such effects observed after short-term paretic leg exercises suggest potential mechanisms for motor learning with TM exercise. Initial intervention studies provide evidence that long-term TM exercise can mediate CNS plasticity, which is associated with improved gait function. Critical needs are to determine the optimal timing and intensities of TM therapy to maximize plasticity and learning effects.