"Human Actions Conciousness"

Concepts and objectives

Action consciousness seems to largely depend on the fact that it is carried out by our own body effectors, particularly our muscles, whose sensory compartment would thus play a determining part. One can nevertheless not deny the part of motor mechanisms (deriving from the motor command) in the arising of self movement consciousness.

The first component of the project aims at bringing forward the knowledge about substrates and neural processes involved in learning, performing and consciously perceiving our symbolic movements. It tends to establish that writing is much more than a simple motor act, but rather that its performance provides cognitive cues which are integrated with those streaming from reading during linguistic learning.

The goal of the second component of the project is to study, at the level of cerebral substrates, the interaction between motor and perceptive mechanisms in the emergence of awareness of our own movement. Two complementary fMRI experiments will be performed in which we will confront subjects to external forces in order to study how, during a voluntary movement, the subject can separate the part of the movement produced by himself from what is produced by the external forces.

There will also be some fMRI methodological development aiming at a detection of functional activity based on a multi-scale analysis of the data. This will permit us to do a multi-subject (group) analysis that takes into account the complexity of the neural network and their inter-subject variability. Finally, technical developments necessary for the fMRI experiments are common for the whole project.

Work schedule for 2002

1st component: Cerebral substrates for the perception of human hand actions.

1. Usual movements of the hand (flexion/extension)
    - fMRI (Marseille) Study of cortical activation associated with perception of virtual hand movements (in press in Cognitive Brain Research).
    - MEG (Paris) Study of cortical activation associated with perception of virtual hand movements. Protocol defined, technical adaptations finished, two preliminary experiment performed.
2. Symbolic movements of the hand (drawing/writing)
    - Proprioceptive neurosensory coding of drawing and writing movements. Microneurography study: neurosensory library to date totally built up, together with the mean stimulation patterns that will be used to induce virtual drawing and writing movements.
    - Development and realisation of the vibratory stimulation apparatus and of its computerised driving program achieved
    - Preparation of the patterns for vibratory and visual stimulation in order to induce elementary drawing sensations achieved.

2002 – 2nd component: Rhythmic extension and flexion of the wrist

- An fMRI study on the conscious dissociation of internal and external forces during the production of a voluntary movement.
- A TMS experiment on the neurophysiological mechanism underlying conscious preparation to react (prior to fMRI experiment).
- Methodology: Start of the methodological development (O. Coulon).

Achievements at mid-course

1. First component:

Cortical substrates for conscious perception of usual hand movements

In order to identify cortical activation associated with movement perception alone using fMRI, one has to distinguish between cortical activities due to projection of sensory afferents from muscle spindle and those underlying their perceptual processing. We compared three conditions in which similar stimuli evoked, or not, illusory sensations of movements.

Results, obtained in 8 subjects, show that in the three conditions all cortical areas involved in somesthesia and motor control are activated. When conditions are contrasted, perception of movement appear to be specifically related to activation in motor and premotor areas, as well as in parietal areas, which were not reported in previous PET studies. Differences in illusory movement velocities seem to be related to activation in supplementary motor area and in primary motor cortex. These results, illustrated in figure 1, are in press in Cognitive Brain Research (Romaiguère, Anton, Roth, Casini, Roll, in press).

Consciousness of symbolic hand movements: drawing, writing

We now have a large body of unitary recordings of "proprioceptive signatures" for graphic movements, such as geometric drawings, letters, figures, short words. Collecting a significant sample of afferent fibres during performing of these various graphical forms required around sixty microneurography experiments, since ones has to record the firing pattern corresponding to each of these forms, and that for each muscle acting on the joint concerned. Figure 2 illustrates our results, where it can be seen that each form executed sends toward the central nervous system a message that is specific and that codes for its own execution parameters.

The "neurosensory library" thus constituted was shaped to drive a set of vibrators each located on one of the muscles acting on the joint in order to induce virtual writing and drawing movements, perceived while not performed.

The driving apparatus and the control of the vibratory stimulation are ready, and experimenting has started. Patterns for visual presentation of geometrical forms were implemented as well.

2. Second component: Interactions between motor and perceptive processes in awareness of voluntary movement production. A fMRI study to cerebral substrates.

Conscious dissociation between internal and external forces in movement production

A first fMRI experiment is performed with a manipulandum permitting to apply different levels of constant friction during a rhythmic wrist movement. In reference conditions, subjects made rhythmical hand movements and knew they had to reproduce, in a subsequent condition in which the resistance to the movement was increased, either their

muscular forces or their kinematics. The idea behind this (well established) reproduction paradigm is that, after an explicit verbal instruction, subjects can only reproduce what they are aware off. The main contrast, i.e. between the condition during which the subjects had to gain awareness of their muscular forces and that during which they had to gain awareness of their kinematics (conditions in which the actual motor output was similar), shows that gaining awareness about muscular forces exerted during movement execution makes much higher demands on many brain structures, in particular posterior insula, primary sensorimotor areas and associative somatosensory areas. This indicates the important role of somesthetic information processing in awareness of produced muscular force. Therefore, the often heard presumption that muscle force sense might be based on the outgoing motor command is not confirmed by the present results. This study was part of a masters diploma (mention: very good, resulting in grant attribution to the student), paper in preparation.

Conscious preparation to react.

A TMS experiment was performed in order to study the neurophysiological mechanisms underlying the conscious preparation to react in a selective way to a central perturbation of a movement: the subject either had to compensate the perturbation or to let-go the hand when perturbed. The study showed that modulations of corticospinal excitability permit to prepare to the emergence of the wanted movement (paper submitted). The study can now be performed with fMRI.

Development of an a-magnetic manipulandum.

A engineer student developed a manipulandum permitting, in the fMRI machine, to impose a movement to the wrist or to vary in real time the moment of the manipulandum. This will be useful for the whole project.

Methodological development

We developed a method to represent images in scale-space for several types of data: 3D volumes (in order to analyse functional activation carts) as well as 2D textures defined on triangular surfaces. We also proposed a method to inflate the cortical surface of the brain in order to better observe functional fMRI results.

Work schedule for 2003

1st component: Cerebral substrates for the perception of human hand actions.

- MEG experiments scheduled for December 2002 and February 2003
- fMRI experiment: simple virtual drawing movements presented using proprioceptive or visual sensory channels (end 2002 and 2003)
- Laboratory study of virtual drawing and writing movements evoked by “natural” vibratory patterns (from prior microneurographic recordings) (2003)
- fMRI study of virtual drawing and writing movements evoked by “natural” vibratory patterns, and comparison with the cortical activation related to visual presentation of the same graphic signs (2003)

2nd component: Cerebral substrates for conscious dissociation of internal and external forces during voluntary movement.

- fMRI experiment with varying external forces during the movement. In an event related protocol, during which subjects produce stable rhythmic movement at the wrist level, they are confronted to moment variations of the manipulandum with different magnitudes. Comparing the conscious or unconscious voluntary compensation for the different levels of perturbations will show us (1) the cerebral network implicated in the emergence of consciousness during movement production, and (2) whether the motor cortex is implicated in this emergence.
- fMRI experiment on consciousness preparation to react.
- *Methodology*: Firstly, we will complete the multi-scale analysis of functional volumes. The important point here is to integrate statistical measures in the representation of each individual activation cart. Secondly, we will study the possibility of spatial normalisation of cortical surfaces in order to be able to do surface analysis.

Publications stemming from the project

1st component

Albert F, Ribot-Ciscar E, Fiocchi M, Bergenheim M, Roll JP (2004) Proprioceptive feedback in humans espresses invariant during writing. . Exp Brain Res. (in press)

Bergenheim M, Ribot-Ciscar E, Roll JP and Thunberg J (2004) Spontaneous bursting neuronal discharges recorded from peripheral nerve in human : injury discharges or not ? Neurosci. Lett. , 359: 1-4

RIBOT-CISCAR E, BERGENHEIM M, ALBERT F, ROLL JP (2003) Proprioceptive population coding of limb position in humans. Exp Brain Res. 149: 512-519

Roll JP (2002) Physiologie de la kinesthèse "La proprioception musculaire: Sixième sens ou sens premier? » Intellectica. (sous presse)

ROLL JP, ALBERT F, RIBOT-CISCAR E, BERGENHEIM M (2004) "Proprioceptive signature" of cursive writing in humans : a multi-population coding. Exp Brain Res. 157: 359-368

ROLL JP, ALBERT F, RIBOT-CISCAR E, BERGENHEIM M (2004) La main écrit sur le papier et ... sur le Cerveau. Ecriture : Approches en Sciences Cognitives. Pp 15-35. PUP sous la Direction de Annie Piolat

Romaiguère P, Anton JL, Roth M, Casini L, Roll JP (2002) Kineasthesia activates both motor and parietal cortical areas in humans: a parametric fMRI study. Cognitive Brain Research (sous presse)

Romaiguère P., Calvin S., Roll J.P. Transcranial magnetic stimulation of the sensorimotor cortex alters kinaesthesia. Neuroreport Sous Presse

2end component

Bonnard M, Camus M, De Graaf JB, Pailhous J (submitted). Binding cognitive and motor function : A TMS study.

Bonnard, M., Camus, M., de Graaf, J., & Pailhous, J. (2003). Direct evidence for a binding between cognitive and motor functions in humans: a TMS study. Journal of Cognitive Neuroscience, 15:8, 1207-1216.

Bonnard, M., de Graaf, J., & Pailhous, J. (2004). Interactions between cognitive and sensorimotor functions in the motor cortex: evidence from the preparatory motor sets anticipating a perturbation. Reviews in the Neurosciences, 15 (5), 371-382.

Camus, M., Pailhous, J. & Bonnard, M. (2004). Cognitive tuning of the corticospinal excitability during human gait: a TMS study. European Journal of Neuroscience, 20 (4), 1101-1107.

De Graaf JB, Gallea C, Pailhous J, Anton J-L, Roth M, Bonnard M (in preparation). Fictive execution of a forthcoming movement revealed by cerebral activity. A fMRI study.

De Graaf, J., Gallea, C., Pailhous, J., Anton, J.L., Roth, M., & Bonnard, M. (2004). Awareness of muscular force during movement production: an fMRI study. Neuroimage, 21:4, 1357-1367.

Pailhous, J., de Graaf, J., & Bonnard, M. (in press). Intention and consciousness in sensorimotor automatisms. In F. Grammont, D. Legrand and P. Livet (Eds.), Naturalizing Intention in Action. An interdisciplinary approach.Cambridge, MA: The MIT Press and ENS Editions.