MARIE SKLODOWSKA-CURIE ACTIONS

Co-funding of regional, national and international programmes (COFUND)

DOC2AMU PROJECT 2017 CALL FOR APPLICATIONS

Neural mechanisms underlying the interlimb transfer of motor learning

1. DESCRIPTION OF THE PHD THESIS PROJECT

1.1 OBJECTIVES OF THE PROJECT BASED ON THE CURRENT STATE OF THE ART

Although the human brain and the human body both seem anatomically symmetric, the multiple asymmetries at the behavioural level highlight the differences between the left and right hemispheres (Serrien et al. 2006). According to Perez et al. (2007), such functional specialization of the cerebral hemispheres may underlie the unique aspect of certain human motor skills compared to other species. One example of remarkable human behaviour is object manipulation, which most often is preferentially performed with one or the other hand. Such manual preference defines handedness, a prominent feature of human motor control. For instance, Oldfield (1971) published the influential Edinburgh Inventory in which manual preference for a few tasks such as writing or screwdriving was evident in this study of 1000+ healthy individuals. While handedness has been well described phenomenologically, recent research on healthy subjects and stroke patients has highlighted the differences in control mechanisms between the two hands/arms (Sainburg 2005; Schaefer et al. 2007, 2012).

Even though differences in control mechanisms are now well established between the two upper limbs, it is also well known that learning a novel task with one arm can transfer to the other arm. For instance, if you exclusively learned to write with your dominant hand and have to write for the first time with your non-dominant hand, you could write legibly. Such performance necessarily reflects an interlimb transfer of the learned skill, even though writing quality and speed with the non-dominant hand may not be as good as with the dominant one. **The aim of the present project is to determine the neural mechanisms underlying the generalization of motor learning from one limb to the other. How does learning transfer across arms when control mechanisms differ? Does interlimb transfer of learning rely on interhemispheric transfer of information?** To gather new insights into these issues, the original feature of our approach is to work with patients with lesions of the corpus callosum, the major commissure between the two hemispheres, and assess with new psychophysical approaches and fine kinematic analyses the characteristics of interlimb transfer.

Understanding generalization of motor learning is important because it reveals the local or global nature of the underlying processes, a critical issue for customized motor training and rehabilitation protocols (Seidler et al. 2015). For instance, consider a patient with a stroke in the left hemisphere leading to hemiparesis in the right arm. After the stroke, he/she is likely to prefer using the least affected arm, the arm ipsilateral to the lesion, as it is less affected than the contralesional arm (Desrosiers et al. 1996; Hermsdorfer et al. 1999; Felician et al. 2003). To boost the functional recovery of the most-affected limb, or in other words to optimize learning of how to re-use the affected limb, the approach of constraint-induced movement therapy promotes mostly rehabilitation based on work with the impaired arm. Support for this technique appears to come from work on healthy subjects showing that there is generally little transfer of learning from one arm to the other (Martin et al. 1996; Lefumat, Sarlegna et al. 2015): based on this work, one could assume that performing daily tasks with the less-affected limb will do little for the most-affected limb. However, the mechanisms and factors underlying the interlimb transfer of motor learning remain unclear. To optimize motor learning and rehabilitation, it appears that additional fundamental knowledge is necessary for a better understanding of the interlimb transfer of motor skills.

When considering the neural mechanisms of movement control, it is well established that hand movements are mostly controlled by the contralateral hemisphere: for instance, imaging studies revealed that dominant hand movements are associated with greater activation of the contralateral hemisphere compared to the ipsilateral one (Dassonville et al. 1997; Pool et al. 2014). However, movements of the non-dominant hand are controlled by a more balanced pattern of hemispheric activation (Kim et al. 1993; Ziemann & Hallett

2001). Neuropsychological studies support the idea that both hemispheres contribute to the control of one limb since damage to the left hemisphere can impair the motor function of both right and left hands (Felician et al. 2003; Sainburg 2014). When considering the neural mechanisms of interlimb transfer of motor learning, much less is known.

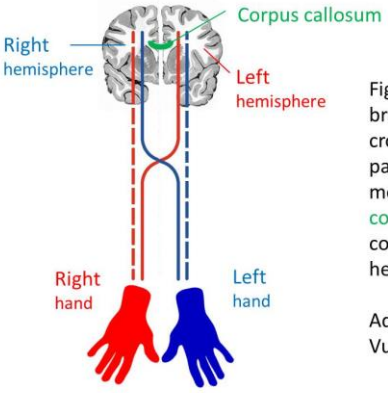


Figure 1. Illustration of the brain hemispheres and the crossed and uncrossed pathways to control hand movements. Also shown is the corpus callosum, the main commissure linking the two hemispheres.

Adapted from Vulliemoz et al. (2005)

Two main theoretical models have been proposed to explain how a limb might benefit from the acquisition of a motor skill with the other limb: the callosal access model and the cross-activation model. Consider an individual learning a new task with his/her dominant arm. The callosal access model postulates that 1/ the motor skill is encoded in a neural network within a single hemisphere, the dominant hemisphere (which controls the dominant arm), and 2/ that the non-dominant arm can 'indirectly' benefit from the learning through callosal connections (Taylor & Heilman 1980). In contrast, the cross-activation model (Parlow & Kinsbourne 1989) postulates that the motor skill is simultaneously encoded in both hemispheres during learning, even though the duplicate encoding is not as good in the nondominant hemisphere (for a review, Ruddy & Carson 2013). This feature of the cross-activation model may explain why the transfer of motor learning from the dominant arm to the non-dominant arm is generally limited (Joiner et al. 2013; Lefumat, Sarlegna et al. 2015). Moreover the callosal access model has received criticism because its initial version seems to fail explaining how transfer can be observed from the non-dominant arm to the dominant arm (Sainburg & Wang 2002). However, two recent studies provided some support for the callosal access model.

First, Bonzano et al. (2011) showed that deficits in intermanual transfer of motor learning were positively correlated with structural damages of the corpus callosum in patients with multiple sclerosis. Phillips et al. (2013) then reported, in non-human primates, a negative correlation between intermanual transfer and structural damages of the corpus callosum. Because the sign of the correlation conflicts in these two studies, it is difficult to conclude whether the corpus callosum is critical for the interhemispheric transfer of learning or whether, as an alternative hypothesis, the corpus callosum rather contributes to interhemispheric inhibition and thus to reduced interlimb transfer of learning. However, these two recent studies support the idea that the corpus callosum does play a role in the interlimb transfer of motor learning. In summary, the neural mechanisms underlying interlimb transfer currently remain unclear.

To add some unfortunate complexity to the issue, the sole study which to our knowledge addressed the role of the corpus callosum in the interlimb transfer of reach adaptation (Criscimagna-Hemminger et al. 2003) showed that such transfer was possible in a split-brain patient (i.e. complete resection of the corpus callosum, which was performed to treat pharmacologically intractable epilepsy). This study thus presented some evidence to reject the callosal access hypothesis and could support a third hypothesis which emphasizes the role of subcortical structures (Day & Brown 2001). **As very little is clear about the neural mechanisms underlying interlimb transfer, the specific aim of the present project is foremost to address the role of the corpus callosum in interlimb transfer of motor learning. To do so, we set out to study patients with lesions of the corpus callosum (Gazzaniga et al. 2001; Paul et al. 2007; Ridley, Felician et al. 2016) and use the new approach on interlimb transfer that has recently been developed in the field of human motor control (Joiner et al. 2013; Lefumat, Sarlegna et al. 2015). The recently developed paradigms allow a clear understanding of the underlying mechanisms. Our general approach is thus to study whether the integrity of the corpus callosum influences interlimb transfer of learning to reach in new environmental conditions. This requires expertise in human movement sciences, neuropsychology, imaging and computational modeling. In addition to filling the gap in fundamental knowledge, this project will lead to a better understanding of the motor deficits of patients with lesions to the corpus callosum.**

1.2 METHODOLOGY

Motor deficits of patients with lesions of the corpus callosum can be extremely delibitating, as described in several textbooks (e.g., Gazzaniga et al. 2001) and articles (e.g., Ridley, Felician et al. 2016). In particular, hemispheric disconnection can lead to diagonistic dyspraxia, i.e., one hand acts against a patient's will and is not under volitional control anymore (the alien hand syndrome). Given that both hemispheres contribute to the control and learning of voluntary behaviour, we set out to explore the interlimb transfer of motor learning in patients with lesions to the corpus callosum and compare it to healthy controls matched in age, gender and education as well as cognitive abilities. Patients with partial or complete agenesis of the corpus callosum (Paul et al. 2007; Ridley, Felician et al. 2016) as well as split-brain patients (Gazzaniga et al. 2001) will be tested to address the issue of neural plasticity and how it affects sensorimotor adaptation and its generalization.

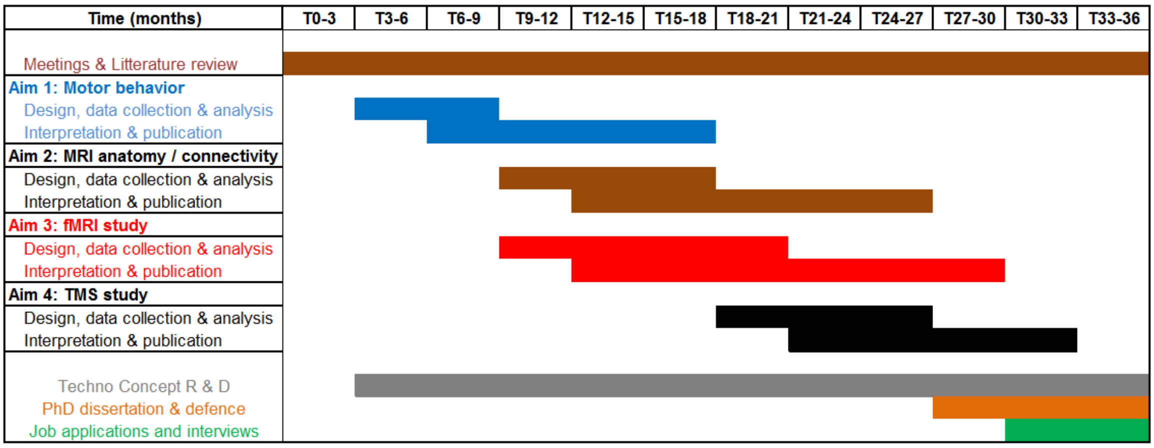
The first aim of the project is to assess whether interlimb transfer depends on the integrity of the corpus callosum. Criscimagna-Hemminger et al. (2003) reported that one patient could transfer learning from the dominant to the non-dominant arm but more evidence would be welcome. Also the split-brain individual that was tested had to adapt to a robotic force field in a two-dimensional reaching task. In the laboratory, we have developed a more natural task in which movements are unconstrained and experience Coriolis forces, as in everyday life. The experimental trick is that the subject is seated on a platform which can turn (Lefumat et al. 2015, 2016). Using this set-up and paradigm, we can thus study the adaptation of unconstrained reaching movements to a novel Coriolis, velocity-dependent force field. As in previous work, we will ask subjects in Aim 1a to seat at the center of a rotating platform and to perform reaching movements with the upper limb toward flashed visual targets before rotation (to determine baseline performance), during rotation (i.e., adaptation) and after rotation. Previous research has shown that as only the dominant arm is used during adaptation, interlimb transfer can be assessed by comparing performance of the non-dominant arm before and after dominant-arm adaptation.

Theoretically, the findings on interlimb transfer of force-field adaptation (Criscimagna-Hemminger et al. 2003) may not generalize to the interlimb transfer of visuomotor adaptation because distinct neural mechanisms appear to underlie adaptation to new visuomotor mappings (using a visuomotor rotation or prisms for instance) and adaptation to new limb dynamics (Haith & Vijayakumar 2009; Donchin et al. 2012; Sarlegna & Bernier 2010). We will thus assess the interlimb transfer of Coriolis force adaptation in patients with lesions of the corpus callosum and controls but also, using the same paradigm except the force perturbation is replaced by prism goggles (Rossetti et al. 1998; Sarlegna et al. 2007), we will assess in Aim 1b the interlimb transfer of prism adaptation (Martin et al. 1996). In addition, we will assess in Aim 1c the interlimb transfer of adaptation to a visuomotor rotation using a set up similar to Sainburg & Wang 2 (2002) but the exact protocol used in Aims 1a and 1b. Both directions of transfer, from dominant to non-dominant hand and vice-versa, will be tested in Aims 1a, 1b and 1c.

One particular feature of visuomotor perturbations such as prisms or visuomotor rotations is that the neural processes underlying adaptation can be studied using a scanner (for magnetic resonance imaging; MRI) or a coil (for transcranial magnetic stimulation; TMS) more easily than with a force-field perturbation (see Luauté et al. 2009). Once the behavioural paradigm and results will be firmly established, Aims 2, 3 and 4 will consist in studying the neural mechanisms underlying interlimb transfer. Anatomical and functional MRI will be used to determine the neural bases of the generalization of sensorimotor adaptation. **Anatomical MRI will be used in Aim 2 to determine whether the quality and/or quantity of intermanual transfer is correlated with structural changes of the corpus callosum** or part(s) of the corpus callosum, in line with the approach used by Bonzano et al. (2011) and Phillips et al. (2013). Perez et al. (2007) previously reported a positive correlation between the amount of intermanual transfer and the activity of the supplementary motor area (SMA), and then found that repetitive TMS over SMA blocked interlimb transfer without affecting skill acquisition. **We will assess whether similar neural mechanisms are identified in healthy individuals as well as patients with lesions of the corpus callosum, using fMRI in Aim 3 (as in Luauté et al. 2009) and imaging-guided neuronavigation of the TMS coil in Aim 4 (as in Perez et al. 2007)**. We hypothesize that if interlimb transfer can be observed in patients with lesions of the corpus callosum, the SMA may underlie the interlimb transfer of motor skill acquisition.

1.3 WORK PLAN

Aim 1 will consist in determining whether interlimb transfer depends on the integrity of the corpus callosum on a variety of behavioural paradigms. Previous literature indicates that interlimb transfer is possible in patients with lesions of the corpus callosum ad we will assess that in psychophysical experiments and compare the transfer to that of healthy controls. We will then assess in Aims 2-4 the neural mechanisms underlying interlimb transfer of motor skills in patients and healthy individuals.



1.4 SUPERVISORS AND RESEARCH GROUPS DESCRIPTION

Olivier Felician is full Professor of Neurology at Aix Marseille University, and serves as behavioral neurologist in the department of Neurology and Neuropsychology, CHU Timone, Marseille, France. Over the past twenty years, his research aimed at a better understanding of brain-behavior relationships, in particular in the fields of visual perception and integration, memory, and body and action representations. Methods rely on brain-damaged studies, along with the use of transcranial magnetic stimulation and (resting-state and task-based) neuroimaging approaches. His current topics of interest include body ownership and action authorship issues and sensorimotor integration by testing healthy individuals as well as neurological patients.

Fabrice Sarlegna is a CNRS research scientist who has developed an expertise in the theoretical understanding of human motor behaviour, how it is shaped by environmental as well as individual factors, but also in technical skills such as kinematics and force recordings, eye movement recordings, electromyography, inverse dynamics and signal processing. Currently, his main project consists in modelling the mechanisms of sensorimotor adaptation and its generalization across different types of movements and different effectors by testing healthy individuals as well as neurological patients.

This project will be conducted in collaboration with Dr Robert L. Sainburg (Penn State University), an expert in lateralization in motor control who has been primarily working with stroke patients and patients with sensory neuropathies. Such collaboration will be supported by a PICS (Projet International de Cooperation Scientifique, funded from the CNRS) to facilitate travel exchanges. The DERCI of the CNRS just awarded this grant to Dr Sarlegna, which essentially guarantees that the team members, including the recruited doctoral student, will be able to travel for substantial time periods to the US from 2017 to at least 2019, i.e. a good portion of the 3-year PhD. In addition, Dr. Sarlegna just filed an application to the 'Mission Interdisciplinarité du CNRS' for the 2017 AUTON call for proposal, to gather additional funds (6000€) for small equipment and organizing patients' visits. Dr. Sarlegna has been funded by the Mission Interdisciplinarité for the last 3 years to develop a national network with specialists in neurorehabilitation in Lyon (CRNL) and Paris (ISIR), neurophysiology in the visual and auditory systems in Toulouse (CERCO) as well as the vestibular system (LNIA) and ophthalmology (INT) in Marseille. These are the necessary first steps to create a functional consortium and apply to the ANR to better understand the neural mechanisms underlying the interlimb transfer of motor skill acquisition in humans.

2. 3I DIMENSIONS AND OTHER ASPECTS OF THE PROJECT

2.1 INTERDISCIPLINARY DIMENSION

The INS laboratory has a strong, international leadership in computational neuroscience and Pr. O. Felician (MD/PhD, see the detailed profile below) will contribute to the project mostly by sharing his clinical expertise as well as his knowledge in neuropsychology and neuroscience techniques. The ISM laboratory is known worldwide for its dedicated work on the multiple (physiological, biomechanical, social) factors which determine human motor skills: Dr. F. Sarlegna (see the detailed profile below) will share his knowledge in human movements sciences in healthy humans to determine sound paradigms and rigorous motion analysis methods for quantifying motor behavior. Techno Concept (see the detailed profile below) is a company providing products for health professionals with the particularity that these products are designed and conceived by the company: Dr F. Albert will share his expertise on the sensory guidance of movement (Albert et al. 2005) and how fundamental knowledge can be used by engineers in a non-academic company to impact patients' everyday life. **This project thus corresponds to the interdisciplinary and intersectoral work promoted by the research axis Imaging and the AMU PR2I 'Health and Life Sciences'.**

2.2 INTERSECTORAL DIMENSION:

Health and Life Sciences, and in particular projects using Imaging to further our understanding of human behavior, relies on a strongly interdisciplinary and intersectoral approach. The present project requires skills in human movement analysis, clinical expertise, great knowledge in neuroscience and will benefit from the fields of engineering, computer sciences, physics and biology. This corresponds particularly well with several ongoing projects at AMU. The specificities of the INS and ISM laboratoires are described elsewhere and here we develop the specifity of our non-academic partner who will keep guiding us toward hopefully a substantial impact on patients' everyday life.

Techno Concept is a company well-known by research laboratories, hospitals and health professionals in academic and non-academic organizations, in medical and paramedical practitioners. Techno Concept is specialized in the field of readaptation as it is developing products to assess mainly motor and sensory functions. Its R&D team consists in engineers and PhDs in neuroscience. Techno Concept is thus ensuring the design, production as well the commercialization of each of its products. Because the ISM and INS members have been dealing with Techno Concept as customers and colleagues, the regular exchanges naturally led to the collaboration for this project. Techno Concept will in particular bring his expertise on re-adaptation and share its knowledge with the doctoral candidate about economic and technologic aspects in the (para)medical business. In addition to provide a better fundamental understanding of the neural mechanisms underlying interlimb transfer using imaging techniques, the aim of the collaboration will be to assess motor deficits of patients with lesions of the corpus callosum and to work on how we can make a difference in minimizing these deficits through sensorimotor re-adaptation in addition to the ongoing pharmacological treatment. Techno Concept will thus be considered as a collaborator in this project, from start to finish, and will likely keep on emphasizing the clinical and economical influence of this project. The long-term goal is to collaborate with Techno Concept to develop new assessment products for sensory and motor functions in a variety of patients with sensory (somatosensory, visual, vestibular and auditory) loss and neurological disorders such as stroke or Parkinson's Disease. Thus this project will contribute to 1) the fundamental understanding of human motor control, 2) the clinical assessment of motor deficits in neurological patients, 3) the optimization of assessment tools and paradigms for readaptation of sensorimotor functions, and 4) to the visibility of Aix-Marseille University for its excellent research and innovation projects.

2.3 INTERNATIONAL DIMENSION:

As previously mentioned, funding has already be obtained to work with Dr Sainburg so that any partner will be able to visit the other partner (with a limit of ~7000€/year) over a 3 to 4 year period. Such funding will also enable the doctoral candidate as well as any team member to attend conferences such as Human Brain Mapping, Society for Neuroscience, Neural Control of Movement and the International Society of Motor Control. Another, long-standing, collaboration has been developed with Prof. R. Chris Miall (Dpt Psychology, Univ. Birmingham) and Dr Cole (Poole Hospital & Univ. of Bournemouth). It was first funded with an AMU International Travel Grant in 2012 then with a Royal Society grant funding, such that for the last 5 years, at least one meeting per year has been organized and frequent (visio)calls are scheduled to work on experimental design, data analysis, research proposals and manuscripts. At last, a recent visit (November 2016) of the laboratory of Prof. Richard B. Ivry (University of California Berkeley) was very promising as Prof. Ivry, who has extensive experience with split-brain patients (Gazzaniga et al. 2001; Handy et al. 2003), is interested by our project and new discussions will be held soon, at the Neural Control of Movement meeting in Dublin (may 2017) to further determine how our laboratories could work together. The doctoral candidate will thus have the opportunity to exchange ideas with at least three laboratories in the UK and USA.

3. RECENT PUBLICATIONS

Here are the references of the main team' articles of interest for the present project. These publications are in Open Access or available upon request or on the website https://sites.google.com/site/sarlegna/

Lefumat HZ, Miall RC, Cole JD, Bringoux L, Bourdin C, Vercher J-L, **Sarlegna FR (**2016) Generalization of force-field adaptation in proprioceptively-deafferented subjects. *Neuroscience Letters* 616: 160–5.

Lefumat HZ, Vercher J-L, Miall RC, Cole J, Buloup F, Bringoux L, Bourdin C, **Sarlegna FR (**2015) To transfer or not to transfer? Kinematics and laterality quotient predict interlimb transfer of motor learning. *Journal of Neurophysiology* 114(5):2764-74.

Ridley B, Beltramone M, Wirsich J, Le Troter A, Tramoni E, Aubert S, Achard S, Ranjeva JP, Guye M, **Felician O** (2016) Alien Hand, Restless Brain: Salience Network and Interhemispheric Connectivity Disruption Parallel Emergence and Extinction of Diagonistic Dyspraxia. *Frontiers in Human Neuroscience* June 2016 10:307.

Romaiguère P, Nazarian B, Roth M, Anton JL, **Felician O** (2014) Lateral occipitotemporal cortex and action representation. *Neuropsychologia* 56:167-77.

Sarlegna FR, Bernier P-M. On the Link between Sensorimotor Adaptation and Sensory Recalibration. *The Journal of Neuroscience* 30: 11555–11557, 2010.

Sarlegna FR, Malfait N, Bringoux L, Bourdin C, Vercher JL (2010) Force-field adaptation without proprioception: Can vision be used to model limb dynamics? *Neuropsychologia* 48: 60–7.

4. EXPECTED PROFILE OF THE CANDIDATE

The candidate will be involved during his PhD in conducting an experimental program consisting on different motor tasks with different devices. Duties will consist in attending professional meetings, recruiting and interviewing research subjects, assisting in the design of psychophysical and neurophysiological experiments, preparing the experimental equipment and protocol, recording and analyzing data, drafting oral presentations and research manuscripts, all under the supervision of F. Sarlegna, O. Felician and F. Albert.

According to this research project, suitable applicants must hold (or be in the process of completing) a degree or equivalent (Masters qualification if European-based, strong GPA from a 4 year undergraduate degree if North American/Australasian-based) in neuroscience or affiliated specialties such as neuropsychology, experimental psychology, human motor control, biomedical engineering... Applicants from other relevant backgrounds in engineering, physics or computing science will also be considered provided they demonstrate additional qualifications in neuroscience. It is essential that applicants are sufficiently qualified in mathematics/engineering/physics to undertake quantitative analysis of movement and imaging datasets. They should demonstrate skills in programming (e.g. Matlab) and data analysis (including statistics), and preferably in data collection. Experience with human neuroscience techniques (fMRI, TMS) is also desirable.

Applicants should have excellent organizational skills, be highly motivated and enjoy working in a vibrant collaborative research environment. They should be able to communicate effectively in English, with evidence of strong scientific writing skills. The ability or desire to speak French is a plus considering the experiments with patients. **Critically, applicants should be passionate about using their expertise for the benefit of patients for whom cross-disciplinary science has the potential to have a positive impact.**

5. SUPERVISORS' PROFILES

Olivier Felician is a neurologist who graduated from Aix-Marseille II University in 1995. He was trained in neuropsychology and behavioral neurology as a Clinical Fellow at Harvard Medical School & Beth Israel Deaconess Medical Center (Behavioral Neurology Unit, Prof A. Galaburda, 1995-1997). He spent an additional year as Research Fellow in the Transcranial Magnetic Stimulation (TMS) Laboratory (Beth Israel Deaconess Medical Center, Prof A. Pascual-Leone, 1997-98), where he studied the effect of rTMS on visual mental imagery in collaboration with Prof Stephen Kosslyn (Kosslyn, Pascual-Leone, Felician, et al., Science, 1999). Back in France in 1998, he has served since as behavioral neurologist in the department of Neurology and Neuropsychology, CHU Timone, Marseille, France. He completed a PhD in Neuroscience (2006) focusing on the issue of shared and differential body representations (Dir. P. Romaiguère). A large body of his research aims to characterize the earliest clinical stages of neurodegenerative diseases (such as Alzheimer's disease or frontotemporal degeneration) in order to develop diagnostic tools (e.g., Barbeau et al. 2004, Didic et al. 2011). Another aspect of his research focuses on the understanding of brain-behavior relationships, in the fields of visual perception (e.g., Busigny et al. 2010), memory (e.g., Tramoni et al. 2011), and action representations (e.g., Romaiguère et al. 2014). Methods encompass cognitive neuroscience approaches, including studies of healthy and brain-damaged subjects, transcranial magnetic stimulation (e.g., Tassy et al. 2012) and neuroimaging (e.g., Felician et al. 2004, Gour et al. 2014, Ridley et al. 2016). His current topics of interest include body ownership and action authorship issues and sensorimotor integration by testing healthy individuals as well as neurological patients.

Fabrice Sarlegna is a research scientist of the CNRS who has been working at the Institute of Movement Sciences since 2011. He obtained a PhD in Human Movement Sciences from Aix-Marseille II University in 2004. His PhD thesis focused on the executive control of upper-limb movements in young and older adults (Dir J. Blouin). He spent 2 years as a postdoctoral fellow in the Movement Neuroscience Laboratory in Penn State University (USA) where he studied the influence of sensory and biomechanical factors on the control of reaching arm movements. He has developed an expertise in the theoretical understanding of human motor behaviour, how it is shaped by environmental (Danion & Sarlegna 2007; Sarlegna and Bernier 2010) as well as individual factors (Lefumat et al. 2015), but also in technical skills such as kinematics and force recordings, eye movement recordings, electromyography, inverse dynamics and signal processing. Currently, his main project consists in modelling the mechanisms of sensorimotor adaptation and its generalization across different types of movements and different effectors by testing healthy individuals as well as neurological patients (Sarlegna et al. 2010; Lefumat et al. 2016). Dr Sarlegna will defend his Habilitation à Diriger les Recherches (HDR) in september 2017 and will be the PhD director.

Thesis history (*in italics, ongoing*):
- Natalina GOUR. Reorganization of anatomo-functional systems and brain topology in early onset and late onset Alzheimer's disease. A behavioral and resting state fMRI approach. Starting date: October 1st 2009; end: December 9 2013; duration 4 years. Co-supervised by Olivier FELICIAN and Jean-Philippe RANJEVA. 2 Ranked A research manuscripts published (NeuroImage, Human Brain Mapping).

- Hannah Z. LEFUMAT. Interlimb transfer of force-field adaptation and consolidation of motor memories. Starting date: October 1st 2012; end: May 11 2016; duration 3.6 years. Co-supervised by Fabrice SARLEGNA and Jean-Louis VERCHER. Currently a postdoc in Dr J. Gold laboratory (University of Pennsylvania), working on the neurophysiological mechanisms underlying decision-making. 2 peer-reviewed research articles (Lefumat et al. 2015, 2016, see reference list), 2 research manuscripts in preparation and 1 review in preparation.
- *Alizee PANN. The role of extrastriate cortex in body ownership. Starting date: January 1st 2014; end planned in December 2017. Co-supervised by Olivier FELICIAN and Patricia ROMAIGUERE. 2 research manuscripts in preparation.*
- *Alix G. RENAULT. Interlimb transfer of visuo-motor adaptation. Starting date: October 1st 2015; end planned in September 2018. Co-supervised by Fabrice SARLEGNA and Jean-Louis VERCHER. 2 research manuscripts in preparation.*
- Sébastien TASSY. The role of prefrontal cortex in moral evaluation. Starting date: October 1st 2008; end: December 6 2012; duration 4 years. Co-supervised by Olivier FELICIAN and Bruno WICKER. 4 research manuscripts published including one Ranked A (Social Cognitive and Affective Neuroscience).

The doctoral candidate will thus have the opportunity to exchange ideas with two doctoral students, Alix RENAULT (currently co-supervised by Fabrice SARLEGNA) and Alizee PANN (currently co-supervised by Olivier FELICIAN).