The long-term goal of the research described herein is to unravel the sensory-motor mechanisms that control manipulation while handling and stabilizing objects within one group. We are especially interested in expanding knowledge in the domain of the complex interactions between feed-forward and feedback mechanisms in the control of dexterous manipulations. We are studying these mechanisms in patients with neurological disturbances as well as in normal subjects under unusual environmental conditions, such as microgravity. Moreover, we are using the Reinh model to develop and validate new outcome measures in rehabilitation, such as ABILHAND (1), a manual ability scale, and ACTIVLIM (2, 3), a measure of activity limitations (http://www.rehab-scales.org).

Motor actions result from a complex combination of motor commands that control muscular contractions to produce the desired movements. To reliably achieve satisfactory motor actions, one must have an internal knowledge of movement dynamics and must also continuously compensate for external forces acting on the body, including omnipresent gravitational forces. Evidence for an internal representation of such dynamics can be found in the literature. However, the role that gravity plays in internal models of dynamics has yet to be clarified. In this research project, we are using experimental and modelling approaches to elucidate the role of gravity in sensorimotor coordination. Motor prediction has been shown to be efficiently processed in hypergravity and microgravity conditions, though human subjects perform better in the former than in the latter. That is, predictions in hypergravity have been reported to be very good (4), whereas anticipatory grip force modulation in 0 \times gravity (g) is associated with greater uncertainty (5) (Fig.1). Confidence in the prediction, and thus motor control performance, may be impaired in the absence of gravity (e.g., 0 g) as such an environment provides no calibration signal for setting force levels and joint torques. We plan to perform a series of human subject experiments involving dexterous manipulations during exposure to hyper- (1.6 g), micro- (0 g), Lunar (0.16 g) and Martian (0.38 g) gravity induced by parabolic flight (Fig.3). Furthermore, our experiment to be launched in the International Space Station in 2014 will enable us to study the long-term effects of microgravity on dexterous manipulation. Upper limb kinematics, precision grip dynamics, task-specific muscular activities, and digit moisture will be recorded and analysed.
ADAPTATION OF GRIP FORCE TO COMPENSATE FOR STATIC AND DYNAMIC TORQUES DURING OBJECT MANIPULATION

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Our research group recently initiated the study of the adaptive control of grip force in the compensation for static and dynamic torques during object manipulation (6). This paradigm, which includes tangential torques, provides a powerful tool with which to extract the adaptive component of grip control during object manipulation (Fig.2). In the present project, we will further investigate the control strategy employed by subjects manipulating an object with a centre of mass off the grip axis during point-to-point movements, rhythmic oscillations, and collisions. These experiments are being conducted on Earth (1 g), while interacting with robots, as well as during parabolic flights producing 1.8 g and 0 g environments (Fig.3). These investigations are designed to focus on grasp force modulation, upper limb movement control, and eye-hand coordination.

THE NEURAL ORGANIZATION OF DEXTEROUS MANIPULATION IN HEALTHY SUBJECTS AND IN CEREBRAL DAMAGED PATIENTS

E. Guillery, A. Mouraux, V. Lognain, J-L. Thonnard

Grasping an object between the thumb and index finger requires precise coordination between grip force and tangential load force; this coordination is impaired in children with congenital hemiplegia and adult stroke patients. Deficits in predictive and reactive control of the paretic hand have been described in such patients previously (7). Functional brain imaging is a powerful tool that may help reveal the neural organization of grip forces during object manipulation. Therefore, we designed an experimental setting in which we can concurrently record functional magnetic resonance imaging, grip-lift forces, and electromyography (EMG) data enabling us to directly correlate EMG and fingertip forces with the functional cortical network. In further studies, assuming that grip requires supervision by high-level cognitive controls, we will investigate the contribution of cognitive factors in grip control using a dual task paradigm (Fig.4). We will compare patterns of brain activity elicited by a grasping task between healthy participants and cerebral damaged patients performing a cognitively demanding task. We will then assess the effects of a functional neuro-rehabilitation program that targets grip precision. Differences in behaviour and brain activity patterns will be assessed before, during, and after completion of the rehabilitation program. A complementary aim will be to estimate the cognitive load needed to perform the grip task, before versus after completion of the rehabilitation program.
MECHANICAL PROPERTIES OF FINGERTIP-OBJECT CONTACT DURING HAPTIC EXPLORATION AND DEXTEROUS MANIPULATION


The aims of this project are to study the mechanical interactions between the fingertip and a touched surface during haptic exploration of textured surfaces as well as during dexterous object manipulation. Fingertip skin is a multi-layered tissue that contains numerous mechanoreceptors and sweat glands. In a recent study, we characterized skin mechanical deformation at the interface between the fingertip and a glass surface (Fig.5). This investigation indicated that moisture content strongly influences skin properties (8, 10). Furthermore, during object manipulation, fingertip moisture was found to be optimally modulated to maximize friction and minimize the grip force (9, 10). We recently acquired a new experimental setup that is composed of a robot, a high-speed camera system, and an integrated real-time measurement of fingertip moisture (Fig.6). This equipment enables us to measure and model the mechanical deformations that are induced actively or passively in the fingertip skin during haptic exploration. We will examine whether these mechanical deformations can predict responses from skin mechanoreceptors during object manipulation and haptic exploration. Elucidation of these mechanisms could have important implications in the development of realistic sensory feedback mechanisms for prosthetic-hand users.

INTENSIVE INTERVENTION FOR CHILDREN WITH CEREBRAL PALSY: NEW PSYCHOMETRIC TOOLS & NEUROPHYSIOLOGICAL CHANGES

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Considering the growing evidences in scientific literature for intensive rehabilitation efficiency, this research project aimed to integrate new measurements in the course of HABIT-ILE interventions (Hand and arm bimanual intensive therapy including lower extremity) recently developed. The first part of the project focused on the measurement of upper and lower extremity activity limitations through a new scale called ACTIVLIM-CP. This instrument, calibrated on the basis of 220 children with the Rasch model, will allow targeting the activity limitations in every-day life including activities combining both upper and lower extremities, a concept that was lacking until now in the assessment of children with cerebral palsy. The second part of this project aimed to measure the changes in manual ability that could be delineated during intensive training for children with cerebral palsy with different instruments, including the ABILHAND-Kids questionnaire. We showed in a sample of 100 children an excellent responsiveness of the ABILHAND-Kids questionnaire, especially in young children. The specificity of this questionnaire allows providing standard error of the measure for each patient, which in turn gives access to individual approaches, providing an idea on the amount of change and its clinical significance. Finally we are investigating the neurophysiological changes that can be noticed at a cortical level during intensive rehabilitation (HABIT-ILE intensive sessions) using MRI, DTI IMRI and TMS cortical mapping. In short term these measure will allow measuring cortical plasticity induced by the neurorehabilitation process. In long term, this could help defining predictors for responsiveness to the treatment and a better targeting of interventions to each child.

INTERLIMB COORDINATION IN CHILDREN WITH CEREBRAL PALSY

D. Ebner, Y. Bleyenheuft, J.L. Thonnard

In the context of the new evidences encouraging combined training of upper and lower extremity in children with cerebral palsy (HABIT-ILE training), a major interest is directed to the interlimb coordination of upper and lower extremity in children with CP.

Interlimb coordination activities are ubiquitous in everyday life, in tasks such as carrying items, opening a door, etc... Although there are a few studies on the coordination between the upper and lower limbs during rhythmic lower limb tasks – typically walking –, there is little information about this interlimb relationship during “discrete” movements of the lower limb, such as holding an object while passing an obstacle. The objective of this project is to study these limitations of interlimb coordination in the context of discrete movement of the lower limb. In addition a randomized controlled study will allows us to compare changes induced by conventional therapy and intensive therapy (HABIT-ILE) in the interlimb control.
PERCEPTION AND NEURAL CODING OF NATURAL AND VIRTUAL TEXTURES

D. Gueorguiev & A. Moungou, A. Mouraux and J-L. Thonnard, in collaboration with M. Adams, School of Chemical Engineering, University of Birmingham, Birmingham, UK; V. Hayward, UPMC Univ Paris 06, Institut des Systèmes Intelligents et de Robotique, Paris, France.

This project is being conducted within PROTOTOUCH, a European Commission Seventh Framework Project. The project aims to develop a new generation of tactile displays that will recreate the perception of touching shapes and textures. In order to achieve that goal, knowledge of the how texture information is transmitted and coded by the mechanoreceptors and the nervous system is essential. In the psychological part of the project, we will modulate tactile stimuli in order to extract the most relevant features of the sensation of touch (active touch, passive touch, normal force modulation, proprioceptive modulation). We will start by evaluating everyday textures. At a later stage of the project, the stimuli will be generated by TDs developed by the partners. Our aim is to understand how physical characteristics influence the perception of textures and to evaluate the performance of TDs at replicating these characteristics. Central neural coding will be investigated through new approaches that isolate and characterize the cortical activity elicited by the mechanical interaction between the contacting finger pad and textured surfaces. Specifically, we examine whether the sustained cortical activity generated by the mechanical interaction between the finger pad and a grated texture can be captured in the form of a steady-state evoked potential (SS-EP) in the EEG signal. During the recording, passive scanning of the right index fingertip across three aluminum gratings whose spatial period (SP) is between 0.4 mm (smooth surface) and 1.6 mm (rough surface). The movement of the gratings is achieved using a robot with feedback force sensors (Figure 7). A constant normal force (1.5 N) and two constant exploration velocities were used (v1 = 1.76 cm/s, v2 = 4.80 cm/s). Depending on the SP, we expect that these dynamic stimuli will elicit SS-EPs at frequencies ranging between 11 and 120 Hz and, possibly, their harmonics.

SELECTED PUBLICATIONS


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Fig. 7. This figure illustrates the robotic device that will be used in the PROTOTOUCH project. The subject’s hand will be stabilized in order to allow easy stimulation of the index fingertip through aluminium plates having different roughness levels. The friction between the fingertip skin and the aluminium plates will be regulated through the normal force generated by the robot.