The 15th

KCMCW

Karniel Computational Motor Control Workshop

Ben-Gurion University of the Negev

Computational motor control is a multidisciplinary research field in which mathematics, engineering, biology, medicine and the cognitive neurosciences play important roles. This workshop brings together world leaders in the field of computational motor control, including Israeli researchers and distinguished guests. The goal is to learn about the current state of the field and to identify the challenges and research directions that will lead to scientific and medical breakthroughs in the next decades.

The workshop is named after Professor Amir Karniel who passed away on June 2nd 2014 at the age of 47. Amir, a leading researcher in the field and head of the biomedical engineering department, was a dear mentor, colleague and teacher. Amir was a man of vision and a pioneer in motor control research in Israel and internationally. He organized this workshop, together with Professor Opher Donchin, from its founding, in June, 2005, until the 10th workshop in June, 2014.

The organizers:

Prof. Opher Donchin – Conference Chair

Dr. Ilana Nisky – Program Chair

Dr. Lior Shmuelof

Orit Cohen-Rothman

Program committee:

Dr. Ilana Nisky, Ben-Gurion University of the Negev

Prof. Opher Donchin, Ben-Gurion University of the Negev

Dr. Lior Shmuelof, Ben-Gurion University of the Negev

Prof. Sandro Mussa-Ivaldi, Northwestern University

Dr. Jason Friedman, Tel-Aviv University

Dr. Mati Joshua, Hebrew University

Dr. Netta Gurari, Northwestern University

Sponsors:

Ben-Gurion University of the Negev – President

Zlotowski Center for Neuroscience

Ben-Gurion University of the Negev – Rector

Ben-Gurion University of the Negev – Faculty of Engineering

Ben-Gurion University of the Negev – Faculty of Health Sciences

Workshop Program

Sunday, March 24

Pre-workshop activities

09:30 – 13:00 Visit to Aleh Negev Rehabilitation Hospital**, Simona Bar-Haim**

13:00 – 14:00 Lunch (on your own)

14:00 – 16:30 Lab visits

Labs tour will start from Student Center at 14:00

Physiotherapy

- The laboratory for Rehabilitation and Motor Control of Walking, **Simona Bar-Haim**
- Schwartz Movement Analysis & Rehabilitation Laboratory, **Itzik Melzer**
- Biomechanics and Robotics Laboratory, **Raziel Riemer**

Biomedical engineering

- Biomedical Robotics Laboratory, **Ilana Nisky**
- Motor Learning Laboratory, **Opher Donchin**

Cognition

- Brain and Action Laboratory, **Lior Shmuelof**

Evening Special Talk

Oren Conference Hall, Building 26

- 16:30 – 17:00 – Gathering and coffee
- 17:00 – 18:00 – **Ofer Blutrich**, Professional Climber and Physical Therapist
  "Rock Climbing **-** Learn Or Learn to Fly"

Kapara Restaurant, Smilansky St., Old city

- 19:00 **Festive dinner** (*speakers, session chairs, and guests by invitation*)

(cars will start leaving U-tel parking or campus at 18:30)

Monday, March 25

Minkoff Senate Hall

- 08:20-08:50 Registration, Poster placement and coffee
- 08:50-09:00 Greetings by **Opher Donchin**, Head of the organizing committee

Session 1 – Motor Learning and Adaptation

Chair: **Jason Friedman**, Tel-Aviv University, Israel

- 09:00-09:30 **Lior Shmuelof**, Ben-Gurion University of the Negev, Israel
  "Modularity in sensorimotor adaptation: explicit control, reward processing and the brain"

- 09:30-10:00 **Frédéric Crevecouer,** Universite Catholique de Louvain, Belgium
  "Motor learning in a split second: adaptive control of human reaching movements"

- 10:00-10:30 **Gelsy Torres-Oviedo,** University of Pittsburgh, USA
  "Corrective muscle responses reveal cerebral-independent sensorimotor adaptation"

- 10:30-10:40 Discussion
- 10:40-11:20 Coffee break

Session 2 – Sensorimotor Control and Stroke

Chairs: **Netta Gurari**, Northwestern University, USA, and **Firas Mawase**, Technion, Israel

- 11:20-11:50 **Netta Gurari**, Northwestern University, USA
  "Torque Perception in Chronic Hemiparetic Stroke"

- 11:50-12:20 **Firas Mawase**, Technion - Israel Institute of Technology, Israel
  "*Piano-like skill learning for stroke rehabilitation: Task completion vs. Movement quality*"

- 12:20-12:50 **Ronit Feingold-Polak,** Ben-Gurion University of the Negev, Israel *"Reach to grasp following stroke: from research to clinical considerations"*

12:50-13:00 Discussion

13:00-13:30 Lunch

13:30-14:30 **Posters**

Session 3 – Keynote session – Touch Interaction with the World

Chair: **Sigal Berman**, Ben-Gurion University of the Negev, Israel

- 14:30 Greetings **Prof. Daniel Chamovitz**, President of Ben-Gurion University of the Negev, in the presence of the Family of Prof. Karniel

- 14:40-15:10 Keynote Lecture
  Allison Okamura, Stanford University, USA
  "Wearable Haptic Devices: From Fingertips to Full-Body Haptics"

- 15:10-15:40 **Helge Ritter,** University of Bielefeld, Germany
  "Manual Intelligence: Linking Motor Control, Robotics and AI"

- 15:40-15:45 **Tamar Flash,** Weizmann Institute of Science, Israel
  Words In memory of Amir Karniel

- 15:45-16:15 **Shlomi Haar**, Imperial College London, UK
  Prof. Amir Karniel Memorial Young Researcher Lecture
  "Data-driven understanding of motor skill learning in a real-world task"

- 16:15-16:25 Discussion

- 16:25-16:45 Coffee break and posters

Session 4– Sensory Systems and Motor Control

Chair: **Mati Joshua**, Hebrew University, Israel

- 16:45-17:15 **Lars Oddson**, University of Minnesota, USA
  "Postural Control in the Absence of Vestibular Otolith Gravitational Cues – Opportunities for Rehabilitation and Research"

- 17:15-17:45 **Anna Montagnini,** Institut de Neurosciences de la Timone, France
  "What drives ocular motion tracking? Role of perceptual, motivational and inferential factors"

- 17:45-17:55 Discussion
- 17:55-18:05 Best poster awards

Coca Bar

19:00 Drinks and light dinner

Tuesday, March 26

08:30 – 18:00 Hike in the Negev

"*A Psalm of David, when he was in the Wilderness of Judah. O God, You are my God, earnestly I seek you; my soul thirsts for you" (Psalms 63:1-2)*

We will go for a trip to the eastern desert of Israel- the 'Judaean Deseret'. This is one of the smallest yet most unique desert regions of the world. The Judaean Wilderness as it is has been known throughout history, lies to the east of Jerusalem and stretching down to the Dead Sea. It is the Biblical wilderness of hills, valleys, natural springs and rugged beauty. Our places of interest will be the 'Zohar Wadi' and the unique cave of Darejat. The cave of Darejat is the place of where last cave-dwelling community in Israel lived and it is also where we will be eating a local traditional lunch.

Meeting place: parking behind building 72 at 08:30.

What to bring: a back pack, sunscreen, a hat, hiking clothes and shoes, water bottles, lunch and snacks for the way back will be provided.

(We will be back approximately between 5:30 to 6:00 p.m.)

Eitan (your tour guide)

elninio76@gmail.com for any question

Talk Abstracts

Evening Special Talk – 24.3.19

17:00-18:00

Ofer Blutrich

Haifa University, Israel

Rock Climbing - Learn Or Learn to Fly

Rock climbing is a complex sport. It has high demand on the athlete both physically mentally and also requires a high level of motor skill combined with the ability to solve problems.

The athlete needs to execute a climb perfectly for him to be able to complete a route from bottom to the top without falling.

The rock offers an infinite amount of variables: textures, angles, rock type, holds size ,holds shape and distance between holds to name a few.

What is the climber approach for learning new routes? What is the process of learning new movement and skills that are often required to complete a climb.

How does a rock climber "work" routes? And how does the rock teaches the climber to Learn or to Fly.

Session 1 – 25.3.19
09:00-10:40

Motor Learning and Adaptation

Chair: Jason Friedman
Tel-Aviv University, Israel

Modularity in sensorimotor adaptation: explicit control, reward processing and the brain

Lior Shmuelof

Department of Cognitive and Brain Sciences,

Ben-Gurion University of the Negev, Israel

Motor adaptation was traditionally considered to be an implicit process that depends on the cerebellum. Nevertheless, in recent years, it became apparent that adaptation, and presumably other motor learning behaviors, involves multiple control and neural mechanisms. I will present a series of behavioral and imaging works that address this modularity in sensorimotor adaptation learning. First, I will show that the consistency of the perturbation across trials affects the rate of adaptation, such that subjects that encounter a consistent perturbation adapts faster, and that this effect is mediated by explicit control mechanisms. Then, I will show that delaying the visual feedback (a manipulation that affects implicit learning) does not affect the rate of adaptation to a consistent perturbation, providing further support for the role of explicit learning in adaptation. The second aspect of modularity that I will address is the differential effect of reward and error on adaptation learning. I will show a distinct effect of reward on the retention of adaptation, and present an imaging study that point to the involvement of the basal ganglia and the primary motor cortex in processing of reward feedback and the cerebellum and the premotor cortex in the processing of errors.

Motor learning in a split second: adaptive control of human reaching movements

Frédéric Crevecouer

Department of Mathematical Engineering
Universite Catholique de Louvain Science, Belgium

Humans and animals can learn to anticipate the impact of forces applied to the limb during motor tasks, and compensate for such forces ahead of feedback information about them. This process engages learning or adaptation, which has been characterised on a movement by movement basis. It remains unclear how quickly can motor adaptation impact on behaviour, which would provide important insight into the function of the underlying neural process. Here I will present several human reaching experiments in which we use a random adaptation paradigm to assess changes in control during un-anticipated disturbances. We show that participants can learn to control reaching movements without anticipating the perturbation, and when they are forced to stop during a trial, the occurrence of a disturbances produced near-instantaneous after effects. Corrections were tuned to the action of the force field as in standard adaptation paradigms, and correlates were found in the motoneurons activity as early as ~200ms following reach onset. Thus, the properties of improvements in online corrections were identical as those measured during trial by trial learning, but they occurred in a few hundreds of milliseconds. Thus the function of motor adaptation is not only to improve performance with practice, but also to complement feedback mechanisms engaged during movement control.

Corrective muscle responses reveal cerebral-independent sensorimotor adaptation

Gelsy Torres-Oviedo

Department of Bioengineering,

University of Pittsburgh, USA

Human movements are flexible as we continuously adapt to changes in the environment by recalibrating our motor commands and generating corrective actions. Sensorimotor recalibration occurs upon repeated exposure to predictable changes in the environment, whereas corrective actions serve as an immediate response to overcome sudden environmental changes. Corrective movements during walking are thought to simply reflect environmental transitions independently from sensorimotor recalibration (Morton and Bastian, 2006). However, recent studies suggest that corrective responses could be influenced by sensorimotor recalibration (Wagner and Smith, 2008). Thus, we asked if corrective motor commands are adapted in walking and the extent to which this is a cerebral-dependent process. We investigated cerebral involvement in adaptation of corrective actions using stroke as a disease model. We specifically characterized changes in muscle activity in stroke survivors (n=15) and unimpaired individuals (n=15) before, during, and after walking on a split belt treadmill moving the legs at different speeds, which has been shown to induce sensorimotor recalibration (Reisman et al. 2005). On the one hand, we found that corrective muscle responses in stroke survivors and controls were equally indicative of sensorimotor recalibration of gait. On the other hand, the steady state structure of muscle activity post-stroke in the novel split environment differed from that of controls. This indicates that stroke survivors have a limited ability to adjust movements to the new environmental demands. In conclusion, our results indicate that corrective responses are indicative of sensorimotor recalibration of the motor system and this recalibration process does not require intact cerebral structures. This is the case even if muscle activity after cerebral damage is impaired in an altered environment. Taken together, our results suggest that the sensorimotor recalibration to generate motor commands and the execution of those commands are partially dissociable processes. The recalibration process does not require cerebral structures, whereas the execution process does. From a clinical perspective our results are interesting because they suggest that sensorimotor recalibration could be exploited to induce gait rehabilitation.

Talks

Session 2 – 25.3.18
11:20-13:00

Sensorimotor Control and Stroke

Chairs:

Netta Gurari

Northwestern University, USA

and

Firas Mawase

Technion - Israel Institute of Technology, Israel

Torque Perception in Chronic Hemiparetic Stroke

Netta Gurari

Department of Physical Therapy and Human Movement Sciences Preceptor

Feinberg School of Medicine, Northwestern University, USA

In the USA, 5.6 million individuals with stroke face great difficulty performing activities of daily living, in part because they are unable to judge the relative torques they generate with their two arms. The impact of this torque perceptual impairment on activities of daily living is unknown, but prior work suggests that the effect is substantial, particularly during bimanual tasks. Therefore, this impairment is important to investigate since it may hinder the ability of individuals with stroke to safely deal with unfamiliar and potentially dangerous bimanual tasks, such as carrying a tray and pushing a grocery cart. By understanding the reason that a torque perceptual impairment occurs, we can develop science-based interventions that lead to improved sensorimotor outcomes in millions of stroke survivors.

In this talk, I will present results from numerous behavioral experiments in which we used mechatronic systems to quantify the ability of individuals with chronic hemiparetic stroke to identify their self-generated torques at the elbow during unimanual and bimanual perceptual tasks. Results from these experiments indicate that judgments about whether individuals with stroke have torque perceptual impairments can depend on how an assessment is executed (e.g., single arm/between arms; matching to paretic/non-paretic arm). I will provide a novel hypothesis to explain the reason that a torque perceptual impairment occurs and will discuss the implications of our findings. The long-term goal of this work is to change the way that clinicians approach rehabilitation by highlighting the importance of intact torque perception, developing appropriate torque perceptual assessments, and providing a targeted rehabilitative treatment.

Piano-like skill learning for stroke rehabilitation: Task completion vs. Movement quality

Firas Mawase

Faculty of Biomedical Engineering

Technion – Israel Institute of Technology, Israel

Stroke is one of the most common causes of physical disability worldwide, and the majority of patients experience impairment of movement. Lesions to the motor cortex and corticospinal tract areas following a stroke cause serious deficits in generating isolated finger movements, thus limiting basic daily functions. To date, most of conventional rehabilitation strategies have generally not produced the magnitude of improvement that will change clinical practice in the chronic stage of stroke. The aim of the current study was to investigate whether intensive training of a novel motor skill would improve finger dexterity in chronic stroke. Critically, we focused on whether our intensive training and challenging environment could boost recovery of motor functions and impairments beyond what would be achieved from spontaneous biological recovery. Eighteen chronic stroke patients were recruited for a longitudinal study. First, patients underwent baseline assessments of hand function, impairment and dexterity. Then, participants were trained for five consecutive days on a *piano chord-like* task in which they learned to simultaneously coordinate and synchronize engagement of multi-finger muscles. The task difficulty was customized for each patient based on the baseline performance. To test retention and generalization following training, patients underwent post-training assessments after both one day, one week and six months. Our data shows that the intensive novel training protocol significantly improves finger coordination and individuation in the chronic stage. Importantly, beyond this task-specific improvement, we found that training enhanced movement quality as expressed by improvement in comprehensive clinical hand function, like improved pinch precision. These effects lasted at least for six months following the training. Our findings support the potential of the intensive novel training protocol to be used clinically to help improve finger dexterity. We propose that chronic stroke could gain improvement at the movement quality level when intensive training of challenging task is carefully used.

Talks

Session 3 – 25.3.19
14:30-16:20

Keynote Session

Chair: Sigal Berman
Ben-Gurion University of the Negev, Israel

Wearable Haptic Devices: From Fingertips to Full-Body Haptics

Allison Okamura

Department of Mechanical Engineering

Stanford University, USA

Haptic devices allow touch-based information transfer between humans and intelligent systems -- enabling communication in a salient but private manner that frees other sensory channels. For such devices to become ubiquitous, they must be intuitive and unobtrusive. The amount of information that can be transmitted through touch is limited in large part by the location and distribution of human mechanoreceptors. Not surprisingly, many haptic devices are designed to be held or worn at the fingertips, which have very high density of mechanoreceptors. Yet stimulation using a device attached to the fingertips precludes natural use of the hands. Thus, we explore the design of a wide array of haptic feedback mechanisms, ranging from devices that can be actively touched by the fingertips to multi-modal haptic actuation that is mounted on the arm. We seek to understand how and when these devices are useful in virtual reality, human-machine communication, and human-human communication.

Manual Intelligence: Linking Motor Control, Robotics and AI

Helge Ritter

Faculty of Technology &

CoE Cognitive Interaction Technology (CITEC)

Bielefeld University, Germany

While research in motor control and cognition has made many advances, the advent of sophisticated robot hardware platforms, together with breakthroughs in data science and in artificial intelligence, creates new opportunities for a fruitful linkage between these fields in order to better understand the principles that underlie skillful sensori-motor interaction, and to bring these to bear on technology, such as robotics.

After a brief sketch of major recent developments we take a look at some of the (many) challenging facets of the "manual intelligence" that is manifested in the daily actions of our hands and that, despite huge research efforts, is still almost entirely absent in what robots endowed with anthropomorphic hands can do today. We point out some of the underlying reasons and provide examples that connect work on haptics, creation of better tactile sensing for robots, machine learning, and the coordination of vision and touch to improve the current manual skills of robots and to probe ideas about the computational basis of sensori-motor interaction by using robots as research platforms. We finally briefly touch on the role of manual intelligence for a deeper understanding of cognition and for integrating robots into our society in a way that is beneficial to all of us.

Prof. Amir Karniel Memorial Young Researcher Lecture:

Data-driven understanding of motor skill learning in a real-world task

Shlomi Haar

Department of Bioengineering, Imperial College London, United Kingdom

Motor skill learning is a key feature of our development and our daily lives. Very little is known about the behavioral and neural process of real-world motor skill learning, allegedly due to its complexity and the difficulty to measure and quantify it, in contrast to highly reductionistic controlled experiments in toy tasks. We demonstrate the feasibility of studying neuroscience in-the-wild: We use mobile brain and behavioral imaging to study real-world motor skill learning in a pool-table billiards paradigm. Billiards is a real-world task ideally suited to neurobehavioral study as motion tracking in terms of movement in space, the natural constraints of game play, and divisibility into trials, captures the style of reductionistic lab-based motor learning tasks. Naïve subjects, performed repeated trials where the cue ball and target ball were placed in the same locations, and subjects were asked to shoot the target ball towards the same pocket. During the entire learning process, we recorded the subjects' full body movements with a ‘suit’ of inertial measurement units, and their brain activity with wireless EEG. The balls on the pool table were tracked with a high-speed camera to assess the outcome of each trial.

The learning curve in this real-life paradigm (measured over the directional error of the target ball relative to the pocket) was similar to those reported in the reductionistic motor adaptation error-based learning studies. We tested if higher levels of task-relevant motor variability, in this complex real-world, can predicted faster learning across individual, as found in simple lab experiments (Wu et al. 2014). Indeed, individuals with higher task-relevant motor variability (variability in the directional error of the target ball) over the first block of trials had faster learning. Studying in-the-wild learning enable looking at global observables of motor learning, as well as relating learning to mechanisms deduced from reductionist models. Full body kinematics was analyzed over the joint angles of 22 joints in 3 degrees of freedom. The analysis of the velocity profiles of all joints enabled in depth understanding of the structure of learning across the body. Most importantly, while most of the movement in each trail was done by the right arm, the entire body learned the task, as evident by the decrease in both inter- and intra- trial variabilities of various joints across the body over learning. Interestingly, while over learning all subjects decreased their movement variability and the variability in the outcome (ball direction), the subjects who were initially more variable were also more variable after learning, supporting the notion that movement variability is an individual trait (Haar et al. 2017). Lastly, when exploring the link between variability and learning over joints we found that only the variability in the right elbow supination shows significant correlation to learning. This demonstrates the relation between learning and variability: while learning leads to overall reduction in movement variability, only initial variability in specific task-relevant dimensions can facilitate faster motor learning. Crucially we are enabling novel hypothesis driven experimental approaches to study behavior where it matters most – in real life settings.

Acknowledgment: The work was supported by the Royal Society – Kohn International Fellowship and by eNHANCE EU Horizon 2020 project #644000

Talks

Session 4 – 25.3.19
16:40-17:50

Sensory Systems and Motor Control

Chair: Mati Joshua
Hebrew University, Israel

Postural Control in the Absence of Vestibular Otolith Gravitational Cues – Opportunities for Rehabilitation and Research

Lars Oddson

Department of Physical Medicine and Rehabilitation, Medical School, University of Minnesota, MN, USA

Postural control is achieved through the integration of somatosensory, visual and vestibular information by the brain to provide optimal motor control for a given situation. Investigating the relative contribution of these sensory inputs benefits from technology that can isolate their individual relevance and use. The current presentation will discuss research on the “Gravity-Bed”, a technology that can isolate the use of somatosensory information for balance control. The Gravity Bed provides a 90 deg tilted environment where subjects “stand” in a supine position while strapped to a backpack frame with friction-free air-bearings that allow the subject to move freely in the frontal plane, like when in upright standing. The frame is attached to a force actuator to provide different levels of a gravity-like load the subject must balance against to remain “upright”. Veridical visual input is provided for the illusion of upright. While in a horizontal position, otolith gravitational cues cannot be used for balance and with eyes closed in the Gravity Bed environment, balance control must rely mainly on somatosensory information. The Gravity Bed System has been used to assess use of somatosensory information for postural control. Furthermore, it has been shown to improve balance performance in healthy subjects and to be safe and feasible for functional rehabilitation of acute stroke patients. Results also show that strength and balance training can be combined to concurrently improve and/or maintain both strength and balance function. In addition, the system may be used to investigate the postural control system under conditions when vestibular information is absent, such as microgravity, providing an on-earth emulation of microgravity effects on the balance control system.

What drives ocular motion tracking? Role of perceptual, motivational and inferential factors

Anna Montagnini

Institut de Neurosciences de la Timone, CNRS & Aix-Marseille Université, Marseille, France

The accurate smooth visual tracking of a moving object is a primates' fundamental skill that allows reducing the relative slip and instability of the object's image on the retina, thereby granting a stable, high-quality vision. In order to optimize tracking performance across time, a quick estimate of the object's global motion properties needs to be fed to the oculomotor system and dynamically updated. The main limiting factor for accurate and timely visual tracking is the uncertainty in the sensory input, such as under variable conditions of motion properties or visibility, as well as in presence of intrinsically ambiguous retinal information. Concurrently, tracking performance can be greatly improved by taking into account extra-retinal, predictive information across different time-scales.

I will present several experimental paradigms whereby the presence of visual motion uncertainty requires the dynamic integration of visual and predictive information for accurate smooth tracking. I will show that the analysis of human tracking eye movements in such conditions provides a reliable continuous readout of object motion processing and perceptual illusions. Then I will focus on a set of experiments addressing the buildup of an internal dynamic representation of the probabilistic structure of the environment, and its influence on predictive and visually-guided tracking. Finally I will present recent work on the influence of reinforcement contingencies on the very early phases of smooth pursuit eye movements, both in healthy and Parkinson's disease participants.

Human behavioral data are modeled within the framework of dynamic probabilistic inference, that seems to provide a comprehensive theoretical ground across different contextual conditions and time-scales.

Projet International de Coopération Scientifique (PICS) –CNRS : « APPVIS- Visual perception and pursuit as readout of cognitive function and dysfunction » Grant to Anna Montagnini

Posters

A difference in perceived stiffness when touching elastic objects by different hands suggests different information processing time between the hands

Shani Arusi and Ilana Nisky

Department of Biomedical Engineering and Zlotowski Center for Neuroscience, Ben-Gurion University of the Negev, Beer-Sheva, Israel

During daily interactions with objects, we assess their mechanical properties to form perception and action. To date, perception and action in interaction with elastic objects have been tested only in unimanual interaction. A previous study examined perception of stiffness in unimanual interactions and found that delayed force feedback causes stronger underestimation of stiffness when using the left hand in both left handed and right-handed participants. They speculated that this is a result of a larger internal delay in the processing of information from the left hand. If this is true, objects that are touched with the left hand should be perceived softer than objects that are touched with the right-hand when compared directly, and adding delay to the force feedback that is presented to one of the hands will either increase (if added to the right hand) or eliminate (if added to the left hand) the difference in perception of stiffness due to the natural delay between the two hands. Here, we set out to test this prediction during interactions with elastic objects that are touched with different hands sequentially. We used two robotic devices to present force feedback to participants in a virtual reality environment and recorded the position of the hand and the trajectories of their grip forces. Right- and left-handed participants probed pairs of virtual elastic force fields with different hands and reported which had a higher level of stiffness. Our results provide support for the model that suggests different processing times between the hands for right-handed participants: they perceived elastic force field that they touched with their left hand as softer than those that they touched with their left hand. But surprisingly, there was no difference in perception between the hands of left-handed participants. This is surprising considering the previous study that showed consistent results between left- and right-handed participants. In the future, we plan to employ these findings in the development of controllers that will present force feedback to surgeons during robot-assisted surgery.

Interaction between position and force control in bimanual tasks

V. Ponassi[1], G. Ballardini[1], E. Galofaro[1], G. Carlini[1], L. Pellegrino[1], F. Marini[2], M. Muller[3], C. Solaro, P[3]. Morasso[2], M. Casadio[1]

[1] *Department of Informatics, Bioengineering, Robotics and Systems Engineering, University of Genoa, Italy*
[2] *Italian Institute of Technology, Genoa, Italy*

[3] *Department of Rehabilitation Mons. L. Novarese Hospital, Moncrivello, Italy*

Proprioceptive deficits are frequently associated with neuromotor impairments that strongly affect daily-life activities, interfere with motor learning and motor control processes and also with rehabilitation outcomes. Despite that, these deficits are poorly understood and less investigated than motor impairments.

Here we aim to assess proprioceptive deficits through the observation of position and force control performance during bimanual tasks. We focused on these tasks because most daily life activities require to coordinate the motion and the force produced by both hands, using position sense, as well as sense of effort. Moreover, several neurological diseases induce coordination problems and often affect the two arms differently. In our study participants had to (1) reach a target position with both their hands while holding objects with equal or different weights and (2) exert an isometric force, pushing equally with the two arms in the upward direction, while their hands were maintained in a fixed position at the same or at different heights. Our primary outcome was the difference between the two hands at the end of each trial, in terms of position in task 1, or force in task 2. First, we tested a population of healthy young subjects and then we provided a first proof of concept that this set-up could be used for people with neurological disease, such as Multiple Sclerosis (MS) with a low to moderate level of impairment.

As for the healthy young participants (20 subjects for task 1; 25 for task 2), we found that the difference in hand positions was greater when the two hands held different weights; instead, the ability to exert forces was influenced by the position of the left hand, regardless of the right hand position and without effects of symmetric or asymmetric arm configurations.

As for MS participants (7 people with MS and different levels of impairment, 7 sex and age matched controls) we found that the ability to exert symmetric forces with the two hands was significantly altered in all subjects with respect to healthy controls, independently of the hand configuration. Conversely, their ability to control the position decreased only for subject with higher level of impairment. These findings, if confirmed on a larger population of MS subjects, could be relevant for the early detection of the disease onset, and to assess how the proprioception and motor control changes in the progress of the disease.

Acknowledgment This work was supported by Italian Multiple Sclerosis Foundation (FISM, 2013-Cod.2013/R/5), by Marie Curie Integration Grant (FP7-PEOPLE-2012-CIG-334201) and Ministry of Science and Technology, Israel (Joint Israel-Italy Lab in Biorobotics Artificial Somatosensation for Humans and Humanoids).

Vibrotactile feedback for improving standing balance: effects of different encoding methods and importance of information content

G. Ballardini[1], V. Florio[1], G. Carlini[1], A. Canessa[1], P. Morasso[2], M. Casadio[1]

[1] Dept. Informatics, Bioengineering, Robotics and Systems Engineering, University of Genoa, Italy

[2] Italian Institute of Technology, Genoa, Italy

The postural control is a complex sensorimotor skill, fundamental for maintaining balance and performing movements. *Balance* is achieved and maintained integrating different sensory inputs. The perception, processing or integration of the sensory information can be impaired or absent because of aging, vestibular disorder or neurodegenerative diseases. These problems impact every daily-life activities increasing also the risk of falls. Supplemental sensory feedback can mitigate this issue. In this work we focused on the effects of vibrotactile feedback on standing balance. We investigated the importance of the information encoded by the vibrational feedback and the relative merits of two different encoding methods. We built a device that recorded the acceleration of the Center of Mass (COM) with a sensor placed at the level of the spinal segment L3. Two tactors, one placed on L5 and the other on the corresponded location in the abdomen, encoded in real time the amplitude and the direction of the COM acceleration respectively in the posterior and anterior directions. We tested two different encoding methods: (i) vibrotactile feedback always on; (ii) vibrotactile feedback with a dead zone, i.e. no vibration in a region corresponding to the standard deviation of the AP acceleration of the COM during quit standing with eyes open. 24 healthy young subjects (9 tested with (i); 15 tested with (ii)) were asked to stand still with feet together and eyes closed. We alternated for three times two trials of 50s: one with and one without vibrotactile feedback. We also verified the importance of the content of the vibrotactile information by applying at the end of the task a sham feedback, i.e. a vibration not related to the postural oscillations. To evaluate the subjects' performance, we computed: (1) the Root Mean Square (RMS), which accounts for the changes in amplitude of the signal and (2) the frequency at which the PSD reaches the 95^{th} percentile (F95). These indicators are computed separately for the AP and the medio-lateral (ML) components of the accelerations.

We found that both encoding methods resulted in a decrease of the RMS and an increase of the F95 in the AP direction (both $p<0.001$), while there were not significant changes in the ML direction. Thus, both methods were able to change the postural oscillations in terms of amplitude and frequency. However, the sham vibration did not lead to the same results, highlighting the importance of the information encoded by the vibration feedback.

Acknowledgment

This work was supported by the Marie Curie Integration Grant (FP7-PEOPLE-2012-CIG-334201) and Ministry of Science and Technology, Israel (Joint Israel-Italy lab in Biorobotics "Artificial somatosensation for humans and humanoids").

Eye movements during motor adaptation: what can eye movements tell us about adaptation and about explicit subject strategy?

Zohar Bromberg[1,2], Opher Donchin[1,2], Shlomi Haar[3]

1. *Dept. of Biomedical Engineering, Ben-Gurion University of the Negev, Israel*
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Researchers dissociate two components of motor adaptation: one explicit and the other implicit. It is generally assumed that behavior is an additive combination of these two components. We have previously reported that eye movements can be used as a measure of this explicit strategy in visuomotor adaption of reaching movements (Bromberg, Donchin, & Haar, 2018; see also De-Brouwer et al., 2018a, 2018b). Despite converging evidence in our research and that of others that the eye movements reflect the explicit component, there was one aspect of the data that did not fit. We used an exclusion test after adaptation as one measure of the implicit component. In this test, subjects were asked to aim directly at the target without receiving any feedback. We found that in some conditions, there was a gap between the implicit component as predicted from the eye movements and from the exclusion test. To explore the time course of this gap, we tested 70 subjects in a modified version of the original experiment. The primary difference was that we tested exclusion during the adaptation phase as well as at the end of the adaptation. We found that subjects could be categorized into two groups. More than half of the subjects showed a good match between implicit adaptation predicted from eye movements and from exclusion throughout the experiment. The other half had eye movements that estimated the implicit component to be larger than when measured using the exclusion test. Interestingly, the first group could be further clustered into two sub clusters:

1. Fully Implicit learners show no evidence of explicit strategy.
2. Fully Explicit learners are dominated by explicit strategy and have reduced implicit adaptation.

In contrast, subjects in the second group showed a tendency to balance implicit and explicit adaptation dynamically with a time course that has been described in the literature. Thus, we conclude that the eyes provide important information not only regarding the explicit strategy used by subjects to learn a task but also regarding the approach to adaptation used by each subject.

Stretching the skin of the fingertip creates a perceptual and motor illusion of touching a harder spring

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During manipulation of objects, we use kinesthetic and tactile information to assess the mechanical properties of objects, and to coordinate the grip force to prevent the slippage of objects. It is well established that the control of grip force relies on predictive control that uses an internal representation of the load forces that the objects elicit on the fingers. A major challenge in understanding the internal representations that allow for a predictive grip force control during contact with objects is to dissociate the contribution of tactile and kinesthetic force stimuli. To date, this contribution was investigated only in pathological cases either through local anesthesia or in patients with sensory impairment. In this paper, we seek to answer this question in the intact sensorimotor system by quantifying the effect of adding artificial tactile information to kinesthetic force feedback on the internal representation of the stiffness of elastic objects. This internal representation affects perception and predictive grip force control. Previous studies showed that artificial skin stretch causes the illusion of touching a harder spring, but the effect on the predictive control of grip force was never investigated to date. Moreover, it is not known if the perceptual illusion develops immediately in the first interaction with the elastic object, or over time with subsequent probing interactions. Our results suggest that the artificial skin-stretch also affects the internal representation of the load force that is applied by the object, and increases the predictive modulation of grip force in anticipation of the load force. We also found that the perceptual illusion is formed immediately at first contact with the object, and does not depend on the build-up of the internal representation that is used for the predictive control of grip force. These results are important for understanding the remarkable human ability to gracefully manipulate a variety of objects manually without breaking or dropping them, and for developing new technologies simulating the human sense of touch.

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Motion and Force Characteristics during Reach to Grasp Functional Task of Post-Stroke vs Healthy Individuals

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Introduction & Aim: Reaching is one of the most important components of daily activities with goals to interact and acquire objects in the environment. Following a stroke, the goal-directed movements are characterized by slowness, spatial and temporal discontinuity. Our aim was to assess the quality and efficacy of task-oriented reach-to-grasp (RTG) movements at different heights and weights in sub-acute post-stroke patients compared with healthy individuals.

Methods: 30 first unilateral post-stroke patients (70.33±9.35 yrs) and 16 healthy age-matched adults (69.12±11.58 yrs) were asked to reach their arm to grasp a cup located on a table, and to place it on a shelf. The cup was either empty or full with water. There were three heights of table. Each combination of weight and height was examined 3 times. Eleven reflective markers were placed on the participants' upper extremity and trunk. The motion was recorded by a portable motion-capture system (V120:Trio ,OptiTrack) and the forces were recorded using a force-sensor embedded in the cup.

Results: Data analysis was performed using SPSS (version 25) and a custom script in Matlab. The analysis of the data on the velocity, the mean squared jerk (MSJ), the index of curvature (IC) and the forces applied on the cup were separately analyzed for each phase of the movement according to the task: 1. Reach-to-grasp the cup, 2. Grasp, 3. Raising the cup. We found a significant difference between healthy and post-stroke participants for the mean, maximum and minimum velocity of all the phases of the movement ($p<0.001$). The RTG IC of stroke patients was significantly higher ($U=46511$, $p<0.0001$) as well as the MSJ for all the phases of the movement ($p<0.0001$). In the stroke-group we found a significant effect for the cup condition (empty\full) on the ratio time between phase 2 to phases 2 to 3, reflecting the amount of time a patient organized his hand on the cup ($U=29191.5$, $p=0.005$). In addition, the height of the table had a significant effect on the variability of the forces applied on the cup between phases 2 to 3 when comparing between the three severity stroke groups to healthy controls ($F=5.119$, $p<0.0001$). **Conclusions**: We found that the height of the table and the cups' weight have an effect on the movement and forces characteristics in RTG task of stroke patients. This information should be taken into consideration when designing post-stroke rehabilitation programs.

Voluntary Actions Modulate Auditory Perception and Neural Responses to Near-Threshold Sounds

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Sensory perception is a product of complex interactions between the physical attributes of a stimulus and the internal state of the perceiving system.

One contextual factor that modulates auditory perception is the agentic source of auditory stimuli; namely, whether they are produced through voluntary, self-generated actions or if they originate from an external source and are perceived passively. A proposed mechanism underlying this modulation suggests that during voluntary action execution, the motor system sends an "efference copy" conveying the expected sensory outcome to relevant sensory cortex resulting in a local "corollary discharge", which changes the state of the perceptual system. This process is considered an essential component of a forward model, which uses sensory prediction errors (comparison between expected and actual sensory inputs) to guide behavior.

In the current study we probed subjects' neurophysiological and behavior responses to self-generated vs. passively perceived near-threshold sounds. We recorded brain activity using Magnetoencephalography (MEG). We used MNE source recognition algorithm to identify the motor and auditory responses.

The experiment was an auditory detection task comprised of *Active* and *Passive* experimental conditions. In the *Active* condition, subjects spontaneously press a button with their right index finger. In the *Passive* condition, visual cue was presented on the screen however participants were not required to perform a button press. In 50% of the trials, the near-threshold sound was presented 500 ms after the cue/press whereas in the remaining 50% of the trials no sound was delivered. In both conditions, at the end of each trial, subjects were asked to report whether they heard a sound or not via button press.

Subjects showed increased auditory sensitivity in the active compared with passive conditions. Furthermore, subjects' mean hit rate in the active condition was greater than chance, while the mean hit rates in the passive condition was not different from chance level.

In line with the theory we presented, in the active condition only, we found higher activity in left auditory cortex (contra-lateral to the press) at the pre-stimulus period (after the press), when the subjects recognized the stimuli ('hit trials') relative to the trials that the subjects didn't hear the sounds ('miss trials').

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Dissociation Between Reaction Time and Pupil Dilation in the Stroop Task

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It has been suggested that the Stroop task gives rise to two conflicts: the information conflict (color vs. word meaning) and the task conflict (name the color vs. read the word). However, behavioral indications for task conflict (RT congruent condition longer than RT neutral condition) appear under very restricted conditions. We conducted Stroop experiments and measured RT and pupil dilation. The results show a clear dissociation between RT and pupil dilation. We found the regular RT pattern—large interference and small, non-significant facilitation. In contrast, pupil dilation showed information conflict—larger pupil dilation to incongruent than to congruent and neutral conditions—and task conflict—larger pupil dilation to the congruent than to the neutral condition. Moreover, pupil indications for task conflict appeared earlier than indications for the information conflict. These results suggest that pupil changes could indicate conflict even in the absence of behavioral indications for the conflict.

Reactivation-Induced Motor Skill Learning

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Learning motor skills is commonly perceived as time consuming, requiring a repeated execution of the skill to achieve gains in performance. However, in a different learning domain, visual perceptual learning was recently shown to be achieved by brief reactivations of the learned task, suggesting a novel rapid learning mechanism. Here, we tested the hypothesis that motor skill learning can be achieved with rapid learning mechanisms through brief reactivations, requiring significantly less practice repetitions. 40 participants learned a motor skill task, in which they were required to tap a sequence with their non-dominant hand as fast and accurate as possible, and returned to the lab for a retest following one week. Changes in corticospinal motor system excitability were evaluated, measuring muscle EMG activity evoked by single-pulse TMS stimulation over the M1 contralateral to the performing hand, before and after learning. Subjects in the *Reactivations* group performed 2 additional sessions between test and retest, in which the skill memory was reactivated for only 30 seconds. Results show that these brief reactivations were sufficient to induce learning gains. An additional experiment showed that learning can be further improved with additional practice of the task. Furthermore, excitability measurements supported the behavioral results, showing elevated excitability following learning for subjects from the *Reactivation* group, while subjects from the control group showed no change in excitability. Interestingly, subjects who performed extensive practice, showed a similar pattern of excitability change as the *Reactivation* group. These results indicate that motor skill learning can be achieved by brief reactivations, significantly shortening the required practice, and suggest that such rapid learning is driven by plasticity mechanisms similar to those which underlie learning by extensive practice. The results demonstrate a novel form of rapid motor skill learning, having far-reaching implications, for example in rehabilitation following neurological injuries.

Suboptimal multisensory integration in Parkinson's disease: visual dominance despite impaired visual self-motion perception.

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Introduction: The motor system is intimately connected with the sensory-perceptual system but in Parkinson's disease (PD), the prototypical movement disorder, the relationship between perceptual (e.g., visual) deficits and motor impairments is not known. Counter-intuitively, people with PD often show increased visual dependence. Posture, gait and balance, all impaired in PD and challenging to treat, depend on self-motion perception yet self-motion perception has not been studied in PD. When exposed to visual stimuli of self-motion, PD patients demonstrate altered veering. However, visual self-motion perception, per se, and integration of visual and vestibular cues for self-motion perception have not been tested in PD. Here, we directly tested visual and vestibular self-motion perception, and visual-vestibular integration, in PD.

Methods: We tested 19 non-demented independently walking PD participants, 23 healthy age-matched adults and 20 healthy young adults. Participants experienced vestibular (motion platform induced inertial movement), visual (head mounted display presented optic flow) and combined visuo-vestibular self-motion stimuli, in a primarily forward direction, but with a slight rightward or leftward deviation. Immediately after each stimulus, participants reported the direction of their perceived motion. PD participants and age-matched controls repeated the same experiment twice. PD participants took their regular PD medications on the first visit and were medication-free from the night before the second visit.

Results: PD participants had significantly impaired visual self-motion perception compared to age-matched controls ($p<10^{-4}$) irrespective of medication status or visit number, but their vestibular performance was unimpaired (comparable to both control groups). Moreover, the PD deficit in visual self-motion perception correlated with clinical disease severity ($r=0.7$, $p=0.002$). Age-matched controls' visual and vestibular self-motion perception was comparable to young controls. Strikingly, despite impaired visual self-motion perception, PD participants significantly over-weighted visual cues in the multisensory condition ($p<0.01$), reflecting sub-optimal visual-vestibular integration.

Discussion and Conclusions: Here we show that PD patients have impaired visual self-motion perception. Furthermore, PD patients sub-optimally integrate visual and vestibular cues. These impairments may contribute to impaired function in PD and be related to PD symptoms (self-motion perception is important for moving around in the world). This is the first demonstration of suboptimal multisensory integration in PD. PD might be characterized by more general integration deficits which needs to be tested using other cues.

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Using Augmentation to Improve the Robustness to Rotation of Deep Learning Segmentation in Robotic-Assisted Surgical Data

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Robotic-Assisted Minimally Invasive Surgery allows for easy recording of kinematic data, and presents excellent opportunities for data-intensive approaches to assessment of surgical skill, system design, and automation of procedures. However, typical surgical cases result in long data streams, and therefore, automated segmentation into gestures is important. The public release of the JIGSAWS dataset allowed for developing, training, and benchmarking data-intensive segmentation algorithms. However this dataset suffers from several limitations: it is small and the gestures are similar in their structure and directions. This may limit the generalization of the algorithms to real surgical data that are characterized by movements in arbitrary directions. In this research, we use a recurrent neural network to segment a suturing task, and demonstrate one such generalization problem - limited generalization to rotation. We propose a simple augmentation that can solve this problem without collecting new data, and demonstrate its benefit using: (1) the JIGSAWS dataset, and (2) a new dataset that we recorded with a da Vinci Research Kit. The performance of the network that was trained without augmentation deteriorated when we tested it with rotated versions of the test data, and went down to chance level when we tested it with a new dataset. In contrast, the performance of the network that was trained with rotation augmentation was mostly steady, and achieved good results for the new data. Our study highlights the importance and prospect of using data augmentation in the analysis of kinematic data in surgical data science.

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Balance perturbation training for rehabilitation of dynamic balance in acquired brain injury victims: an exploratory interventional prospective trial and a neuroimaging investigation.

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Background and aims: Acquired brain injury is a major cause of functional disability and is often characterized by a deterioration of dynamic balance. We aim to evaluate the effect of long-term unexpected constant balance perturbation training on dynamic balance and on the modularity in the motor control brain network pre and post-training.

Methods: In an exploratory clinical interventional trial, 34 subjects with chronic ABI received 22 sessions of perturbation-training using Re-Step™ technology. Before and after training we assessed dynamic balance and resting state functional connectivity (FC) using fMRI.

Analysis of the neural data was conducted at two levels: (i) model free Independent Component Analysis (ICA) (ii) Regions of interest (ROIs) analysis focusing on the representation of the lower limbs in the primary motor cortex and in the cerebellum.

Results: Following 3 months of perturbation training, balance control improved significantly ($p=0.001$). This improvement was greater than the improvement due to the exposure to the clinical examinations and to time passage alone ($p=0.043$). ICA analysis detected a reduction in the strength of the sensori-motor and cerebellar networks post-training. Following the identification of functional and anatomical regions of interest (ROIs), we ran a multivariate linear regression analysis in order to explain dynamic balance using the FC measures. Dynamic balance at baseline had a negative relationship with modularity (i.e., the inverse of FC) between the left thalamus and the right cerebellum at baseline ($r=-0.44$, $p=0.011$). Dynamic balance recovery was negatively associated with modularity at baseline between the right putamen and the left cerebellum, between the left thalamus and the right cerebellum and between the cerebellar ROIs ($p=0.005$, $p=0.049$, $p=0.031$ respectively). Finally, dynamic balance recovery was positively associated with changes in modularity after training between the right putamen and the left cerebellum and between the cerebellar ROIs ($p=0.026$, $p=0.004$).

Conclusions: Perturbation training improves dynamic balance control in ABI subjects. Dynamic balance recovery can be predicted based on baseline modularity and can be explained by an increase in modularity (reduction in FC) in subcortical and sensorimotor networks. These effects could be a direct outcome of the brain damage or mediated by the motor deficits.

Does object location affect the angle of the dart throwing motion?

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Introduction: Complex wrist motions are needed to complete various daily activities. Analyzing the multidimensional motion of the wrist is crucial for understanding our functional movement. Several studies have shown that numerous activities of daily livings (ADLs) are performed using an oblique plane of wrist motion from radial-extension to ulnar-flexion, named the Dart Throwing Motion (DTM) plane. However, the DTM plane angles differ between various tasks and between subjects. Moreover, some tasks are performed at different heights, e.g. taking a book off a high shelf or hammering a nail close to the ceiling. These tasks may produce different DTM plane angles. To the best of our knowledge, the DTM plane angle performed during ADLs has not been compared between different heights.

Objective: We therefore aimed to (a) compare the DTM plane angle when performing different ADLs between three different heights, and (b) to examine the relationship between the DTM plane angles and the limb position, (shoulder and elbow angles) while performing different ADLs.

Method: A six-camera motion capture system tracked coordinates of 14 markers placed on the upper right limb of 40 healthy subjects performing 9 daily tasks at 3 different heights. The DTM plane angle differences between the three heights for each task were compared and a multilevel model was used to compute the correlations between the angles of the shoulder and elbow and the DTM plane angle during performance of ADLs at 3 heights.

Results: The height had a significant effect on the DTM plane angles. The mean DTM plane angle was greater at the lower level compared to the mid and higher levels. The DTM plane angle for the tasks also differed depending on the height, as shown by a significant interaction of height and task. A significant effect of the shoulder position on the mean DTM plane angles was shown in the sagittal and coronal planes: a 10° change in shoulder angle led to a 1.3° or 2.4° change in DTM plane angle.

Conclusion: DTM plane angles were significantly different at different heights, and the shoulder posture predicted a significant amount of the variance of the DTM plane angles. These findings support the importance of training daily tasks at different heights during the rehabilitation phase after injuries to the wrist.

Look where you are thinking

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Background: When negotiating complex terrains, humans use vision, proactively, to tailor their walking pattern to upcoming ground. Compared to usual walking, complex-terrain walking has been associated with increased prefrontal cortex (PFC) activity, which is assumed to indicate a shift from "automatic" to "executive" control of walking. In the present study, we investigate PFC activity and the visual exploration pattern under an unusual walking condition in which **visually** the terrain is perceived as flat, yet each foot placement is on a new, unexpected terrain. **Aim:** To investigate the causal relation between walking stability and both PFC activity and the visual exploration pattern. **Methods:** Eleven healthy young adults walked in two conditions: normal walking and perturbed walking. To monitor PFC activity, we measured the change in oxy and deoxy hemoglobin concentrations (Δ[HBO] and Δ[HHB] respectively) using two portable functional near-infrared (fNIRS) devices. To characterize the visual exploration pattern, we used a wireless eye-tracker, which provides the location of the instantaneous gaze-fixation on the projected two-dimensional space in front of the participant. Based on the geometry of the environment, we calculated the vanishing-point (VP), i.e. a point on an image plane where the two-dimensional projections of parallel lines in three-dimensional space appear to converge. The VP served as a fixed reference point for all gaze-fixations detected by the eye-tracker. **Results:** In the normal walking condition, participants walked significantly faster (MD 0.169 m/s ± SE 0.013, $p<0.001$) and looked further ahead (MD 7.32 percent ± 1.76SE, $p<0.001$) onto the future path (i.e. closer to the VP) than they did in the perturbed condition. [HBO] increased and [HHB] decreased during perturbed walking (MD 0.277µmol ± 0.095SE, $p=0.004$; -0.063µmol ± 0.031SE, $p=0.043$, respectively) compared to the normal walking condition. **Discussion:** We interpret the decrease in walking velocity, caused by the perturbations, as indicative of a change in walking strategy due to an increase in the perceived challenge. This notion is supported by the increase in PFC activity, as indicated by the increase in [HBO] and decrease in [HHB], signifying that walking-control has shifted from "automatic" to "executive" control. Gaze-fixations were also affected by this increase in perceived challenge and were more often directed at the walking surface (i.e. downward-gazing), presumably to acquire information about the terrain. **Conclusions:** Walking with mechanical, unpredictable perturbations shifts walking from "automatic" to "executive" control, possibly due to the need to acquire visual information about the walking surface.

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The Effect of Tactile and Kinesthetic Uncertainty on Stiffness Perception

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When manipulating objects, tactile and kinesthetic information are used to estimate their mechanical properties and create our perception. Artificial skin stretch has been shown to increase the perceived stiffness of objects, yet how tactile and kinesthetic information are combined is currently unknown. Previous studies proposed that humans combine visual and haptic information via maximum likelihood integration. We set out to find if this is true for the integration of tactile and kinesthetic information as well. To accomplish this, we decided to implement two ways of manipulating the uncertainty in the haptic feedback in order to affect the weighting between the tactile and kinesthetic modalities. Firstly, we added sinusoidal noise to the tactile signal. We designed a stiffness discrimination task in which participants (N=25) received varying levels of kinesthetic (load force) and tactile (skin stretch) information by probing virtual objects. We found that the artificial skin stretch, both with and without the sinusoidal tactile noise, increased the perceived stiffness, however with no significant difference between them. These results indicate either that the tactile and kinesthetic information are not integrated according to maximum likelihood, or that the participants interpreted the tactile noise as stronger stimulation rather than as uncertainty. To distinguish between these explanations, we decided to introduce uncertainty into the tactile signal using a second method: by varying the tactile information between consecutive probes of the same virtual object. Prior to conducting the experiment with variability in the tactile feedback, we investigated the effect of between-probe variability in the kinesthetic feedback on stiffness perception. Similar to the first experiment, we used a stiffness discrimination task in which the level of stiffness in each probe was selected from a normal distribution with an identical mean and four levels of standard deviation (zero, low, medium and high). Our results indicate that the medium level of between-probe variability lead to greater uncertainty than the zero variability level. Contrarily, the low and high levels of variability did not affect the uncertainty. Based on these results, we will design an experimental protocol in which we introduce a sufficient, but not too high, level of between-probe variability into the tactile information.

Stochastic motion modeling of the effects of elbow spasticity on reaching in stroke

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Stochastic mixture models, e.g., Gaussian mixture models (GMM) can incorporate time, space, and variability within a single representation. They are therefore suitable for modeling human motion. Moreover, advanced goodness-of-fit measures can be used for assessing the similarity between GMMs, thus facilitating the use of this modeling technique for measuring various motion related phenomena. Classical, maximum likelihood goodness-of-fit methods cannot be used due to the multivariate nature of the distribution, yet alternative measures exist, such as the bi-directional Kullback-Liebler Divergence (BKLD) and Hellinger's distance. Since there is no closed form for the log likelihood of mixture of two or more Gaussians, the measures cannot be directly computed but highly accurate estimates are available. BKLD can be estimated using Monte Carlo integration and Hellinger's distance can be estimated based on the unscented Hellinger's distance. By using the unscented transform we create an expectation function of nonlinear transduction which is much easier and faster to approximate due to existing generic solutions. Hellinger's distance is bounded between 0 and 1, and is therefore simple to interpret but susceptible to ceiling effects. In contrast, BKLD only has a lower limit, and is thus less easy to interpret while being less susceptible to ceiling effects. We applied GMMs for assessing the influence of elbow spasticity on reaching kinematics in subjects with sub-acute stroke. Spasticity, a motor disorder common following stroke, is characterized by a velocity-dependent increase in the stretch-reflex. The effects of spasticity on reaching kinematics are poorly quantified using current methods, and stochastic models offer a highly suitable alternative. Thirteen healthy age-matched controls and 35 subjects with stroke performed reach-to-grasp movements towards 4 targets placed on a table before them. Arm motion during reaching was recorded using electromagnetic sensors (G4™ Polhemus). Elbow spasticity was quantified using the tonic stretch-reflex threshold (TSRT), the velocity sensitivity of the response (μ), and the Modified Ashworth Scale (MAS). GMMs were constructed from motion trajectories using expectation maximization, initialized by K-means. GMMs of subjects with stroke were compared with the nearest neighbor method to GMMs of controls using Hellinger's distance and BKLD. Results suggest that both Hellinger's distance and BKLD are explained by the interaction between target location, TSRT, and μ. Measures are also explained by flexor MAS, target location, and their interaction. Thus, the method may be sensitive to quantify improvements in underlying motor control mechanisms during recovery of reaching movements in people with stroke.

Cerebellar climbing fibers encode expected reward size

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Climbing fiber inputs to the cerebellum encode error signals that instruct learning. Recently, evidence has accumulated to suggest that the cerebellum is also involved in the processing of reward. To study how rewarding events are encoded, we recorded the activity of climbing fibers when monkeys were engaged in an eye movement task. At the beginning of each trial, the monkeys were cued the size of the reward that would be delivered upon successful completion of the trial. We found increased climbing fiber activity during cue presentation when information about reward size was first made available. Reward size did not modulate activity at reward delivery. These results indicate that climbing fibers encode the expected reward size and suggest a general role of the cerebellum in associative learning beyond error correction.

Postural responses to unstable conditions and external perturbations while sitting and standing in Parkinson's disease

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Postural responses to unstable conditions or imposed perturbations are important predictors of the risk of falling and can reveal balance problems in people with neurological disorders, such as Parkinson's Disease (PD). Postural instability is one of the most common symptoms of PD, which has a fall rate five times higher than seen in age-matched controls. Specifically, people with PD responded to perturbation with abnormal muscle co-activations. Moreover, PD people rely more on visual feedback for maintaining balance and also assume abnormal postures with the entire body, including the trunk. Here, we tested ten people with PD (two female) and ten age-matched controls to provide a comprehensive evaluation of their postural responses in different tasks. Participants stood or sat on Hunova platform (Movendo Technology srl, Genoa, IT). We first evaluated performances of participants during static balance, i.e. while maintaining the upright posture with eyes open and closed. Then, we tested them in unstable conditions, both standing and sitting. The seated condition was again tested with eyes open and closed. Finally, we investigated how subjects react to forward, rightward and leftward inclinations of the platform on which they were standing with eyes open. In the unstable task the device simulated a plate (corresponding to the feet platform or to an unsupported seat) with a central pivot and a tilting elastic force field that tends to restore the horizontal position of the platform, while in the second case, the foot platform moved according to a pre-programmed angular rotation reaching 6 degrees in 300 ms and going back to the horizontal position. During all these tests, Hunova device measured the inclination of the platform and the displacement of the center of pressure, while the trunk movements were recorded with an inertial measurement unit placed on the sternum. Participants with PD had worse performance when they were standing under unperturbed conditions, as well as when they were standing and sitting on the unstable platforms. Although, as expected, both PD subjects and controls had worse performance with eyes closed, this degraded performance in the absence of visual feedback was not influenced by the disease, neither in the unperturbed condition nor while sitting on the unstable platform. As for the imposed perturbations, the two populations responded differently to the inclination in the forward direction and specifically, to the second part of the perturbation, when the device moved backward to return in the initial position.

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Conflict of interest: A.D.L., V.S., C.S. and J.S. works for Movendo Technology company that commercializes the Hunova robotic device used in this study. The other authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Linking cognition and action: cognitive processes during adaptation to visuomotor rotations

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Aims

Generally, two main processes are assumed to operate during adaptation to visuomotor rotations: a fast explicit process, which learns rapidly, requires long preparation times and is driven by task performance error (TE). The second is a slow implicit process that is temporally stable, expressible at low reaction times and driven by both TE and sensory prediction error (SPE), the discrepancy between the expected and observed sensory consequences of a given motor command. Recent studies have started questioning the two-process model, suggesting the presence of multiple explicit and implicit components. The goal of the present study was to dissociate between two implicit components of motor adaptation and show that different components are derived from distinct error signals.

Methods

We imposed an invariant rotation on the feedback cursor while varying the target size. This way, we eliminated TE while still inducing adaptation. Furthermore, we introduced a test phase in which subjects were exposed to variable waiting times, which would enable us to separate between labile and stable implicit components.

Results

Preliminary data confirmed previous findings: we found one TE-driven implicit component and another component, which is driven by SPE. Moreover, we found the TE-driven component to be labile (instable across breaks) and the SPE-driven component to be stable.

Conclusion

Thus, the assumption of a two-process account of adaptation, and with it, the assumption of additivity of components should be reconsidered. The present finding need to be confirmed by computational architectures based on the updated adaptation model.

Group Synchrony and Coordinated Movement Impairments in ASD

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From simple routine behaviors, such as walking together along the street, to more complex and planned actions, such as mutual dance, our daily lives involve continuous social interactions that require synchronizing with others. It has been previously shown that synchrony plays a role in the formation of effective social interaction by promoting positive social outcomes such as affiliation, cooperation and rapport. In typically developing individuals, group synchronization emerges spontaneously and subconsciously, whereas in individuals with Autism Spectrum Disorder (ASD) previous reports indicate aberrant dyadic synchrony. Thus far, little is known about the connection between the behavioral and neural manifestations of synchrony, and even more so, about the effect of ASD on the ability to simultaneously synchronize with multiple partners. The purpose of the present study was to compare the ability of individuals with high and low autistic traits to synchronize with the group and to examine the neural underpinnings of synchrony during virtual interaction. We hypothesized that impaired group synchrony will be found in individuals with high autistic traits, and that these behavioral impairments will correlate with a decreased neural synchronization in the interior frontal gyrus (IFG), a brain region associated with body alignment and perspective taking. We used a novel computerized task in which groups of four participants, each represented as a colored circle on the computer screen, were instructed to either: i) move freely [Free Movement condition (FM)] or (ii) move in synchrony [Intentional Synchrony condition (IS)]. Synchrony was measured using the mean directional correlations between each participant's movements and the movements of the other participants. In experiment 1, we found a significant effect for condition type, indicating that individuals were less synchronized with the group in the FM condition, confirming the task's validity. Moreover, we found a significant interaction effect between the condition type and the level of autistic traits, indicating that individuals with high, compared to low autistic traits, were less synchronized with the group, in the IS condition. In experiment 2, we measured the brain activity of two interacting partners simultaneously, using functional infrared spectroscopy (fNIRS). Wavelet transform coherence (WTC) analysis of the fNIRS data show interbrain synchrony in the IFG during IS. Results demonstrate that movement synchronization can be measured at both behavioral and neural levels and can possibly differentiate those who are impaired in their ability to sync with the group.

Introducing self-scaffolding to reinforcement learning of haptic Exploration

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Over the course of development characterized by an increasing motor control mastery, humans acquire goal-directed haptic exploration capabilities. This process results in a restricted set of optimized haptic exploration patterns, the so-called exploratory procedures (EPs) [1]. However, due to a high complexity of the three-dimensional environment that surrounds us, haptic exploration is still a great challenge even for very advanced robotic platforms. In our work we investigate a question: how to master motor control to perform haptic exploration with a predefined robot morphology? We propose a computational approach that learns a strongly restricted model of haptic attention by optimizing motor control for a tactile sensor array Myrmex [2]. To this end, we train a neural network architecture to represents a haptic exploration policy. We employ the REINFORCE algorithm. The resulting policy controls the pose of a simulated floating rigid tactile sensor array in a simulated 3D environment. As a proof-of-concept task we employ haptic object identification that is conducted in an environment consisting of four simple three-dimensional geometrical shapes.

The resulting exploration performed by the sensor array optimizes the haptic information intake for the given sensor morphology and could therefore be considered to be a sensor-specific exploratory procedure. The innovative aspects of our approach are threefold. Firstly, we employ the concept of haptic glaces [3] as a foundation for our control policy. Secondly, we perform optimization of both attention and motor control based on a multi-module neuronal network architecture inspired by the recurrent attention model (RAM) [7]. Finally, we extend our previous work [4], [5], [6] based on RAM with a self-scaffolding mechanism. We do this by extending the architecture with an extra belief network sub-module to decide about the length of the haptic exploration sequences.

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Using analogies to improve motor control

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Analogies have been shown to improve motor learning in various tasks and settings. In this study we aim to apply this method to motor control, investigating movement primitives and strategy preference. We tested if the use of analogies has an effect on movement kinematics and task outcomes. This study will open additional perspectives on the ways in which cognitive processes including attention, consciousness and imagination influence motor control.

For this purpose we used a point-to-point task, in which subjects drew lines to connect dots. The movement of the pen on a tablet was recorded and analyzed for coarticulation and movement duration. All subjects were instructed to connect the dots with as much speed and precision as possible. In addition, half of the subjects were told to imagine they are working with a paint brush, and their goal is to avoid leaving water marks on the dots.

Subjects who received the verbal analogy showed a significant improvement in a measure of coarticulation ($p<0.05$). However, no difference in movement duration was observed between the groups, i.e. the use of the analogy caused subjects to change their movement strategy while taking the same amount of time to complete the task.

We conclude that a verbal analogy can be a useful tool for changing motor kinematics and movement strategy. It remains to be determined why the path changed while the duration of the movement stayed the same, but this finding suggests improvements in these different facets of performance may be independent.

Markerless gait analysis based on deep learning technique: preliminary results

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Measuring and understanding human motion is an essential task in several domains, ranging from neuroscience to rehabilitation and sports biomechanics. Quantitative information is fundamental to study how our Central Nervous System controls and organizes movements, as well as to evaluate performance and deficits. Recently, this field has made important progress. In the motor control and clinical field, the technology that provide useful and accurate quantitative measures is based on marker systems. However, markers are intrusive, their number and location are determined a priori, and they can modify the naturalness of subjects' movements. Last, they are computationally expensive in time and space. For these reasons would be important to find out a robust and reliable markerless system that allow extracting quantitative information about human motion. Recent advances on markerless pose estimation based on computer vision and deep neural networks are opening the possibility of adopting efficient methods for extracting movement information from RGB video data. In this work we focus on the study of gait analysis. The evaluation of kinematics parameters during gait is also important for monitoring orthopedic problems and neurological diseases. We used two different databases composed by frontal and lateral gait videos of people without motor deficits and stroke survivors. The first step was to automatically recognize the anatomical points of interest (hip, knee, ankle and foot) in each video. To do that we adopted a program called DeepLabCut that uses a variant of Residual deep network (ResNet-50) allowing the extraction of specific features after appropriate fine tuning. At the end a deconvolutional layer is added to extract spatial density probability. We selected 5 frames in the videos and we manually labeled the points of interest in order to use this information to train the neural network to recognize them. DeepLabCut allows us to efficiently train a network using less than 200 input images since it initializes the weights of the network with the ones obtained by training it on the ImageNet dataset. The goal is to obtain a network that can recognize the anatomical features for the whole duration of each video in our dataset. Once we have the coordinates of each point in image coordinates it is possible to compute the value of the joint angles for a gait cycle. The purpose is to compare these values with the ones obtained with the standard marker-based gait analysis for the same instance of walk.

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EEG beta power modulation during upper-limb reaching movements is not affected by age

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Movement planning and execution are associated with beta EEG power modulation (15-30 Hz) over the sensorimotor areas. Beta power decreases during the planning phase, reaches a minimum during the movement itself (event-related desynchronization, ERD) and rebounds with a maximum when the movement ends (event-related synchronization, ERS). We previously found that, in a group of subjects older than 50, beta modulation increased during one-hour practice block over two Regions of Interest (ROIs), a left and a frontal cluster, and returned to baseline values 24 hours later. Here we determined whether younger subjects display similar practice-dependent increases. A group of thirteen younger subjects (age range 20-36 years) and a group of thirteen older healthy subjects (age range 42-68 years) performed planar reaching movements (15 sets of 56 movements each) for one-hour while high density EEG activity was recorded. Performance indices improved during practice: total movement time and hand-path area (area included in the trajectory normalized by path length) significantly decreased across sets. We also found that total movement time, hand-path area and peak velocity were significantly worse in the older group. EEG data showed that in both groups beta modulation and ERS significantly increased across sets in the two ROIs without group difference. Additionally, the frontal ROI showed a significant ERD increase across sets. Timing analysis revealed a progressive delay of the ERS that correlated with total movement time. Altogether these results suggest that, first, despite the differences in performance indices, age does significantly affect practice-related beta modulation changes, at least in the age ranges we explored. We thus conclude that beta modulation is not linked to on-line performance changes, but it might reflect saturation of cortical excitability and plasticity-related phenomena. Further studies are needed to explore other age ranges.

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Multiplexing rhythmic information by spike timing dependent plasticity

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Rhythmic activity has been associated with a wide range of cognitive processes including the encoding of sensory information, navigation, the transfer of emotional information and more. Past studies have shown that spike timing dependent plasticity (STDP) can facilitate the transfer of rhythmic activity downstream along the information processing pathway. However, STDP has also been known to generate strong winner-take-all like competition between subgroups of correlated synaptic inputs. Consequently, one might expect that STDP will induce strong competition between different rhythmicity channels; thus, preventing the multiplexing of information across different frequency channels.

Here we ask: **Can STDP facilitate the multiplexing of information across different frequency channels, and if so, under what conditions?**

This question was addressed using the framework of a modelling study. We investigated the STDP dynamics of two competing sub-populations of neurons that synapse in a feedforward manner into a single post-synaptic neuron. Each sub-population was assumed to oscillate in an independent manner and in a different frequency band. First, a mean field Fokker-Planck theory was developed in the limit of slow learning. Surprisingly, our theory predicted limited interaction between the different sub-groups. Next, we generalized our results beyond the simplistic model using numerical simulations. We found that STDP can facilitate the multiplexing of rhythmic information across different frequency channels. Our theory further reveals that the interaction between those channels is mainly mediated by the shared component of mean (DC) activity. Thus, in a purely feed-forward architecture of excitatory neurons that relies on STDP to transmit the rhythmic signal downstream, modulation depth is expected to decrease in the downstream layer.

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Multimodal Human-Computer Interface Based on Artificial Intelligence for Rehabilitation of People with Motor Disorders

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There are millions of people with movement disabilities, however, modern medical and technical solutions have very limited capability to restore lost motor skills (Rehabilitation 2030 WHO, 2017). The objective of the project is to develop a novel solution to improve the quality of life of people with severe movement deficits. The solution is a multimodal human-computer interface system for touchless control of devices and motor rehabilitation, which performs decoding of brain and body signals using artificial intelligence methods. The project aims to solve the problem of improving efficiency of rehabilitation for patients with motor disorders (after stroke, spinal cord injury, and traumatic brain injury) using a non-invasive, portable and affordable system.

A multimodal real-time system combining brain and body signal analysis has been developed. It is based on parallel acquisition and decoding of electroencephalograph (EEG) and inertial measurement unit (IMU) signals and mutual validation of decoded motor commands. The system performs the following main steps: (1) real time acquisition of EEG and IMU signals; (2) signal preprocessing; (3) advanced feature extraction (including principal component analysis and spectrum analysis); (4) automatic feature selection; (5) decoding of motor commands by means of classifiers based on machine learning; and (6) control of devices. A detailed block diagram of the system is shown in the figure below.

Most of target users – people with severe motor disorders can still make small residual movements, e.g. movements of shoulders. For movement data acquisition two IMU sensors were placed on two shoulders inside special bracelets. Four types of shoulder movements and rest were recorded. Filtering, time-series analysis and principal component analysis were performed on the 14-dimensional data to decrease its dimensionality to two dimensions. Descriptive features, such as kinematic landmarks and velocity peaks, were extracted from the first principal component for each IMU. A classifier based on machine learning was trained and tested for each subject (5-fold cross-validation was performed). The mean classification accuracy was 95%. Decoded motor commands in real time might be applied to control of assistive devices and specialized applications. The basic principle of the multimodal system is to use mutual validation of motor command decoding obtained from both IMU and EEG pattern recognition. If one classifier recognizes the pattern corresponding to a motor command, the other classifier has to validate it, with minimal time delays. Within the scope of the project special neurofeedback applications in game form were developed and paired with the prototype.

Vigorous exercise and components of motor learning in healthy adults

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Background: Vigorous exercise in the form of a single session of aerobic training might enhance neuroplasticity, which is important for improvement of motor-skill learning. In continuation of previous studies that were conducted mainly on upper-limb tasks and cognitive domains, we want to examine and verify the effects of a single session of vigorous exercise on motor-learning ability with reference to locomotor coordination and adaptation.

Objectives: The aim of this study was to examine, by means of "adaptation" measures and "after-effect" measures, the effects of a single session of vigorous exercise on lower-extremity coordination and on motor learning abilities in healthy young adults.

Methods: 20 healthy young adults (ages 25.6 ± 1.84 years) were recruited and randomly allocated to an experimental group (n=10) or control group (n=10). Both groups underwent two sessions of walking conducted one week apart. They walked on a split-belt treadmill to generate step-length symmetry measures. In the first session, participants performed a locomotor-learning test on a split-belt treadmill and a lower-limb coordination test (LEMOCOT) establishing base-line measures before and after walking; the experimental group, however, did an additional 10 minutes of vigorous walking (65-75% HR_{max}) on a regular treadmill before the second LEMOCOT and locomotor-learning test were administered. One week later, both groups again underwent a locomotor-learning test on a split-belt treadmill and LEMOCOT to assess retention.

Outcome measures: The measures recorded were step-length symmetry adaptation and step-length symmetry post-adaptation, as well as the lower-limb coordination test scores.

Results: Two analyses— based on survival analysis models and logistic regression— were performed to examine adaptation and post-adaptation measures. The survival analysis demonstrated a group effect $p<0.01$, without significant interaction; this difference between the two groups remained unchanged throughout the other two time points. The logistic regression found none of the effects to be statistically significant. The results of the Poisson regression analysis were statistically significant over time ($p<0.01$) and in their correlation to the LEMOCOT results.

Conclusions: While a comparison of the results from the single session of vigorous exercise in the test group and control group did not indicate effects on elements of motor learning, locomotor coordination within each group showed significant improvement over time. These results are consistent with other studies that examine plasticity in the upper-limb cortical representation following a single session of aerobic exercise. These findings suggest that further studies with large sample sizes are needed to understand the frequency and duration of exercise required to influence brain plasticity.

Motor and Visual Representations by Single Neurons in the Human Subthalamic Nucleus and Globus Pallidus Internus

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The subthalamic nucleus (STN) and globus pallidus internus (GPi) are important parts of the human motor control system. However, unlike the primary motor cortex, where a well-known model relates single neuron activity with motor activity, the precise encoding employed by single neurons in the STN and GPi is still an open issue.

Our goal is to understand and compare the neuronal encoding of manual reaching movements and visual movements in these brain regions, focusing on relations of single-neuron activity to kinematic parameters (velocity, acceleration and position) and to direction of hand movement.

We intraoperatively recorded single unit activity in 17 patients with Parkinson's disease (PD) undergoing implantation of deep brain stimulator (DBS), while performing hand movements in four directions (“*Center-Out”)*.

We found single neurons in both brain regions whose activity directly encodes the aforementioned parameters of the end-effector in both actual hand movements and visual movements. In the STN, a significantly larger percent of responsive neurons was observed during actual (72%) than visual movements (27%), whereas in the GPi this percentage was similar (actual: 60%; visual: 50%). In the STN, almost half of the units encoded a specific kinematic parameter independently of the other parameters during actual movements (46%), but not during visual ones (4%). In the GPi, the percentage during actual movements was similar (44%) to the STN, but specificity to a specific kinematic parameter was much higher (20%) during visual movement. Units that combine both directional and kinematic responses (in the same unit) were common in the STN during actual movements (31%) but not visual ones (2%). In the GPi, however, the percentage was much lower (16%) during actual movements, but much higher (10%) during visual ones.

The percentage of neurons correlated with kinematic parameters during actual movements with negative time-lags (i.e., neuronal activity preceding movement) was significantly larger in the STN than in the GPi. However, during visual movements, the percentage of neurons correlated with kinematic parameters was significantly larger in the GPi than in the STN.

These findings show greater subthalamic involvement in actual movement, and specifically in motor planning, than the GPi, and greater involvement of the GPi in visual movements. Our study thus provides better understanding of the roles of the STN and GPi in motor control and visual processing of movement and may pave the way to better targeting DBS electrodes for specific PD symptoms and to avoid DBS side effects.

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Adaptation of muscle synergies in transition between interaction with stable and unstable virtual environments

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One of the current progress-impeding challenges in teleoperation is the absence of force feedback to the operators. This limits the information that the operator can get back from the remote environment and thus limits the tasks that could be performed using teleoperated robotic systems. State-of-the-art teleoperation with force feedback suffers from a conservative design due to the problem of instability. However, such conservative approaches ignore the potentially stabilizing contribution of human manipulation. To incorporate a model of the stabilizing input of the human neuromuscular control into the control of these systems, we need to model the human motor control during physical interaction with unstable systems.

A fundamental idea in the neuromuscular control of movement is Muscle Synergies. According to the muscle synergies hypothesis, the complicated task of motor control is simplified by using pre-set groups of muscles whom the CNS activates together for the creation of movements. In this work, we investigate whether the muscle synergies may be different when humans interact with stable haptic simulations compared to when they interact with unstable haptic simulations. Other papers that investigated changes in muscle synergies reached a conclusion that these synergies may change following physiological changes such as neurological diseases or following training for special capabilities like dancing. We investigated whether the number and the composition of the synergies changed when participants interacted with elastic objects with and without delay.

20 participants interacted with stable and unstable virtual elastic force fields, and we recorded their movement and the activities of 16 muscles of the arm. Muscle synergies can be described by two separate models, time variant and synchronous synergies. In this work, we employed Non-negative Matrix Factorization to extract synchronous synergies from the recorded muscle activations. We found that the composition but not the number of synergies was affected by the stability conditions. We discuss the implications of our results on understanding the control of movement as well as on the field of teleoperation.

Motor learning decline with age is related to differences in the explicit memory system

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The ability to adapt one's movements to changes in the environment is markedly changed across the lifespan. Although traditionally regarded as an 'implicit' process, recent research has linked motor adaptation and its reduction with age to differences in 'explicit' learning processes. Here, we examine the differences in brain structure that underlie reduced adaptation with age. A large population-based cohort from the Cambridge Centre for Ageing and Neuroscience (n=322, aged 18-89 years) performed a visuomotor learning task and underwent structural MRI scans. A whole-brain analysis showed that reduced movement adaptation with age was associated with age-related reduction in grey matter volume in striatal and sensorimotor cortical regions, but not in the cerebellum. Moreover, positive interactions between age and grey matter volume in the medial temporal lobe, hippocampus and amygdala showed that grey matter volume in these regions became a stronger positive determinant of adaptation in older adults. Post hoc behavioural analyses showed similar interactions between age and scores on two independent explicit memory tasks. These results support the notion that cerebellar-based learning is largely unaffected in old age, and show that age-related differences in the explicit memory system contribute to the decline in motor adaptation in older age.

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Different Sensorimotor Information about Movement Errors Affects Unwanted Movements Variability

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Motor adaptation involves learning from errors and this requires estimating the errors. In order to achieve optimal error estimation, people must weight different sources of sensory information. However, little is known about how information about errors coming from different modalities affects motor performance. Our goal is to characterize the effects of weighting of visual and proprioceptive inputs and how this reflects the noise in each signal. To predict how different types of feedback will change movement accuracy and variability, we adapted the equations of the well-established trial-to-trial adaptation model (Donchin, Francis, & Shadmehr, 2003) and used it predict the results of changing the weighting of sensory information on movement errors. Our model predicted that eliminating visual feedback on errors will increase movement variability and decrease adaptation more than in a case in which there is no visual input at all. We used an experiment to test our prediction. During the experiment, the participants held a robotic handle and performed targeted reaching movements. The sensory information on error was manipulated using two visual feedback conditions: (1) Visual Clamp – A false visual feedback that eliminated all visual directional errors; (2) No Visual – No visual feedback. In the Visual Clamp condition, the hand moves freely but there are no visible errors. The results of the experiment (N = 26) match the prediction that giving false visual feedback or not giving visual feedback at all will increase the variability of the movements. However, we did not see much difference in variability between the Visual Clamp condition to the No Visual condition, in contrast to the model's prediction.