Research Workshop of the Israel Science Foundation
Ein Gedi, June 12-14 2011
Ben Gurion University, June 15 2011

The Seventh Annual Computational Motor Control Workshop
Ben Gurion University
June 16 2011

Dear Colleagues,

In what has now become a tradition, we wish to invite you to participate in the Seventh annual **Ben-Gurion University Workshop on Computational Motor Control** on **June 15-16, 2011**, in the W. A. Minkoff Senate Hall at Ben-Gurion University of the Negev, Beer-Sheva, Israel.

This year we will host a workshop sponsored by the Israeli Science Foundation (ISF) in Ein Gedi and BGU June 12-14 that will precede our usual one day workshop. Poster presenters are invited to post their posters at both.

Overview: The nervous system analyses sensory information and orchestrates motor commands. In so doing, it faces challenges that it shares with many artificially engineered systems. In the spirit of the classic field of cybernetics, the field of computational motor control makes scientific and technological progress simultaneously by exploring the differences between artificial control theory and biological motor control.

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

The ISF workshop will include longer presentations and panel discussions while the one-day workshop will consist of many short talks.

Thank you for your attention,

Opher Donchin and Amir Karniel

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- The Dean of the Faculty of Engineering, BGU

Program*

*Subject to Changes

Sunday June, 12, ISF workshop, Ein Gedi

9:30 -10:30	**Registration - Coffee**

Opening session – Simulated Movement and Moving **Amichai Hall**

Chairperson: Gerry Loeb (University of Southern California, Los Angeles)

10:30–11:00	**Simulated Behavior and Behavior** Amir Karniel (BGU) **Reaction Conducted** by Opher Donchin (BGU	p.1
11:00-11:30	**Simulated Physiology and Physiology** Opher Donchin (BGU)) **Reaction Conducted** by Amir Karniel (BGU)	p.2
11:30-12:00	**Break**	
12:00-12:30	**Panel – Simulated Movement and Moving What is the Difference?** Tamar Flash (Weizmann), Neville Hogan (MIT), Gerry Loeb (USC)	
12:30-13:10	**Movement Feldenkrais Lesson I** Dr. Eilat Almagor (The Rubin Academy of Music and Dance, Jerusalem)	
13:20	**Tour to Matzada, Ein Bokek and the Dead Sea** Guide: Ittai Herrmann	
	Dinner time	

Monday June, 13, ISF workshop, Ein Gedi

Session Spinal Cord — **Amichai Hall**

Chairperson: Dagmar Sternad (Northeastern University, Boston)

9:30-10:20	**Spinal Circuitry Makes Motor Control Easy to do But Hard to Understand** Gerry Loeb (University of Southern California, Los Angeles)	p.3
10:20-11:10	**Temporal Properties of Motor Actions** Yifat Prut (Hebrew University, Jerusalem)	p.4
11:10-11:40	**Break**	
11:40-12:30	**Reconfiguration of Motoneuron Input-Output Properties for Different Motor Tasks** Charles J Heckman (Northwestern University, Chicago)	p.5
12:30-13:10	**Movement Feldenkrais Lesson II** Eilat Almagor (The Rubin Academy of Music and Dance, Jerusalem)	
	Lunch break	

Session: Motor Planning, Learning and Control — **Amichai Hall**

Chairperson: Amir Karniel (BGU)

15:00-15:50	**Stability and Variability in Learning an Interactive Task** Dagmar Sternad (Northeastern University, Boston)	p.6
15:50-16:40	**On Motion Planning And Coordination at The Intrinsic Joint and Body Levels: Computational Models and Brain Mapping Studies** Tamar Flash (Weizmann Institute, Rehovot)	p.7
16:40 -17:10	**Break**	
17:10-18:00	**Movement Planning in the Frontoparietal Reach Network** Alexander Gail (Deutsches Primatenzentrum, Göttingen)	p.8
18:00-18:40	**Panel** Charles J Heckman (Northwestern University, Chicago) Tamar Flash (Weizmann Institute, Rehovot) Alexander Gail (Deutsches Primatenzentrum, Göttingen), Amir Karniel (BGU), Gerry Loeb (University of Southern California, Los Angeles), Yifat Prut (Hebrew University, Jerusalem) , Dagmar Sternad (Northeastern University, Boston)	
	Dinner time	

Tuesday June, 14, ISF workshop, Ein Gedi

Session: Analysis and Synthesis of Motor Behavior in Human Machine Interfaces and Teleoperation Systems — **Amichai Hall**

Chairperson: Miriam Reiner (Technion, Haifa)

9:30-10:20	**Perception, Action and Interactions between Time and Space Representations** Amir Karniel (BGU)	p.9
10:20-11:10	**Towards Haptic Human-Robot Interaction - How to Learn from Human Dyads** Angelika Peer (Technische Universität München, Munich)	p.10
11:10 -11:40	**Break**	
11:40 -12:30	**Application of the Rubber Hand Illusion to Motor Learning in a Hapto-Visual Virtual Environment** Miriam Reiner (Technion, Haifa)	p.11
12:30 -13:10	**Movement Feldenkrais Lesson III** Eilat Almagor (The Rubin Academy of Music and Dance, Jerusalem)	
	Lunch Break	

Session: Movements and Costs- the Cortico-Basal Ganglia Loops — **Amichai Hall**

Chairperson: Opher Donchin (BGU)

15:00 - 15:50	**Physiological Investigations into Human Probabilistic and Reward Based Motor Learning** John Rothwell (University College London, London)	p.12
15:50 - 16:40	**Gain-cost Optimization Rather than Reward Maximization in the Basal Ganglia Network** Hagai Bergman (Hebrew University, Jerusalem)	p.13
16:40-17:10	**Break**	
20:00	**Full Moon Havarim Stream Hike** Guide: Eitan Krokovski	
24:00	Check in Leonardo Plaza *AKA* Golden Tulip Beer-Sheva	

Wednesday June 15, ISF workshop, BGU Beer-Sheva

	Free morning Free Lunch time (on your own).	
13:30-14:00	**Poster Placement and Coffee**	
14:00-14:10	**Opening of the ISF-BGU afternoon session** Amir Karniel	**W. A. Minkoff Senate Hall**
14:10-15:00	**Understanding Haptics by Evolving Mechatronic Systems** Gerry Loeb (University Southern California, Los Angeles)	p.14
15:00-15:20	**Break (Posters)**	
15:20-16:10	**Frames in Locomotion, Kinematics and Planning** Daniel Bennequin (University Paris 7, and LPPA College-de-France)	p.15
16:10-17:00	**Participation of the Motor Cortex in Feed-Forward Control of Motor Actions, Learning and Kinesthesia in Humans** Anatol Feldman (University of Montreal, Montreal)	p.16
17:00 -18:00	Lab Visits (Karniel, Donchin, other labs at BGU)	
19:00	**Dinner**	

Thursday June 16, ISF workshop, BGU Beer-Sheva

8:20-8:50	**Registration, Poster Placement and Break**

8:50-9:00 **Greetings** – Dr. Amir Karniel, Head of the Organizing Committee, BGU

9:00-9:10 **Opening remarks** – Prof. Rivka Carmi, President, BGU

Session title: Planning movements **W. A. Minkoff Senate Hall**

Chairperson: John Rothwell (University College London, London)

9:10-9:40 **Coordinate Frames and Metric Structures in Motor Control Models** p.17
Neville Hogan (Massachusetts Institute of Technology, Cambridge)

9:40-10:10 **Optimal Selection of Arm Movements During Evidence Accumulation** p.18
Jason Friedman (Macquarie University, Sydney)

10:10-10:20 **Discussion**

10:20-11:00	**Poster Session and Break**

Session: Rehabilitation **W. A. Minkoff Senate Hall**

Chairperson: Anatol Feldman (University of Montreal, Montreal)

11:00-11:30 **Robotic Orthoses: A Perspective for the Rehabilitation of Upperlimb Synergies at Joint Level** p.19
Roby-Brami Agnès (Université Paris Descartes, Paris)

11:30-12:00 **Brain Stimulation Interventions and Their Potential**
John Rothwell (University College London, London)

12:00-12:30 **Neurocorrelates of Movements as measured with EEG** p..20
Ulrich Hoffmann (TECNALIA, Spain)

12:30-12:40 **Discussion**

12:40-14:40	**Posters Session and Lunch**

Session title: From Neural representation to movement primitives W. A. Minkoff Senate Hall

Chairperson: Dagmar Sternad (Northeastern University, Boston)

14:40-15:10	**Neural Responses to Disturbances and Novel Environments** Miriam Zacksenhous (Technion, Haifa)	p.21
15:10-15:40	**Sparse Decomposition for Decoding Movement Direction from the Activity of Multiple Neurons in The Human Frontal Lobe** Ariel Tankus (Department of Biomedical Engineering, Technion - Israel Institute of Technology, Israel)	p.22
15:40-16:10	**Learning of Movement Primitives as Basis for the Analysis and Synthesis of Emotional Body Expressions** Martin Giese (University Clinic Tübingen, Tübingen)	p.23
16:10-16:20	**Discussion**	
16:20-16:30	**The Alpha Omega, Sensegraphics and NanInstuments Best poster and Travel Awards**	

16:30-17:00	**Posters Session and Break**

Session title: From Geometry to Physiology W. A. Minkoff Senate Hall

Chairperson: Gerry Loeb (University of Southern California, Los Angeles)

17:00-17:30	**Riemannian Geometric Approach to Human Arm Movements** Armin Biess (Max-Planck-Institute for Dynamics and Self-Organization, Goettingen)	p.24
17:30-18:00	**The Cerebellar Role in Motor Control and in The Motor Hierarchy** Opher Donchin (BGU)	p.25
18:00-18:10	**Discussion**	

19:00	**Dinner**

TOUR

Wadi Havarim Moon Rise

After having a taste of the Dead Sea region and the Judean desert it is time to experience something deferent now, Havarim wadi at night. A night walk in the wadi accompanied by the white rocks (the marl stone and the silt) shining under the moon rise with a fine tune to the sounds of silence.

The Havarim Stream is located in the Negev, an hour ride south to the city of Beer Sheva The Havarim Stream is one of the tributaries to Nahal Zin. The hike takes approximately 3 hours, it is not a difficult one and begins with a downhill to the beautiful canyon, it requires a fair ability of hiking to reach and walk through the narrow cracks.

It is recommended to bring comfortable clothes & shoes for the hike & a small bag pack for snacks (water will be provided).

Departure at 20:00 from the Hotel Lobby

See you there,

Eitan your tour guide

Lectures

Simulated Behavior and Behavior

Amir Karniel,
Department of Biomedical Engineering, Ben-Gurion University of the Negev, Beer-Sheva, Israel

In this workshop we intend to address issues related to the connection between simulated movements and motor control and real movements and motor control.
The Turing test provides a measure for our progress in artificial intelligence research based on questions and answers to a model and to a person; however, it is limited to the linguistic aspects of intelligence. The ultimate Turing-like test would be to build a robotic device with abilities indistinguishable from those of a human being.
I will briefly describe our a one dimensional Turing-like handshake test for motor intelligence (Karniel et al JoVE 46, 2010, doi:10.3791/2492) and report our comparison methods and the models submitted to the Tournament.
I will then extend the discussion to some open questions in computational motor control, and the engineering approach to neuroscience describing research hypotheses using engineering tools such as circuits or block diagrams, and control theory concepts such as servo control, clocks, internal models, intermittence control, and optimal feedback control.

This research is supported by ISF grant No 1018/08

Simulated Physiology and Physiology

Opher Donchin

Department of Biomedical Engineering and Zlotowski Center for Neuroscience Ben-Gurion University of the Negev

Models are ubiquitous in physiological research and theoreticians are an integral part of neuroscience today. Still, one might ask: what sort of physiological models are most useful and what is the appropriate relationship between the actual physiological research and the modeling. For the purpose of discussion, I will present two extreme ideas of the role models play. The first idea, and the one most commonly put forward, is that the essential function of models is to make predictions that can be tested by physiological experiments.

Another point of view -- incompatible only in its most extreme form -- is that the essential function of models is to communicate ideas.

Having created this false dichotomy for the purpose of illustration, I will champion the second position. I will illustrate my arguments by presenting a model of the oculomotor system that we have been developing. The model overturns earlier ideas about the function of different brain areas in oculomotor control and suggests that the optimal control framework -- currently popular in describing the voluntary motor system -- may also be relative to describe compensatory eye movements.

Spinal Circuitry Makes Motor Control Easy to Do But Hard to Understand

Professor Gerald E. Loeb, M.D., Giby Raphael, George Tsianos, Jared Goodner and Yao Li
Biomedical Engineering, University of Southern California, CA

It has been fashionable to interpret activity in motor cortex as directly computing and controlling aspects of motor performance that are easily measured, e.g. end-point position, velocity, force or activity of individual muscles. While this may be easy to understand, it would be hard for the nervous system to work this way. Little, if any, of the motor cortical output goes directly to most motoneurons and the remaining circuitry of the spinal cord does not seem suited to computing the nonlinear inverse dynamics required to transform end-point parameters into patterns of muscle activation. Instead of interpreting motor cortex from the top down, we are trying to understand it from the bottom up. We have constructed a fairly complete model of the known spinal interneuronal circuitry, where descending signals from brain are integrated with multimodal proprioceptive feedback and distributed to many motoneuron pools as both excitatory and inhibitory drive. We assume that the motor cortex evolves gradually (both phylogenetically and ontogenetically) to take advantage of the repertoire of motor coordination afforded by the spinal cord, which is capable of many stable and adaptive motor behaviors in the absence of any input from the brain. Simple trial-and-error learning algorithms have proven surprisingly effective in learning to generate command signals that generate natural looking behavior in model musculoskeletal systems, including a 2DOF wrist with four muscles and a 2DOF planar elbow-shoulder with six muscles. Despite the very high dimensionality of the control space (~200 adjustable gains for the wrist, ~400 for the elbow-shoulder), performance converges quickly and reliably. Rather than trying to find a globally optimal solution (which would be nearly impossible), the controller takes advantage of large numbers of “good enough” solutions that are distributed throughout the hyperspace. This is presumably a consequence of a nervous system that evolved to make it easy for organisms to learn new tasks quickly, which has obvious evolutionary advantages. Unfortunately for neuroscientists and control engineers, this design does not yield to analytical tools such as optimal control and forward and inverse dynamic models of the musculoskeletal plant.

REFERENCE: Raphael, G., Tsianos, G.A. and Loeb, G.E. Spinal-Like Regulator Facilitates Control of a Two-Degree-of-Freedom Wrist. The Journal of Neuroscience, 30(28):9431-9444 2010.

Temporal Properties of Motor Actions

Yifat Prut
Hebrew University, Jerusalem

Performing voluntary movements require interactions among multiple cortical and subcortical motor elements. It is assumed that the cortically derived motor command is further processed by downstream elements until it finally reaches muscles. The exact contribution of cortical vs. subcortical structures to the translation of motor commands into motor actions is still unclear. In this system, corticospinal interactions are considered to play a paramount role in executing motor actions, as revealed by the severe motor deficits emerging when this pathway is damaged. In recent years we have implemented a unique experimental paradigm in which electrophysiological recordings are made from the motor cortex and cervical spinal cord simultaneously while monkeys perform a wrist task. This makes it possible to track the evolution of motor commands along the motor cascade.
In the first part of the talk I will describe our findings on coordinate transformation in the motor system. I will show that just before movement onset, the coordinate frame of cortical neurons is in between extrinsic and intrinsic, while spinal neurons express a near-muscle (i.e., intrinsic) coordinate frame. Furthermore, during the time from cue onset to movement time, cortical neurons express a gradual shift in coordinate frame from extrinsic to intrinsic. A fully intrinsic frame is obtained only later when movement has already started. This implies that the transformation of the coordinate frame is first completed downstream of M1, and that motor cortical neurons dynamically integrate information from the available sources, by assigning a time-dependent weight to each of these sources.
In the second part of the talk I will describe that results we obtained from studying the response profile of cortical and spinal neurons. Here we found that cortical activity tends to be transient during periods of changes in motor states (onset and offset of active torque period). In contrast, spinal activity evolves after cortical activity, but provides a faithful signal of ongoing motor states. We suggest that cortical neurons cannot operate as a low-level controller for two reasons: the inadequate coordinate frame at which they operate, and their transient response properties which deviate from the required signal for activating muscles. Certain circuitry located downstream to M1 needs to rotate and integrate the descending cortical command to provide the appropriate muscle signal.
Finally, I will present our recent findings showing the excitatory-inhibitory impact exerted by the ascending pathways on motor cortical activity. The combined impact of these pathways may act to shape the cortical command into a transient signal which thus dictates the timing of actions.

Reconfiguration of Motoneuron Input-Output Properties for Different Motor Tasks

CJ Heckman and Michael Johnson
Northwestern University, Physiology, Physical Med. & Rehab, Physical Therapy & Human Movement Sciences, Chicago, USA.

Normal motor behavior comprises a diverse array of movement patterns. Motoneurons, which provide the motor output to muscle fibers needed for all movements, must thus receive an equally diverse set of motor commands. The textbook model of the motoneuron posits that its input-output properties are simple, consisting of a threshold to reach spiking (recruitment) and an increase in firing rate in response to increasing suprathreshold input (rate modulation). The underlying assumption is that this behavior is consistent across all motor tasks. This consistency is perhaps appealing from a computation standpoint, in that descending and sensory motor commands can “rely” on motoneuron behavior always being the same. Yet the past 20 years of research on motoneurons have demonstrated that their electrical properties are any but consistent. The main source of these differences in electrical behavior is neuromodulatory input. Probably the strongest neuromodulatory input to motoneurons is the monoaminergic system that originates in the brainstem and whose axons release either 5HT or NE onto motoneurons. The monoaminergic system markedly increases excitability in motoneurons, resulting in gain increases up to 5-fold. A major mechanism of this gain increase is via facilitation of persistent inward currents (PICs), which not only amplify synaptic input but also markedly prolong it. This prolongation is especially marked in low threshold, type S motoneurons, whose behavior can approach that of a neural integrator. Recent studies have established that local inhibitory circuits, especially Ia reciprocal inhibition, can control the PIC and allow the motoneuron to act as an amplifier instead of integrator. Moreover, recent studies also show that inputs mediated by glutamate NMDA receptors can induce membrane oscillations in adult motoneurons. Neuromodulatory inputs arising locally from spinal interneurons likely also impact motoneuron behavior. Thus, depending on the relative levels of activity in neuromodulatory, inhibitory and NMDA inputs, motoneurons can behave as integrators, amplifiers or oscillators. It is thus possible the properties of motoneurons are reconfigured by these inputs to match the demands of different motor tasks, e.g. integration for posture, amplification for many voluntary movements and oscillation for locomotion. Perhaps the computational principle applying is that motoneuron electrical properties are, in a sense, “optimized” for each motor behavior.

Stability and Variability in Learning an Interactive Task

Dagmar Sternad
Biology, Electrical & Computer Engineering, Physics, Northeastern University, USA

How does the brain coordinate our actions and interactions with the environment? How do we throw or bounce a ball; how do we drink a cup of coffee without spilling it? Revealing the fundamental principles that underlie motor control and skill learning in the healthy nervous system is a necessary basis to understand neurological dysfunction and to develop intervention. Recent research of my lab has examined three interactive model skills: the rhythmic task of bouncing a ball, the discrete task of throwing a projectile to hit a target, and the continuous task of carrying a cup filled with coffee. Key concepts that drive our empirical and theoretical inquiry are variability and stability. Characteristic for our approach is to start with a mechanical model of the task and render it in a virtual environment. As such, the human interacts with a known task environment. Based on stability analyses of a dynamical model of the task, we study how the neuro-mechanical system develops robust solutions to meet the task demands. Using the three skills as model examples, we show that developing skill means 1) exploiting solutions with dynamical stability, 2) finding the most error-tolerant strategy and channeling sensorimotor noise into task-irrelevant dimensions, and 3) optimizing safety margins and taking advantage of small perturbations. Based on these insights into healthy function, new intervention techniques can be developed that facilitate learning and relearning of motor tasks.

On Motion Planning and Coordination at the Intrinsic Joint and Body Levels:
Computational Models and Brain Mapping Studies

Tamar Flash
Dept of CS and Applied Math, Weizmann Inst. Of Science
Rehovot, Israel 76100.

In my talk I will discuss the results of two studies. In the first study conducted jointly by Barliya, Omler, Giese and Flash (Barliya, 2010) we addressed the question of how the kinematic degrees of freedom are coordinated during drawing movements in order to accomplish different movement tasks and to resolve kinematic redundancies. Using a new blind-source separation algorithm (Omlor & Giese, 2007) a method was developed to analyze the relationship between task and joint spaces. The extracted sources for the hand trajectories vs. those of the joint movements were compared for several alternative representations of arm configuration. A surprising similarity between the derived set of sources for the hand vs. the joint spaces was observed when the arm is represented by means of a specific coordinate frame involving both intrinsic and extrinsic coordinates. The use of a similar kinematic representation was supported by many earlier behavioral and physiological studies (Bianchi et al., 1998, Soechting & Ross, 1984).
Our observation that both task and joint spaces may share the same sources has led to the idea that these sources can serve as mediators for the inverse mapping from task to joint spaces. We show here that indeed this mapping can be mathematically performed.

In the second part of my talk I will describe the results of brain mapping studies conducted jointly by Zeharia, Flash and Amedi addressing the question of whether the representations of neural information regarding the movements of different body parts is modular or distributed. This question concerns the representation of single organ movements across the entire Penfield homunculus. Here we use a phase locking fMRI design to achieve the most detailed imaging yet of the Penfield homunculus. Surprisingly, the somatotopic information for any single organ movements (e.g. single finger, toes, tongue) is spread across the entire M1 homunculus in different forms (positive and negative BOLD), creating the known positive homunculus and a novel inverse "coarse negative BOLD homunculus". Furthermore, applying fMRI pattern classification techniques the best prediction of the organ being moved isobtained using the entire homunculus. Thus, information in M1 is highly distributed, probably allowing maximal flexibility in movement encoding.

Rule-Based Movement Planning in the Frontoparietal Reach Network

Dr Alexander Gail
Sensorimotor Group, BCCN Göttingen

In natural situations, movements are often directed towards locations different from that of the evoking sensory stimulus. Movement goals must then be inferred from the sensory cue based on rules. When there is uncertainty about the rule that applies for a given cue, planning a movement involves both choosing the relevant rule and computing the movement goal based on that rule. Under these conditions, it is not clear whether primates compute multiple movement goals based on all possible rules before choosing an action, or whether they first choose a rule and then only represent the movement goal associated with that rule. Supporting the former hypothesis, we show that neurons in the frontoparietal reach areas of monkeys simultaneously represent two different rule-based movement goals, which are biased by the monkeys' choice preferences. Apparently, primates choose between multiple behavioral options by weighing against each other the movement goals associated with each option.

Perception, Action and Interactions Between Time and Space Representations

Amir Karniel
Department of Biomedical Engineering, Ben-Gurion University of the Negev, Beer-Sheva, Israel

Does the brain use time representation?
In this talk I will argue that the concept of time representation can be used to account for perceptual tasks, however, the motor system employs pure state representation and lack time representation.
I will start with a review of our studies during the last decade to uncover the complex relation between perception, action, time representation and delayed environments. We have failed to find any evidence for time representation during motor adaptation to time varying force field and delayed force fields (Karniel and Mussa-Ivaldi. Biol. Cybern. 2003, Levy et al. PLoS ONE 2010), and have developed a regression based model for the perception of stiffness as well as boundary representation (Pressman et al. IJRR 2007, Nisky et al. IEEE TOHJ 2008, Pressman et al. Advanced Robotics 2008, Nisky et al. J. Neurophysiol. 2010, Pressman et al. J. Neurosci. 2011).
I will then describe two recent studies performed at the Robotics Laboratory of the Rehabilitation Institute of Chicago using the MIT manipulandum, providing two new important pieces to the puzzle of time representation. The first study demonstrates that we use time to estimate the simultaneity of two events. The second study demonstrates that our motor system uses temporal simultaneity assumption to modify our proprioception position map, in a task of virtually playing the game of pong with delay.
Finally, I will discuss the implications of these results to answer some key open question in neuroscience, and conclude with some future applications to the upcoming technologies of teleoperation and telepresence.

This research is supported by the Binational US-Israel Science foundation (BSF).

Towards Haptic Human-Robot Interaction - How to Learn from Human Dyads

Angelika Peer
Technische Universität München, Munich

Abstract: Natural and intuitive haptic interaction is considered one of the prerequisites for future robotic systems that are supposed to share their working space with humans and to closely collaborate with them. When realizing a natural, physical interaction partner a number of new challenges have to be faced as the human expects to interact with a system that shows human-like behavior, i.e. it is able to estimate human intentions, to communicate intentions, to take decisions, and to adapt its behavior to its partner. Starting from the observation of human-human dyads, the talk will illustrate how such an interactive and proactive robotic partner can be developed.

Application of the Rubber Hand Illusion to Motor Learning in a Hapto-Visual Virtual Environment

Miriam Reiner
The Virtual Reality and Neurocognition lab, Department of Education in Science and Technology, Technion, Haifa, Israel

The rubber hand illusion is based on embodiment of a rubber arm. The classical experiment of the rubber hand illusion suggests that the rubber arm, is perceived as part of the physical body under conditions of multimodal integration of dislocated visual and touch stimuli. The subject sees the rubber hand being touched but feels the touch on the real hand. The real hand is hidden from sight. The rubber hand illusion was applied for studying perception of the self-body with practical applications to rehabilitation.
We replicated the rubber-hand illusion in the context of virtual environments and developed male and female virtual realistically-looking arms. We replicated the rubber-hand illusion with the virtual arm using a hapto-visual stereographic virtual world. We then studied the functionality of the embodied arm such as performance and learning new motor tasks using the virtual arm under the illusion, and especially when the real hand is limited. We ask questions such as whether participants are able to learn how to play ‘piano’ by activating the virtual arm but not the real arm? Open virtual doors? Will learning to perform with the virtual arm transfer to the plastic brain processes applied to the real arm?
We tested processes of learning using three tests: (1)emotional responses to threat of the virtual arm using changes in pupil diameter; (2) Event related fluctuation analysis of pupil area to analyze the Level of Motor Task Workload. Previous work has suggested that cognitive load decrease with learning. It has also been shown that fluctuations of pupil are correlated with changes in cognitive load. We used changes in fluctuations of pupil area to measure changes in cognitive load when performance has been done with the virtual hand, under the illusion, and compared to performance with the real hand. (3) Tested similarity of changes in enhancement of performance due to neuromodulation when performing with a real and virtual arm under the illusion and without the illusion.
Results of all three tests suggest a close similarity between processes of learning with the real arm and the virtual arm under the illusion, suggesting that the illusion may be a way to modulate brain processes correlated with motor learning.

Physiological Investigations into Human Probabilistic and Reward Based Motor Learning

John Rothwell
University College London, London

We don't always know exactly what we will have to do next: at an upcoming traffic light it might be press the brake or press the accelerator. Experiments show that the amount we prepare an upcoming movement depends on how probable we think it is going to be. This can be investigated experimentally in a probabilistic reaction time task, in which the probability of each of a number of options can be varied by the experimenter. Subjects do not know these probabilities, but gain implicit knowledge of them by performing the task a number of times. Physiologically we can measure what is occurring in the motor system by quantifying corticospinal excitability (measured with TMS) and reaction times, which are higher and faster to more probable cues. A second factor also influences our reaction times: the "unexpectedness" of a response. The more unlikely the cue, the longer the reaction time on that trial. We can quantify these factors using information theory as "entropy" and "surprise" to allow formal analysis of the results on a trial by trial basis to show how the neural circuits use this information to prepare for subsequent actions.

In a second set of experiments we tested how patients with Parkinson's disease performed on probabilistic learning tasks when ON of OFF their normal L-dopa therapy. When ON, their (overall slower) reaction times behaved as in elderly volunteers. However, when OFF, they had a specific deficit when responding to highly improbable cues. This suggests although they could prepare in advance for a highly probable response, they had a reduced ability to switch from the expected to an unexpected action, which we could quantify formally as being related to the "surprise" of the cue. This suggests that dopamine is not only involved in switching responses from highly probable to improbable, but that the deficit is modulated by the degree of "surprise".

In a third set of experiments we tested how the excitability of the corticospinal motor system was modulated by reward by giving participants unexpected monetary rewards in a task in which they were told to explore movement parameters (speed, smoothness, extent etc) in order to find out what sort of movement received the greatest reward. The data show that excitability on the following trials is modulated by the unexpectedness of the reward which again can be quantified on a trial by trial basis in terms of information theory.

Gain-Cost Optimization Rather Than Reward Maximization in the Basal Ganglia

Hagai Bergman,
Department of Physiology and ELSC, The Hebrew University, Jerusalem, Israel

Previous reinforcement-learning actor/critic models of the basal ganglia network have highlighted the role of dopamine in encoding the mismatch between prediction and reality. These models underscore the role of dopamine in modulating the efficacy of the cortico-striatal synapses and modification of the state to action mapping. Far less attention has been paid to the computational algorithms of the main-axis (actor) of the basal ganglia network. In any case, these models suggested that computational goal of the basal ganglia is to maximize cumulative (positive and negative) reward, whereas cost (pain, punishment, policy complexity) correspond to negative gain (pleasure).

Here, we construct a top-down model of the basal ganglia with emphasis on the role of dopamine as both a reinforcement learning signal modulating the efficacy of the cortico-striatal transmission and as a pseudo-temperature signal controlling the general level of basal ganglia excitability and motor vigilance of the acting agent. We argue that the basal ganglia endow the thalamic-cortical networks with the optimal dynamic tradeoff between two constraints: minimizing the cost and maximizing the expected future reward (gain). This multi-dimensional optimization processes results in an experience-modulated version of the softmax behavioral policy. Thus, as in classical softmax behavioral policies, probability of actions are governed according to their estimated values and the pseudo-temperature, but in addition action probability also vary according to the frequency of previous choices of this action.

We conclude that the computational goal of the basal ganglia is not to maximize cumulative (positive and negative) reward. Rather, the basal ganglia aim at optimization of independent gain and cost functions. Unlike previously suggested single-variable maximization processes, this multi-dimensional optimization process leads naturally to a softmax-like behavioral policy. We suggest that the direct affects of dopamine on striatal excitability provide a fast and robust pseudo-temperature signal that immediately modulates the tradeoff between gain and cost and the ongoing behavioral policy. The modulation of the efficacy of the cortico-striatal transmission and the state to action mapping is a slow and subtle process. The resulting experience and dopamine modulated softmax policy can serve as a theoretical framework to account for the broad range of behaviors and clinical states governed by the basal ganglia and dopamine systems.

Understanding Haptics by Evolving Mechatronic Systems

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Haptics can be defined as the characterization and identification of objects by voluntary exploration and somatosensory feedback. It requires multimodal sensing, motor dexterity, and high levels of cognitive integration with prior experience and fundamental concepts of self vs. external world. Humans have unique haptic capabilities that enable tool use. Experimental animals have much poorer capabilities that are difficult to train and even more difficult to study because they involve rapid, subtle and variable movements. Robots can now be constructed with biomimetic sensing and dexterity, so they may provide a suitable platform on which to test theories of haptics. Robots will need to embody such theories if they are ever going to realize the long-standing dream of working alongside humans using the same tools and objects.

We have developed a biomimetic tactile sensor (BioTac®; see www.SynTouchLLC.com) that provides most of the modalities and dynamic range of the human fingertip: point of contact, force vector, radius of curvature, slip, texture and thermal properties. We have integrated these sensors onto industrial robots, including the Barrett and Shadow hands. As we started to use these sensors to identify and handle objects, it became obvious that perception could not be separated from the intelligent selection of exploratory movements. We are developing an interactive approach to Bayesian decision-making in which each movement is accompanied by an expectation of specific sensory feedback based on a probabilistic hypothesis about the nature of the object that has been encountered. The actual feedback is compared to this expectation to validate or refute this hypothesis. Each successive movement is a further test of whatever hypothesis is currently most likely.

Frames in Locomotion, Kinematics and Planning

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The presentation will begin by reporting new investigations on the anticipatory behaviour of the head and the gaze during human locomotion. These experiments and analysis were conducted in LPPA (Collège-de-France, Paris, France) under the direction of A.Berthoz, and were supported in part by the European project Robosom. A first complete publication is in preparation (D.Bernardin et al.), a summary was published (H.Kadone et al. IEEE 2010). Our findings established the hierarchical ordering of gaze and body segments orientations during locomotion on complex trajectories, i.e. gaze direction anticipates the head orientation and head orientation anticipates the orientation of the other body segments, they also shown the influence of the geometry of the trajectory on the temporal ordering, and the over-anticipation of the gaze when the direction of the trajectory is changing. We relate these results to the contribution of head and gaze for visual and vestibular sensory integration and prediction, and we propose the hypothesis that head and gaze belong to a Cartan moving frame for the Galilean group. This fits well with the yaw of the gaze and the head in direction of GIA and a corresponding movement in pitch and roll (Raphan et al., Imai et al. 2001). Then the presentation will connect these investigations to the use of Cartan frames for the explanation of kinematical rules of hand movements and locomotion (D.Bennequin, R.Fuchs, A.Berthoz, T.Flash 2009).

Participation of the Motor Cortex in Feed-Forward Control of Motor Actions, Learning and Kinesthesia in Humans

Anatol Feldman

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A view that has dominated the field of motor control for over a century is that neural control of motor actions consists of specification of mechanical variables or variables closely related to them − movement trajectory, extent, speed, acceleration, muscle forces, torques, stiffness, damping, "impedance", motor commands (EMG patterns) and copies of them (efference copy). This view that can be called mechanical reductionism (MR) was accepted without reservation by many (e.g. Helmholtz, Graham Brown, von Holst and Bernstein). Indeed, there were others who did not accept MR (e.g. Gibson who considered the efference copy concept as speculative both for action and perception). In recent years, MR has been ensconced in engineering control theories and computer terminology such as pre-programming of the motor output, internal inverse and forward models, Kalman filter, Smith predictor, etc. Thus, while expressed in different ways, the underlying MR approach has remained unchanged. However, the MR approach is severely limited in its ability to solve some basic problems in motor control. In particular, it does not specify which variables the system uses to choose between different positions of the body or its segments. It will be illustrated that this choice is accomplished by setting the threshold position of body segments, i.e. the position at which muscles begin to be recruited, a fundamental concept of the equilibrium-point hypothesis. Threshold position control shows that, contrary to what MR suggests, the brain is released from the burden of programming of motor commands, muscle forces and kinematics – changes in these variables *automatically emerge* depending on the magnitude of the gap between the actual and the threshold position of body segments. These findings also show that MR rearranges cause and effect in motor control and therefore cannot be modified to accommodate the experimental fact of threshold position control. Using the TMS technique, it is shown that corticospinal influences mediate central changes in the wrist threshold position. These changes are sub-threshold for motoneurons, which represents the basis for feed-forward control of motor actions, as illustrated by analyzing how subjects learn to diminish the wrist excursion elicited by unloading of preloaded wrist flexors. To diminish post-unloading wrist excursion, the motor cortex tonically facilitates, in a subthreshold way, antagonist (extensor) motoneurons *prior to* unloading. Thereby the response to unloading is generated in the absence of changes in corticospinal influences. Threshold position is also a component of position sense: $Q=R+P$ where Q is the actual (perceived) position, R is the centrally specified threshold position, and P is the deviation of Q from R signaled by proprioceptive feedback. Thus the central R and proprioceptive P components are equivalent for the perception of position. This kinaesthetic rule was tested in experiments in which changes in the wrist position perceived from afferent feedback, P (during the unloading responses) were compared with those perceived from central changes in R (during voluntary changes in the wrist angle). The kinaesthetic rule explains position sense in different experimental conditions, kinaesthetic illusions as well as the phantom limb phenomenon.

Coordinate Frames and Metric Structures in Motor Control Models

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Contact robotics—close physical contact and cooperation between robots and humans—is an emerging frontier. Robotic therapy to aid recovery after neurological injury is a flagship application, with haptic interaction as an essential element. Since modest beginnings over a decade ago, clinical evidence has mounted that robotic therapy is effective and provides durable benefits (Miller et al. 2010).

Successful upper extremity robotic therapy has relied heavily on insights drawn from motor control neuroscience. Model-based planning and control are common themes of computational motor control and observations of recovering patients support this description. However, the *form* of any internal model remains unclear. The usual approaches are approximations based on engineering mechanics, but that implicitly assumes a Riemannian metric underlies the model structure. I will review experiments showing that haptic perception and performance cannot be reconciled with a Riemannian metric (Fasse et al. 2000).

Another fundamental question is the coordinate frame of any internal model used in motor control. Human motor performance is intrinsically variable and one appealing idea is that motor redundancy is exploited to minimize the detrimental consequences of noise. Unfortunately, most analyses presented to support this hypothesis are fundamentally sensitive to the coordinate frame and metric structure assumed in the analysis (Sternad et al. 2010). I will review some initial attempts to develop coordinate-insensitive analyses and models.

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Optimal Selection of Arm Movements during Evidence Accumulation

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Most studies of arm movements have focused on point-to-point trajectories (i.e., movements between two well-defined points). The stereotypical trajectories produced by subjects have led investigators to demostrate that these trajectories are optimal in that they minimize some quanitity (such as mean-squared jerk, torque change, or end-point variance). In this work, we study arm movements performed while subjects are still accumulating information about which target to reach to. Similar to the optimal selection of trajectories given a target, in this work we show that the selection of a trajectory given partial information about the target is also optimal. In this study, subjects reached out and touched targets in response to random dot kinetograms which moved with varying coherence levels. According to most cognitive models of decision making, a target is only selected after accumulation of evidence has reached a bound. In contrast, we show here that when subjects have accumulated only partial evidence, they make movements (submovements) only part of the way to the target. The angle of these submovements is selected based on the current accumulated evidence in an optimal way. This technique offers a unique way of studying in detail the temporal dynamics of evidence accumulation in decision making in humans.

Robotic Orthoses: A Perspective for the Rehabilitation of Upperlimb Synergies at Joint Level

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Hand movements in hemiparetic patients after stroke are generally slower and more segmented with irregular trajectories. The relationships between impairments at joint level (weakness, loss of individual joint control, spasticity) and the interjoint coordination of the movements are still not clear. A hypothesis is that the disordered hand movements are a consequence the disruption of the spatial inter-joint coordination (Levin 1996). The question of inter-joint coordination in hemiparetic patients is complex. On one hand, they clinically show abnormally fixed “synergies” which are stereotyped and appear as global patterns of movements triggered by any effort to move. During attempt to make reaching movements these synergies may induce excessive arm abduction bringing the elbow at excessive height. On the other hand, the normally flexible interjoint coordination is disrupted, in particular, the coordination between elbow extension and shoulder flexion which is normally used to reach forward.

Rehabilitation robots with an orthosis structure offer the opportunity to interact at the joint level with human individuals. This property is appealing accounting for the impairment of inter-joint coordination in hemiparetic patients but has been little explored. The aims of the present poster is to present preliminary data on an innovative robotic mode of control at joint level. Principal Component Analysis (PCA) applied on joint rotation velocities has been used first to analyse human upperlimb synergies for reaching and second to define and impose viscous force fields at joint level. The force field is computed from the explicit formulation of joint space kinematic constraints (i.e. the last PC) with modified coefficient in order to modulate the stiffness and viscosity at joint level during human-robot interaction. Experiments were performed with the ABLE orthosis (CEA-LIST) which has four degrees of freedom (DOFs, 3 in shoulder and elbow flexion-extension) actuated by screw-cable mechanical transmission allowing a good reversibility and equiped with custom fixations with passive DOFs to avoid hyperstaticity. We recorded the kinematics of reaching toward four 3D targets, thanks to Coda motion system and interaction forces measured at each attachment point thanks to two six-axis force/torque sensors (Jarassé et al. 2010). Experiments in healthy subjects demonstrate that such viscous force fields can be used to alter inter-joint coordination. Preliminary experiments in hemiparetic stroke patients have demonstrated the feasibility of this approach. These observations may open a new direction for research in the domain of robotic rehabilitation.

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Electroencephalogram Correlates of Movements and Brain-Computer Interface Systems for Rehabilitation

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The electroencephalogram (EEG) is a non-invasive method for measuring electrical brain activity. Among the typical characteristics of EEG recordings is oscillatory activity in specific frequency bands such as the alpha-band (7-13 Hz) or the beta-band (13-35 Hz). In this talk I will present spatiotemporal maps of changes in oscillatory brain activity measured while healthy subjects performed different types of wrist movements. More specifically, maps of brain activity corresponding to active movements, passive movements, imagined movements, and movements obtained via functional electrical stimulation will be presented and compared.

The changes in oscillatory activity over the motor cortex corresponding to movement imagination can be used to build a brain-computer interface (BCI), i.e. a system which allows a user to control a device only by imagining movements. A promising application for such systems is in rehabilitation of stroke and spinal-cord injury patients where a BCI can be used to move limbs using a robot or functional electrical stimulation. In the second part of the talk, I will present the basic ideas underlying such systems and discuss the implications of the data presented in the first part of the talk for the development of such systems.

Neural Response to Disturbances and Novel Environments

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The development of Brain-Machine Interfaces (BMIs) was motivated by the observed correlation between the neural activity of cortical motor neurons and the direction and speed of movement. However, these correlations were established during skilled arm movements. In contrast, given the limited accuracy of BMIs, their initial operation represents a novel motor task, and thus may evoke additional neural processing involved in error detection and correction

Indeed, our recent results demonstrate that the variability of neural rate-modulations increased abruptly when starting to operate the BMI, and gradually declined with subsequent training.

Expecting similar phenomena in EEG-based Brain-computer interfaces (BCIs), we investigated the effect of visuo-motor disturbances on EEG activity. Such disturbances are expected due, for example, to miss-interpretation of the human intention by the BCI. The experimental result show well defined disturbance-locked potentials with negative and positive components, whose peak-to-peak amplitude is related to the magnitude of the visuo-motor disturbance. The areas that are most active were detected using sLORETA and agree well with the brain areas that are hypothesized to be involved in error detection and processing

We hypothesize that the enhanced modulations reflect how the brain initially responds to and compensates for the inaccuracies in the interface. In particular, we model these phenomena using the framework of optimal control and state estimation and relate the enhanced neural modulations to the changes in the variance of the internally estimated signals.

Using this theoretical framework, we demonstrate, both theoretically and by simulations, that the neurons exhibit the same phenomena observed in the BMI experiments: the percent neural modulations is higher in brain control without hand movements than in pole control, while the percent task-related modulations does not increase. We suggest that these changes are related to the higher variability of the internally estimated state, and address possible implications for motor learning and both BMIs and BCIs.

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Sparse Decomposition for Decoding Movement Direction from the Activity of Multiple Neurons in the Human Frontal Lobe

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Brain-machine interfaces for controlling external devices and basic research for understanding the encoding and control of movement – both benefit from decoding motion kinematics from neural ensemble activity. An initial step in decoding involves feature selection. Due to the size of the neuronal ensemble, this usually results in high dimensional feature vectors which are then projected onto a low dimensional space where actual classification or estimation takes place. Part of this dimensionality reduction involves the selection of neurons which are best related to the task and contribute most to classification. This study proposes a novel projection method, that combines the neuron- and feature- selection into the projection process itself using sparse decomposition. We compare classification by the proposed sparse decomposition method with that of the common iterative neuron dropping.

We apply the proposed sparse decomposition method to decoding of multiple single-unit spike trains from several non-primary motor cortex (non-MI) areas. Movement encoding observed in non-MI datasets [Tankus et al. 2009] is more complex than in MI, where the firing rates of most neurons directly encode the trajectories of hand movements [Shoham et al. 2005]. Participants were patients with pharmacologically intractable epilepsy undergoing invasive monitoring with intracranial depth electrodes to identify the seizure focus for potential surgical treatment. The participants performed a variety of motor tasks including a center-out task (moving a computer cursor from a central location to 8 peripheral ones) and continuous movements in a maze game using a stylus pen and a joystick. The proposed procedure was found to dramatically increase the decoding accuracy, in some case from the chance level, by neuron dropping, even up to 100% accuracy. Our method also improves the computational runtime by orders of magnitude with respect to neuron dropping. Sparse decomposition appears to extract more classification-relevant information than contemporary methods, in much shorter runtimes.

Acknowledgements:

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Learning of Movement Primitives as Basis for the Analysis and Synthesis of Emotional Body Expressions

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Emotions are conveyed by facial expressions, but also by bodily movements. Natural body movements are characterized by complex hierarchical spatio-temporal patterns. The learning of appropriately parameterzed structured models of such human behavior is crucial for the visual analysis of body motion and also for applications in computer graphics and robotics.
The talk will discuss learning-based approaches for the modeling of human motion based on temporal and spatial movement primitives. The proposed methods combine supervised and unsupervised techniques. It will be demonstrated how such primitive-based models can be exploited for the analysis of the visual recognition of emotions from body motion. In addition, an approach that extends such models for the real-time synthesis of human body movements and interactive behavior of groups will be presented. Finally, it will be shown how Contraction Theory can be exploited to design dynamically stable architectures within the proposed framework.

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Riemannian Geometric Approach to Human Arm Movements

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In modeling human arm movements optimization principles have been used to describemathematically the kinematics and dynamics of point-to-point arm movements. Most models have assumed an underlying Euclidean structure of space in the formulation of the cost functions that determine the model predictions. We present a generally co- variant (coordinate-independent) formulation of human arm dynamics and optimization principles in Riemannian configuration space. We extend the one-parameter family of mean squared-derivative (MSD) cost-functionals, previously considered in human motor control, from Euclidean to Riemannian space. Solutions of the one-parameter family of MSD variational problems in Riemannian space are given by (re-parametrized) geodesic paths. We discuss different metrics of configuration space and apply the resulting models to unconstrained point-to-point arm movements and arm movements under constraints. Finally, movement invariants, which define signatures of a computational model, are derived from symmetries of the Riemannian manifold. We argue that the geometrical structure imposed on the arm's configuration space may provide insights into the emerging properties of the movements generated by the human motor system.

The Cerebellar Role in Motor Control and in the Motor Hierarchy

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I combine two views of the motor system that are widely accepted.
First, the idea that the cortex performs its motor control functions through loops to subcortical areas including the cerebellum. Second, that the cortical areas involved in motor control are hierarchically organized. Since cortical connections to the cerebellum are organized in parallel, segregated loops, this suggests that the areas of cerebellum associated with each part of the cortical motor control hierarchy are performing separate and perhaps different functions.
Specifically, I propose that the cerebellum plays different roles in its connections with parietal reach region, premotor cortex, and motor cortex, but that the different roles it plays are in keeping with the general functional role it plays: error-driven non-linear function approximation. The specific role played by the cerebellum in each case depends on the role of the associated cortical area in the motor hierarchy. In higher motor areas, responsible for task-level control, the role of the cerebellum probably reflects the need for accurate ongoing prediction of current state. In moving from a task-level representation to an implementation-level representation in lower parts of the hierarchy, I suggest that the cerebellum becomes increasingly involved in appropriate translation of the desired motor commands into the actual motor commands. Thus, I hypothesize that the cerebellum plays a role like that of a forward model in support of the parietal reach region and a role like that of an inverse model in support of premotor and primary motor cortex. I present current evidence on motor adaptation in light of this theory, and suggest key experiments to test the hypothesis.

Posters

Neural Correlates of the Kinematic 2/3 Power Law in Human Visual Motion Perception: an EEG Study

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It seems that only relatively few kinematic laws of motion govern geometrical and temporal features of human movement generation. One dominant law is the 2/3 power law, which imposes a strong dependency between movement speed and curvature. This link has been established both theoretically and based on behavioral studies in human subjects. An analogous expression of this law, expressing the relationship between the movement speed V and the radius of curvature R is:

$$V = K \times R^{\beta}$$

where an exponent of $\beta=1/3$ precisely complies with the 2/3 power law. Additionally, an increasing body of evidence supports the prominent role that the 2/3 power law plays during visual motion perception, suggesting a close action-perception coupling. A previous functional MRI study demonstrated that the brain's response to movement complying with this law of motion is much stronger and widespread than to other types of motion. Nevertheless, the mechanisms responsible for the role played by the 2/3 power law in motion perception are elusive. In this study, we hypothesize that the 2/3 power law can also be identified by using Electroencephalography (EEG), which holds the benefit of a high temporal resolution. An increase in neural activity is indicated by Event Related Desychronization (ERD) in the EEG mu rhythm band. Mu rhythm desynchronization (8-13Hz), depicted by mu wave attenuation, arises during action observation, motor imagery, and action execution, thus it seems to reflect the modulation of cortical activities and action-perception interaction. Here, we used this method in order to examine whether the brain is more active while observing visual stimuli that are consistent with the 2/3 power law ($\beta=1/3$). We expected to see stronger activation in response to observation of movement obeying the 2/3 power law, in the form of greater ERD. Participants (n=12) viewed a cloud of dots moving along elliptic trajectories according to four different laws of motion. The motion type was determined by the β value (-1/3, 0, 1/3 and 2/3). EEG signals were recorded continuously via 64 cortical sites using active electrodes (ActiveTwo, BioSemi). Results showed that the ERD was indeed significantly greater in response to observing movement obeying the 2/3 power law, compared to other laws of motion, at right frontal-central channels ($p<0.05$). These findings suggest that visual motion representations are best tuned to biological motion kinematics and geometrical invariants, and that this preference is evident in the neural activities as captured by EEG signals.

Dissociation between Perception and Visually Guided Action in Early Childhood

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The functional distinction between vision for perception and vision for action is well documented in the mature visual system. Ganel and colleagues recently provided a dramatic demonstration for this dissociation showing that while visual processing for perception follows Weber’s law (i.e. minimum detectable increment in stimulus magnitude increases proportionally with stimulus magnitude), action violates this fundamental psychophysical principle. Interestingly, the developmental trajectory of this important functional dissociation is still not yet clear and this was the goal of the present investigation. Specifically, we asked whether the qualitatively different pattern observed in adults between perception and action in relation to Weber's law would also be evident early in life. Children aged 5-8 and adults were asked to either perceptually estimate (or reproduce) the size of discs, or grasp discs varying in radius. In perception, the just noticeable difference (JND) for a given size was determined in the method of adjustment by the variance of the reproductions. In grasping, we measured the anticipatory opening between the thumb and index finger (maximum gripaperture). JND increased with object size in accord with Weber’s law in the perceptual task, at all ages tested, with more pronounced linear increment in JND with age. In a clear contrast, Weber’s law was violated for grasping. These results provide evidence for a functional dissociation between vision for perception and vision for action that is already evident early in childhood, with visual processing for perception becoming more sensitive to relative metrics with age.

Effects of Rhythmicity and Amplitude on Transfer of Motor Learning

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We have previously shown (Levy-Tzedek S. et al., Exp Brain Res 202:733-46, 2010, Levy-Tzedek S. et al, Brain Res Bull, in press) that the frequency of the movement can determine whether the movement is rhythmic or discrete. The literature on motor control is not conclusive regarding whether there is one mechanism that generates both rhythmic and discrete movements or different neural processes are involved in the control of the two movements. Previous studies have shown that learning can be transferred between different categories of movement, and that this transfer is not necessarily bi-directional (Dean N.J. et al., Acta psycho 127:355-68, 2008, Abeele S. and Bock O., Exp Brain Res 148:128-32, 2003) . The goal of this work is to study which aspect is important for learning to be transferred from one type of movement to another: rhythmicity or amplitude. We propose two hypotheses: (1) Rhythmic and discrete movements are generated by different mechanisms; therefore we expect to see no transfer of learning between the two types of movements. (2) Within each movement type (rhythmic/discrete), there will be asymmetric transition of learning between larger movements to smaller ones. 36 participants were instructed to perform flexion/extension movements with their forearm, while presented with a display of a phase-plane of their forearm motion, and were instructed to move within a dictated region (Levy-Tzedek S. et al., Exp Brain Res 202:733-46, 2010, Levy-Tzedek S. et al, Brain Res Bull, in press, Levy-Tzedek S. et al., Exp Brain Res, in press). The task consisted of several conditions which differ one from the other in the rhythmicity and amplitude of the movement. In addition, we implemented a model based on the coupling between a Central Pattern Generator (CPG) and the limb to predict the transition of learning between differently scaled rhythmic movements. We found that subjects are able to learn the different conditions of the task up to 90% accuracy. Moreover, we found that there was no transfer of learning between the two movements types (rhythmic / discrete) and that there was asymmetric transfer of learning between bigger movements to smaller movements (within the same type of movement), not vice versa. Likewise, our model predicts the asymmetric learning within rhythmic movements. Our findings suggest that there are two different mechanisms underlying the generation of rhythmic and discrete arm movements, and that practicing on larger movements helps perform smaller movements; the latter might have implications for rehabilitation.

Clustering Cerebellar Interneurons According to ISI Distribution

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The morphology of cerebellar cortex interneurons suggests a clear distinction between the different types of interneurons such as Golgi, granule, basket, stellate, and unipolar brush cells. While the interneurons play an essential role in the cerebellar function, there are only a few functional studies of their activity due to a lack of clear physiological signatures.

Recent studies searched for such physiological signatures in the statistical measures of spontaneous activity, using juxtacellular labeled data sets. While this method can suggest how morphologically different interneurons might be identified physiologically, the focus on morphologically characterized cell types may hide functional groupings in the spontaneous activity. In order to complete the picture, we searched for functional groupings in the activity of interneurons and then asked whether it is possible to map these functional groups on the different cell types. We recorded extracellular spontaneous activity of cerebellar cortex interneurons in anesthetized cats. We applied unsupervised clustering algorithms to the interspike interval (ISI) distribution of the recorded neurons. Because earlier studies had failed to find well-separated groups using standard parameterizations of the ISI distribution, we used a non-parametric approach. We applied Unsupervised Optimal Fuzzy Clustering on the ISI distributions using Kullback-Leibler distance. Our results suggest that there are five different functional groups. When we classified juxtacellular labeled cells into these five functional groups, we found only weak relationships between the functional groups and the morphologically defined cell types. This raises the possibility that while certain interneurons are predisposed to play certain functional roles, there may also be significant functional differences in the roles played by morphologically similar neurons.

Do Pauses in the Neural Activity of Cerebellar Interneurons Correlate to Sensory Stimulation and/or to the Activity of Neighboring Pcs?

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Cerebellar Purkinje cells (PCs) have bimodal activity: a "down state," devoid of simple spike firing and an "up state" characterized by high simple spike firing rates. Recently, patch clamp studies have demonstrated that the activity of a single interneurons can toggle a PC between the two states (Oldfield et al, 2010). Thus, discharge characteristics of interneurons, such as burst and pause patterns and the duration of pauses might play a role in filtering out weaker or less significant PC activity and they may also play a role in the learning and memory processes of the cerebellar cortex.

The goal of this research was to explore the existence of long pauses in different cerebellar interneuron types in vivo. We also checked correlation between their activity pauses and sensory stimulation and/or to the activity of neighboring PC.

We recorded 124 cells from the forelimb area of the C2 zone of the cerebellar cortex of cats. Units were classified as PCs or CIN according the presence or absence of complex spikes. Using a recently published algorithm for classifying CIN (Ruigrok et al, 2011), four types of CIN were identified in our recordings: molecular layer CIN, Golgi cells, granule cells and unipolar brush cells . We discriminated pausing CIN (PCIN) from non pausing CIN (nPCIN) on the basis of the coefficient of variation (CV) of the interspike interval (ISI) distribution, with PCIN having CV > 1. Pauses in PCIN were defined as ISIs above the cell's pause threshold. Using the criteria developed by Yartzev et al (2009) for defining the pause threshold, considering the variability in baseline firing rates between different CIN rather than using a fixed threshold. Using our criteria most of our molecular layer CIN present had pauses in their neural activity compared with only small amount pauses of the Golgi cells. The effect of skin electrical stimulation on pause burst patterns reveal that most of the tested CIN have presented significant increase of their neural activity compare to baseline while pauses dependent stimulation presented rarely. We also had pairs of neurons recorded simultaneously. About half of the CIN tended to fire during the period when their adjacent cell was silent. Cross-correlation analyses confirmed this negative dynamic correlation between adjacent CIN . The long pauses found in the molecular layer CIN suggests that their activity could affect the bimodal activity of the PCs. No relation was found between sensory stimulation and pauses.

Explaining Mouse Compensatory Eye Movement Response with the State Prediction Feedback Model

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We present a quantitative version of the state predicting feedback model (SPFC) of the compensatory eye movement (CEM) system originally proposed by Fens and Donchin (2009). We test our model with behavioral data collected from mice using vestibular and visual stimulation to activate the CEM system. Our model reproduces key non-linearities in the mouse optokinetic reflex (OKR) and it provides a resolution to the current confusion regarding the functional role of one of the key nuclei of the CEM.

Compensatory eye movement is a general term for several reflexes whose goal is to maintain a stable image on the retina during movements of the body or the surroundings. In afoveate animals like rabbits and mice, at least two reflexes are involved: the vestibulo-ocular reflex (VOR) and the Optokinetic reflex (OKR). The SPFC was originally suggested to explain key results in the activity of neurons at various stages of the CEM system that could not be explained using classical models of the system. However, since the SPFC was not actually developed and simulated, there was some question about whether it could, in fact, reproduce behavioral data. We now present a quantitative version of this model, using parameters taken from earlier reports on the CEM system, and test it on data collected from mice in VOR, OKR, and visual vestibulo-ocular reflex (VVOR). We show that our model successfully predicts most of the properties of the animal's response to sinusoidal and triangular stimulations. In particular we show that the specific properties of the non-linearity in the OKR response are well modeled by the SPFC using saturation of the retinal slip input. In addition, we show that recent findings suggesting that the nucleus prepositus hypoglossi (NPH) generates efference copy [Ghasia at el. (2008)] and classic findings suggesting that the NPH is a neural integrator [Robinson 1981] are compatible.

Thus, our combined experimental and modeling work suggests that the SPFC is currently the most parsimonious model explaining the behavior and physiology of the CEM network.

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Minimum Acceleration with Constraints: An Experimentally Confirmed Mathematical Model for Movements and Object Manipulation.

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Many daily tasks, such as moving a cap of coffee, involve controlling objects. While simple reaching movements are easily controlled, the control of objects with complex dynamics and additional degrees of freedom is much more challenging. In a simple unconstrained reaching movement it was demonstrated that subjects implicitly minimize the hand smoothness and a minimum acceleration with constraints model fits typical reaching movement trajectories with interesting prediction about the intermittent nature of the controller. Previous studies investigated the strategies used by humans to control one degree of freedom objects which was simulated by mass attached to a spring. To explain the observed arm movements in such tasks, new computational models were suggested to account for subject's and object's trajectories. Three such strategies were based on solving an optimization problem that minimizes (i) the mean square Jerk of the hand trajectory or (ii) the mean square crackle of object trajectory (crackle being the fifth time derivative of the object position) or (iii) the mean-squared force change of the hand trajectory. Although providing logical solution for object manipulation, these criteria poses mathematical or experimental limitations: Criteria (i) could not account for subject performance in some cases, criteria (ii) is not applicable when trying to explain reaching movements with multiple objects, while for simple reaching movement, criteria (iii) can be solved only numerically by iterative scheme. We suggest a criterion, which define the optimization problem for the system center of mass. More specifically we propose minimizing the acceleration of the center of mass with the same constrains used for reaching movement optimization by Ben-Itzhak and Karniel (Ben-Itzhak and Karniel, Neural Computation 20:779-812, 2008). We show that the minimum acceleration criteria with constrains can be expended to account for both reaching movements and object manipulation task without the need for two separate models. In the one degree of freedom object manipulation task based on experimental results in our lab, we show that our model fits the data at least as well as the previous suggested models and overcomes their limitations. This model not only fits the observed behavior, it also suggests that the brain use intermittence control and a single cost function as it controls reaching as well as manipulating complex objects. The simplicity of explaining both simple movements and movements in complex environments without altering between models opens new possibilities in research on the control strategy of human motor system.

Environment Effects on Grasping: Case Study - Pepper Harvesting

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Grasp characteristics are affected by object characteristics, task requirements and manipulator characteristics. Yet, the environment may also affect the selected grasp. Agricultural environments are characterized by harsh, dynamic and unpredictable conditions (light, humidity, high temperature, etc.) and agricultural objects such as fruits are usually unstructured. Peppers are considered a high valued crop. Their growing environment is complex and they are available in a variety of types, sizes, and shapes to which the grasp must be adapted. When selectively harvesting a pepper fruit, it has to be separated gently from the plant, without damaging its or the plant structure. This research aims to analyze human grasps while harvesting peppers and examine the effect of two different environments, which represent two extreme conditions, on the grasp configuration; a laboratory model and a greenhouse.
Five right handed subjects participated in the experiment. Their grasp configuration and hand orientation were measured while they performed grasps of various peppers with the intention of harvesting the fruit. The experiment was performed in a laboratory using a physical model of a pepper plant and in a peppers greenhouse, located in the Institute of Agricultural Engineering at the 'Volcani' center. The grasps were recorded using a motion capture data-glove (CyberGlove, Immersion) and a 6 DOF tracking sensor (Fastrak, Polhemus).
Greenhouse recordings of two subjects had many missing samples and were taken out of the analysis. This could be due to the heat and humidity in the greenhouse that affected the CyberGlove recordings. The recorded data of the three remaining subjects was analyzed using Principal Component Analysis (PCA). Initial results show that most of the variance between grasps is reflected in the hand orientation as opposed to hand configuration. The effect of the experimental environment on the grasp characteristics was relatively low and much lower than between subject differences. Our results support the validity of the laboratory model. Different sensing technologies should be used in greenhouse environments.
Key words: grasping, harvesting, peppers, greenhouse, PCA
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When Robots Become Humans: A Turing-like Handshake Test

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As long ago as 1950, Turing proposed a novel test for estimating the intelligence of a computer. According to the Turing test, a computer is considered "intelligent" if it can generate answers that are indistinguishable from those of a human. However, this test is limited to the linguistic aspects of machine intelligence. A salient function of the brain is the control of movement; the human hand movement is a sophisticated demonstration of this function. Therefore, we propose three versions of a Turing-like handshake test, for machine **motor intelligence**. We administer the test through a telerobotic system in which the interrogator is engaged in a task of holding a robotic stylus and interacting with another party: human, artificial or a linear combination of the two. Instead of asking the interrogator whether the other party is a person or a computer program, we employ a two-alternative forced choice method and ask which of two systems is more human-like. We extract a quantitative grade for each model according to its resemblance to the human handshake motion and name it "Model Human-Likeness Grade" (MHLG). We present three methods to estimate the MHLG:

(i) **The pure test-** we compare pure model and pure human handshakes, and calculate the proportion of subjects' answers that the model is more human-like than the human.

(ii) **The weighted test-** we compare two weighted combinations of human and model handshakes, fit a psychometric curve and extract the point of subjective equality (PSE).

(iii) **The noise test-** we compare a pure model with a weighted combination of human handshake and noise, fit a psychometric curve to the answers of the interrogator and extract the PSE.

We present a simulation study that explores which of the versions of the test is appropriate for different assumptions about the accuracy of the decision process of the human interrogator. In addition, we use these methods in an experimental study in order to compare between three candidate models for human handshake. Altogether, we provide a protocol to test computational models of the human handshake.

We believe that building a model is a necessary step in understanding the mechanical and neural mechanisms responsible for the generation of the human handshake.

Modeling human arm motion with overlapping submovements

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Understanding the planning of complex human arm movements is a challenge, since a single task can be performed by the unconstrained arm in an infinite number of ways, by varying not only the trajectory but also the timing at which the task is completed. Considering the previous research, we propose a hierarchical computational model describing the hand movements through a set of via-points. The constructed model utilizes the idea of motion being constituted of primitive components, which were computed here as fifth-order polynomial segments. Additionally, the model suggests a mechanism to account for the observed spontaneous use of more than just one solution per task. This choice of a solution is represented as a Markov process, thus proposing how central nervous system (CNS) may choose among various solutions and how motor memory might affect the future CNS' decision. The model initially prepares a sequence of time-stamped patterns, constituting the particular solution to the motion problem, i.e. the plan. Each of these patterns is additionally associated with a family of strokes of similar shape and timing. When the movement is executed, its accuracy is realized by online prediction of the motion through a forward model that utilizes previously created families of strokes and the sensory input of already completed motion, and by online corrections to deal with the inaccuracies of the movement resulting from the noise. The forward model takes the visual feedback, and by interpolating the corresponding strokes onto the trajectory already completed predicts the future trajectory, applying the corrective movements if necessary. The outputs demonstrate successful completion of the task according to the task specifications (with respect to speed, accuracy and smoothness) and show close matches to the observed experimental results in the variety of trajectory shapes, the velocity profiles and the characteristic curvatures. These results are achieved despite the significant delays in visual feedback, and thus render the proposed scheme, which uses the model-based feed-forward loop that compensates for large motion variability and the sensory delays, an efficient strategy for the motion planning performed by the CNS.

Tactile Interfaces Assisting Navigation for The Visually Impaired

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Navigation is known as one of the most difficult tasks for the visually impaired, especially when navigating in unfamiliar places including buildings and streets. Numerous attempts have been made to enable such navigation using auditory and tactile stimulation. With the aim of creating an intuitive tactile interface enabling the visually impaired to seamlessly navigate in newly encountered environments, we conducted an experiment employing five different vibro-tactile interfaces, each encoding nine spatial directions using different vibrating cues on various arm anatomical locations. Ultimately, the vibro-tactile interface will be connected to an external engine (GPS or any solution for local positioning) that will indicate the needed direction on the given path from point A to point B. Our subjects were presented with a series of vibro-tactile cues, for each interface, conveying spatial directions and were asked to verbally describe the stimulated direction. We inspected the percentages of correct answers and response times and our results show the superiority of interfaces that employ fewer vibrators that use both the right and left arms for conveying right and left navigation commands respectively.

The Positive and Negative BOLD Homunculus: Entire M1 Predicts Best Single-Organ Movements

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One of the main principles of organization in the brain is the topographic organization that exists in different modalities including the motor domain. The existence of the motor homuculus in the primary motor cortex (M1) in humans was demonstrated by Penfield as early as 1937. Since then, fMRI experiments also demonstrated the existence of motor homunculi in M1 and in other CNS motor areas. The vast majority of these experiments used the GLM method as the method of analysis, and most of the previous studies focused on a limited number of organs, which resulted in an incomplete mapping.
In the present study, we used a periodic experimental design which enables phased-locked analyses approaches, thus enabling us to map the whole body motor and somatosensory representations in multiple homunculi, localized in different areas of the human brain (E.g. M1, SMA, RCZ, CCZ, putamen, cerebellum etc.).
In addition, we further investigated the somatotopic properties of the SMA and M1. We found that the overlap in somatotopic representations of different organs are much more extensive in the SMA than in M1, and increases in the more anterior portions of the SMA. We also found that while in the SMA no negative BOLD signal was observed following movement, in M1 an extensive negative BOLD, which was organized somatotopically was present. This negative BOLD is organ-specific and creates an inverse pattern to the known positive BOLD homunculus (E.g. in the medial legs area, positive BOLD was elicited due to leg movements, and negative BOLD was elicited due to the hands and face movements).

Further investigation of M1 somatotopic properties using multi-voxel pattern analysis (MVPA) revealed that the pattern of voxel activation inside each modular area differed among each of the neighboring body parts represented in this area, and therefore allows for the accurate prediction of which of the close body parts was moved.
Surprisingly, predictive information from each body part was also found in somatotopically distant locations in M1 (e.g. information from the face area enabled the distinction between the movements of the different fingers Information of negative BOLD from the distant areas also enabled classification.
Furthermore, population information from the entire M1 enhances movement classification, supporting a distributed representation of single-organs movement across the entire homunculus. This might be the mechanism that is at the basis of coordination and flexible representation of movements from different parts of the body in M1.

Modeling the Elongation and Bend Propagation of the Octopus Arm

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The control of the octopus arm requires special motor control schemes because it is composed almost entirely of muscles and lacks a rigid skeletal support. Elongation patterns of the octopus arm were observed during reaching movements (Hanassy et al., 2009 [1]). When modeling octopus arm elongation and when using the original 2D dynamic model developed by Yekutieli et al. (2005a, b [2] [3]) an unrealistic high ratio of transverse to longitudinal muscle activations ratio was required. Hence the muscle model was modified incorporating into it neutrally controlled muscle rest lengths whose magnitude depends on the neural dependent firing rate as in the tongue model by Crago (1992) [4] applying the parameters used by Chiel et al. (1992) [5]. Using the new muscle model it was possible to obtain lengthening movements with realistic levels of muscle activations. Using a genetic algorithm, sequences of firing rates that gave rise to arm movements best fitting the experimental data (elongation and bend propagation movements), thus demonstrating that a possible strategy for controlling the amount of arm elongation is through the control of the activations' firing rates. These conclusions are consistent from the results of electrophysiological recordings and electrical stimulation studies conducted both at the level of multi-muscle and single-cell recordings (Nesher & Hochner, 2010 [6]; Matzner et al., 2000 [7]; Rokni & Hochner, 2002 [8]).

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Shape From he Depths - Shape Recognition Using Distance Information

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There are many ways to recognize a shape – using visual, tactile, and even auditory information. Here we present the examination of another potential parameter, the distance between the subject and a point on the object which can be used to scan in a "flashlight" fashion. We use this scanning method to explore subjects' ability to recognize various virtual 2D and 3D shapes and shape orientations, and observe the scanning strategies and patterns they develop. Usually when viewing 2D images in pictures, or upon computer screens, depth information is given by implicit cues (such as slight shading, fine color changes etc.), which are inaccessible to the visually impaired, and which cannot always convey the exact spatial position and orientation of objects in the image even to the sighted (e.g. convex vs. concave, objects leaning out-of or into the image, relative spatial location in environments with no reference frame etc.). Using our method such virtual scenes can become more accessible and meaningful. In addition, isolating depth as a single novel parameter for shape and orientation identification provides us with yet another tool to research the formation of novel sensory-motor loops both behaviorally and by using this virtual setup in real time with brain imaging techniques to observe the way this information is processed within the brain. Our results show that such recognition is indeed possible and that the accuracy increases with the use of scanning strategies and with experience.

Stiffness Discrimination Learning: Effects of Practice, Knowledge of Results and Modality.

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Stiffness sensitivity is crucial for perception and discrimination of objects and is essential for many complex tasks. When examining an object, the haptic system provides tactile information as well as kinesthesic information about arm displacement in conjunction with signals of applied force (Clark&Horch, 1986). Yet information regarding the displacement of an object may also be obtained from the visual system (Lederman&Klatzky, 2009). Recent studies argued for a facilitatory effect of multisensory training on unisensory learning (Seitz et al., 2006). Additional training manipulation, which known as having an enhancing effect on performance is Knowledge of Results (KR) (Adams, 1987). In this study we examined when does learning for unimodal stiffness discrimination occur and whether training enriched by visual information or KR will affect the course of learning.

Experiments were conducted using a virtual-environment touch-enabled computer interface providing users with various levels of haptic stiffness intensities and corresponding visual changes. We used a 2AFC discrimination task, in which participants were asked to indicate in each trial which of the two targets presented is softer. Participants were trained in two consecutive days and were tested on haptic only condition before and after training. During training two variables were manipulated between participants: KR and/or addition of congruent visual information.

Training resulted in both immediate but also latent, overnight learning in the proportion of correctly discriminated pairs of targets (PC), in all groups.

Discrimination decision time (DT) gains were obtained only during practice, while between sessions partial deterioration was evident. Affordance of visual information during training blocks resulted in higher PC during these blocks, but lower PC in the haptic-only retests. This finding challenges the notion that long-term unisensory learning mechanisms operate optimally under multisensory training conditions, at least for the combination of the visual and haptic modalities. We didn't find evidence that KR training enhances discrimination ability in terms of PC. However, we found transient effects of KR and visual-haptic trainings on DT: while visual-haptic training resulted in slower decisions, KR training induced faster decisions. Nevertheless, these effects disappeared in the long run and were mainly evident during the training blocks.

To our knowledge, this is the first study that specifically addressed the time-course of stiffness discrimination learning and evaluated effects of training with additional modality or KR. Our findings have implications for optimization of training protocols in virtual environments for perceptual motor tasks relying on stiffness perception, such as surgery.

Averaging Process Underlies the Adaptation to Sequential Force Perturbations

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During reaching movements, the brain's internal models map desired limb motion into predicted forces. When the forces in the task change, these models adapt. Current theories and computational models about motor adaptation in the force-field paradigm suggest that the human brain performs predictions based on weighted sum of past experience in order to predict the next external perturbation. What would happen if we expose subjects to a trial by trial increasing force field, would they still base their predictive control on the past trials or shall they demonstrate an ability to anticipate the future?. Little is known about adaptation to series of force perturbations and how these force environments are represented in the motor working memory.

In this study, we monitored the movements dynamics (lateral forces) and kinematics (movements error) during goal-directed arm movements to examine the way in which human motor memory compensate of sequence of force-fields. Our main finding is that motor memory responsible for representing force perturbations counts solely on the past few trials, supporting the current models of adaptation to force perturbations. Additionally we found that adaptation to small force perturbations is faster than adaptation to larger forces.

This result, combined with our previous opposite findings for a lifting task, suggests that the brain can generate at least two different types of motor representation, addressing either the past or the future. The underlying difference probably lies in the prior experience about the nature of changes in the objects' weight and force field, where the former is expected to change from trial to trial, thereby encouraging future based memory, and the latter is expected to remain constant, thus explaining a past average type of memory.

Evaluation of Levels of Physical Activity in Teenagers with Cerebral Palsy – a Pilot Study

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Promotion of Physically Active Lifestyle in Populations of Teenagers with Cerebral Palsy in
Middle East (CP-PALS) is a collaborative project of scientists from Israel, Morocco, Jordan, and the Palestinian Authority, in the frame of Middle East Regional Cooperation Program. It aims to raise awareness of, and promote, a physically active lifestyle for Middle East teenagers with disabilities due to cerebral palsy (CP), a severe motor disorder of a central origin. One of the objectives of the study is to monitor and explore the daily habitual activity of teenagers with CP by use of accelerometers, and to draw conclusions on the rehabilitation needs in regards to their functioning in their natural environments. The goal of this pilot study was to examine and to choose the appropriate activity monitor to meet the objective of the CP-PALS project. Following a literature survey Actigraph and ActivPAL were chosen to fulfill the research needs. These two devices were tested simultaneously in a pilot experiment (laboratory and field tests) on two healthy subjects and one subject with CP. The laboratory tests were video recorded and performed according to a standard protocol of common activities, e.g. lying, sitting, standing, walking, climbing stairs, and postural transitions. The field test lasted 72 hours when subjects performed their routine daily activities along with completing a 15 minutes epochs activity diary. Several signal processing methods for activity classification were tested for accordance with real video-recorded activities and with diary records. The best method to classify the subjects' activity into 5 activity levels used activPAL raw data and consisted of 3 steps: discrimination between sedentary and upright positions, based on their baselines; discrimination between standing and physically active periods based on the variance level; and separation of active periods into three levels, (moderate, vigorous, and very vigorous) using thresholds determined by unsupervised optimal fuzzy clustering method (Geva & Gath, IEEE TPAMI 11:773-780, 1989). This algorithm showed good ability to detect activity level as was compared to video observation. However, different levels of activity at various walking speeds of the subject with CP could not be distinguished by it. We discuss the results of this pilot study and the potential future improvements to monitor the activity of teenagers with CP.

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Parametric Compliant Contact Model for Human Finger

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Contact properties depend on the nature of bodies in contact, including their material and elastic properties, the contact deformation and the applied force. Exact contact dynamic is difficult to model and in many cases very simplified models are used such as hook law based models. Better contact models can be critical for correct grasp force characterization. In this research we adapt two lumped parameter models used in robotics to the human finger and use them for predicting contact forces applied against a rigid surface.
Walton (1978) developed the force-displacement model for the normal and tangential contact forces applied between two identical homogeneous isotropic elastic spheres. Walton's model suggested that normal force is proportional to $\delta_n^{3/2}$ (normal deflection) and the tangential force is proportional to $\sqrt{\delta_n} \cdot \delta_t$ where δ_t is the tangential deflection. Xydas & Kao (1999) proposed a power-law model for the contact between a soft fingertip and a rigid object. This model relates the growth of the circular contact radius to the applied normal force for soft fingers.
A controlled experiment for establishing the contact model parameters was conducted. 21 subjects participated in the experiment: 7 males (age: 26.14±2.26), and 14 female (age: 24.42±1.45). All subjects were without any known finger soft tissue disorders or visible calluses on the tested fingertip. The forces and the fingertip displacements were recorded using 6-axis force-torque transducer (Mini-40, ATI Industrial Automation) and 3D digitizer (MicroScribe 3DLX, Immersion). During the experiment subjects applied a specified normal force (4N, 8N, 12N) on the surface of the force sensor with different fingertip angels at contact. The recorded data was analyzed using nonlinear regression model.
Initial results show that the loading data in the normal and tangential directions fitted the Walton model, and that the loading data in the normal direction fitted the Xydas & Kao power-low model. In the next stage the fitted models will be used for grasp force prediction and compared to actual recordings.

Key words: grasp, dynamics, contact modeling
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Perception of Stiffness in Laparoscopy – The Fulcrum Effect

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In Minimally Invasive Surgery (MIS), the surgeon operates with long tools through a small incision in the abdominal wall of the patient. Reduced pain, complications, and hospitalization time, and improved cosmetic results are just examples of the vast advantages of MIS over traditional open surgery. However, when a surgeon operates through MIS, his motor control system faces various challenges due to the "fulcrum effect". These challenges include inversion and scaling of movements, and accurate sensation of forces, which is altered due to mechanical advantage and friction at the incision point. While the fulcrum effect was studied extensively in the context of performance, haptic perception through laparoscopic device was largely overlooked.

Over the last two decades, extensive research was performed to assess and improve laparoscopic skills acquisition. These include a large variety of mechanical simulators – boxes with small incisions for practicing operation and sensation. In the recent years, virtual reality based simulators are becoming prominent as a tool for skill assessment and training in MIS.

We designed an experimental setup for studying perception of mechanical properties in MIS. We combined mechanical simulator with haptic device, and designed a system that can apply a computer generated force at the tip of a long tool which is moved through a small incision. The force can be any function of the position of the tip of the tool and its derivatives. In the current study, we focused on perception of stiffness, and therefore, we implemented linear elastic force fields.

When moving a tool through small incision, there are two possible types of movements: the surgeon can push the tool through the incision – radial movement, or rotate the tool about the incision – tangential movement. These two movements are completely different. The latter is affected by the fulcrum effect, and therefore there is inversion and scaling of motion and reciprocal inversion and scaling of forces. The former movement does not suffer from these effects.

We explored perception of stiffness when probed with radial and tangential movements. To explore the influence of mechanical advantage of the laparoscopic tool, we set different values of the ratio between internal and external length of the tool. We found a bias in the perceived stiffness when tangential probing is compared to radial, but not when the comparison was within tangential or within radial probing.

Understanding the perception of stiffness in MIS is important for surgical training and future development of surgical techniques.

The Handshake Hypothesis

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Abstract

The human hand movement was extensively studied as a fine demonstration for the human movement control. A well practiced and quite fascinating implementation of this movement is the act of handshaking. Though rather short in duration, we perform this active sensing process in a fashion enabling us to gather relevant information about the other party. In the Turing-like handshake test for machine intelligence, handshake models are designed and tested through a telerobotic interface to estimate their human likeness (Karniel et al. JoVE 2010). We hypothesize that the most human like handshake model is expected to be optimal as active sensing component for handshake discrimination.

As an eminent first step to test this hypothesis, we performed a computer simulation of telerobotic handshake between five parametric families of handshake models, consisting of linear and non-linear spring-dashpot (parameters are spring and dashpot constants, with linear relation), sine power source (Frequency) and a combination of linear spring-dashpot and sine power source (again spring and dashpot constants), each family containing five "family members". All possible pairs of models performed simulated handshakes and features such as maximal force and velocity, position change frequency, mean acceleration and jerk, energy were extracted from each simulation. Following the simulation, we performed a classification process assessing each model type for its efficiency in discrimination between family members of the same parametric family (graded separately for discrimination of each of the five families).

Simulation results indicate that the sine model, consisting only a force generating source perform significantly better than the spring-dashpot model on spring-dashpot family classification task and vise versa. It is obvious that active handshake is essential in classification between passive handshakes, however it is interesting to note that passive handshake is better at classifying between active handshakes. Altogether, the combined sine-spring-dashpot model has achieved the highest average classification performance.

The combined model will be further examined on the Turing–like handshake test, assessing human handshake discrimination ability and human likeness for various linear combinations of "active" and "passive" models. This will be followed by application of a pruning algorithm, facilitating the extraction of the most eminent features for discrimination.

Providing evidence to support or refute the handshake hypothesis is expected to yield new insights about the process of human handshake control, with potential applications in medical diagnostics, rehabilitation prosthesis and biometric systems.

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Error-Related Potentials Due to Visuo-Motor Disturbances During Continuous Reaching Movements

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Abstract

Error related potentials (ErrP) in EEG signals are the focus of major research efforts, both for understanding error processing in the brain and for facilitating early error detection and correction by Brain-Computer Interfaces (BCI). The purpose of this study is to identify and characterize the error-related potentials evoked in response to visuo-motor disturbances during continuous reaching movements. Visuo-motor disturbances are unpredictable externally-induced deviations between the expected and observed visual feedback from the controlled device. In the context of BCIs, such disturbances include incorrect interpretations of user intention by the BCI. Our experimental paradigm is unique in generating controlled visuo-motor disturbances, which are well localized temporally, to facilitate synchronized averaging. The experimental results show well defined disturbance-locked potentials with negative and positive components whose amplitudes vary with the magnitude of the visuo-motor disturbance. Source localization at the negative and positive peaks indicates strong activation in the vicinity of Brodmann areas (BA) 6, 5 and 7. Increased activation was also detected around BA 2, 3, 4, 8, 9, 24, 31 and 32. These results demonstrate the presence of detectable ErrP associated with visuo-motor disturbances, which can be used to facilitate early error detection and enhance the capabilities of Brain-Computer Interfaces.

Use of Different Types of Sensory Information for Estimating Hand Location in Cerebellar Patients

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When planning a reaching movement towards a target, the human subject's arm's position is estimated twice, in two different stages of the planning (Sober and Sabes 2003) First, in calculating the direction of the desired movement vector, the arm position must be estimated to determine where the target is relative to the arm ($\hat{x}_{\mathrm{MV}}$); second, in calculating the motor command to create movement in that direction, the arm position must be estimated to determine the appropriate inverse kinematic or dynamic transformation ($\hat{x}_{\mathrm{INV}}$). For both of these estimates, the motor control system may rely on information from more than one sensory modality; the two dominant modalities are vision and proprioception**.**

We replicated earlier findings from a study by S.Sober and P.Sabes in 2003 showing that $\hat{x}_{\mathrm{MV}}$ depends mostly on visual information while $\hat{x}_{\mathrm{INV}}$ depends more on proprioception. To do this, we used their paradigm: the relative weight of visual and proprioceptive information in each estimate of hand position was found by dissociating the pattern of errors caused by errors in each of the estimates by perturbing visual feedback. In addition, we reproduced their results showing that increasing visual feedback of joint positions increases the role of vision in $\hat{x}_{\mathrm{INV}}$. We then tested patients with cerebellar ataxia. We found that, in these patients, the role of vision in $\hat{x}_{\mathrm{INV}}$ was not affected by manipulation of the visual information. Further, we found significant correlation between the volume of cerebellar grey matter and the affect of increasing information on the role of visual input. Specifically, degeneration in the anterior right cerebellum was associated with a decreased affect of the visual manipulation and patients with the most degeneration in this area even showed an effect in the opposite direction, so that increased visual information actually reduced the use of visual information.