Faculty of Health Sciences

Faculty of Engineering Sciences

מרכז זלוטובסקי למדעי העצב
Zlotowski Center for Neuroscience

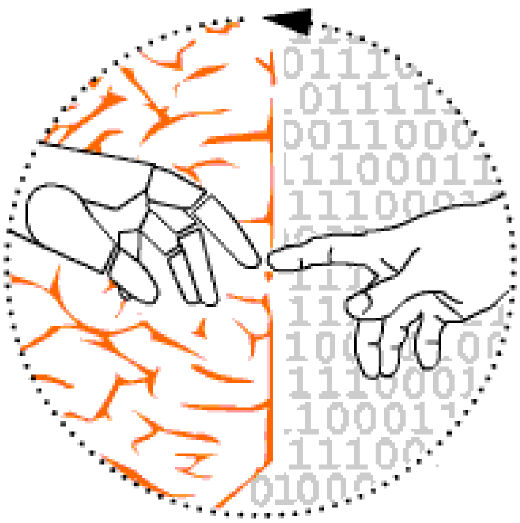
The 12th Karniel

Computational Motor Control

Workshop

Ben-Gurion University of the Negev

June 19-21, 2016, W.A. Minkoff Senate Hall,
BGU Marcus Family Campus, Beer-Sheva, Israel



http://www.bgu.ac.il/cmcw

The 12th Karniel Computational Motor Control Workshop
June 19-21, 2016
W. A. Minkoff Senate Hall, BGU Marcus Family Campus,
Beer-Sheva, Israel

Department of Biomedical Engineering,
Zlotowski Center for Neuroscience at Ben-Gurion
ABC Cognitive Robotics Center
supported by Leona M. and Harry B. Helmsley Charitable Trust

Sunday, June 19

Lab visits

- 15:00-17:00 Motor control labs at BGU:

Physiotherapy

- The laboratory for Rehabilitation and Motor Control of Walking, **Simona Bar-Haim**
- Cognition Aging and Rehabilitation laboratory, **Shelly Levy-Tzedek**
- Schwartz Movement Analysis & Rehabilitation Laboratory, **Itzik Melzer**

Biomedical engineering

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

Industrial Engineering and cognition

- Biomechanics and robotics Laboratory, **Raziel Riemer**
- Telerobotics laboratory, **Sigal Berman**
- Brain and Action Laboratory, **Lior Shmuelof**

Labs tour will start from Student Center (near bank Hapohalim) at 15:00

Festive dinner

- 18:00 Location "Lola", Friend café
- Dr Eilat Almagor, The Jerusalem Academy of Music and Dance, Israel
  & Prof Dorit Aharonov, School of Computer Science and engineering, The Hebrew University, Jerusalem
  "Awareness Through Movement as a guide to Mathematical Learning"

Monday, June 20

- 08:30-08:50 Registration, Poster placement and coffee
- 08:50-09:00 Opening Remarks **Prof. Rivka Carmi**, President of Ben-Gurion University

Session 1 – Motion Planning

Chair: Sandro Mussa-Ivaldi, Rehabilitation Institute of Chicago, USA

- 09:00-09:30 **Bjöern Brembs**, Universität Regensburg, Germany
  "The common biology of motor learning, operant conditioning and model-free learning"
  Keynote Lecture
- 09:30-10:00 **Lior Shmuelof**, Ben-Gurion University, Israel
  "On the fly planning of pre-planned curved trajectories"
- 10:00-10:30 **Einat Couzin**, Konstanz university, Germany
  "Control of 6-legged locomotion"
- 10:30-10:40 Discussion
- 10:40-11:20 Coffee break

Session 2 - Rehabilitation

Chair: Mindy Levin, McGill University, Canada

- 11:20-11:50 **Mark Latash,** Pennsylvania State University, USA
  "Impaired control of movement stability in neurological patients"
- 11:50-12:20 **Tamar Weiss,** University of Haifa, Israel
  "A multi-dimensional approach to evaluate performance of complex daily activities of young and older adults in a simulated mall"
- 12:20-12:50 **Darcy Reisman,** University of Delaware, USA
  "Locomotor Adaptation and Learning after Stroke"
- 12:50-13:00 Discussion
- 13:00-13:30 Lunch
- 13:30-14:30 **Posters**

Session 3 - Motor Control

Chair: Anatol Feldman, University of Montreol, Canada

- 14:30-15:00 **Ron Meir,** Technion, Israel
  "Optimal Neural Codes for Estimation and Control"
- 15:00-15:30 **Robert Scheidt,** Marquette University, USA
  "Neural correlates of nonlinear multisensory integration during wrist stabilization"
- 15:30-16:00 **Prof. Amir Karniel Memorial Young Researcher Lecture**
  Marc Deffains, Hebrew University, Israel
  "Computational physiology of Basal Ganglia & Parkinson's disease"
- 16:00-16:10 Discussion
- 16:10-16:40 Coffee break and posters

Session 4 – Locomotion Control

Chair: Sigal Berman, Ben-Gurion University, Israel

- 16:40-17:10 **Raziel Riemer,** Ben-Gurion University, Israel
  "Biomechanical energy harvesting from human motion: Theory, design, and results"
- 17:10-17:40 **Mati Joshua**, Hebrew University, Israel
  "Linking the dynamics of activity in the frontal eye field to the planning of action selection"
- 17:40-17:50 Discussion
- 17:50-18:00 **Best poster awards**
- Sponsors: NBT, AlphaOmega
- 19:00 Dinner at "Avaz Hazahav" restaurant

Tuesday, June 21

Hike

An invitation to explore the ancient views within the beautiful landscape on a hike from The 'Jerusalem heals to Judea's Low lands. The core of the trip will be a 4-miles hike along 'Nahal HaMe'ara'(the cave wadi).

Talks

The common biology of motor learning, operant conditioning and model-free learning

Björn Brembs

Regensburg University, Germany

Computational neuroscientists use the term "model-free learning" to describe processes by which an agent learns direct rules of how to behave in situations it encountered previously. Psychologists distinguish between two phases of operant learning. The first phase consists of flexible, goal-directed actions, which become more stereotyped with continued training until they have been transformed into habitual responses. Motor and skill learning describe the increased efficiency and the decreased error rate of movements during training. While the three fields of enquiry can be traced to separate origins and often seem to share little literature, recent evidence from invertebrate models suggests they may share a common biology. This biology appears conserved across the bilaterian branch and distinct from other, similarly ancient forms of learning.

Planning beyond preparation time: on the fly trajectory planning of curved trajectories

Lior Shmuelof

Ben-Gurion University, Israel

To what extent the trajectory of a movement is planned before the initiation of the movement? While in point to point reaching tasks the motor plan of the entire trajectory is planned before movement initiation, in movements that are composed of multiple segments, trajectory planning may continue after movement initiation. In the first part of the talk I will describe a study where we used the Timed Response task to enforce subjects to initiate movements prematurely. Fifteen subjects performed obstacle avoidance movements to 1 of 4 targets that was presented 25 or 350 ms before the 'go' cue, imposing short and long preparation times, respectively. While the trajectories that were performed after short preparation times were more variable, and showed a larger target-relative angular deviation, they were still accurate and their duration was comparable to the duration of the movements in the long preparation time condition. Corroborated by a novel trajectory prediction analysis and geometrical modeling, showing indications for a later specification of the trajectory in the short preparation time condition, our results suggest that in the lack of sufficient preparation time, trajectory planning processes could also occur after movement initiation. In order to study the neural basis of trajectory planning, subjects performed curved trajectories using a delayed reaction time task during an fMRI scan. Multivariate analyses revealed a network of parietal regions that show similar patterns of activation during movement planning and movement execution. This network of areas may underlie the representation of movement’s trajectory.

Coordination in 6-legged locomotion - interplay between central control and proprioception

Einat Couzin

Konstanz university, Germany

The study focuses on the neuro-mechanics of inter-leg coordination in cockroaches. Cockroaches are renowned for their very fast, yet highly stable running gaits which had significantly contributed to their evolutionary success and inspired engineers to develop roaches-like robotic agents. In general, locomotion is produced through the interaction of animals' nervous systems and body mechanics with their environment to maintain stability in changing environments. Using neurophysiology, quantitative behavioral analysis and computer simulations we seek to understand these interactions with the focus on the interplay between centrally-generated motor commends and the sensory inputs that shape them.

Theoretical predictions suggest that the degree to which sensory feedback is used for coordinating movement depends on the specific properties of the movement and the environment; i.e when animals navigate slowly through a complex environment where great precision is required, motor activity is expected to be mostly modulated by neural reflexes and sensory information. In contrast, during very fast running or under noisy conditions, the relatively slow neural processing makes feedback-based coordination unlikely (too slow or unreliable) and locomotion must predominantly rely on "preprogrammed" motor commands. We hypothesis that animals dynamically switch between these different control strategies and test our hypothesis through neurophysiological experiments under different experimental conditions.

Specifically, we record neural activity patterns and monitor behavior from preparations whose legs movements are controlled and manipulated. The recorded traces are then compared with model generated activity to estimate underlying physiological parameters using a maximum likelihood techniques. Our findings suggest segmental hierarchies (Fuchs et al., JEB 2012), speed-dependent control (Couzin-Fuchs et al., JEB 2015) and provide insights to how sensory information from a moving leg dynamically modulates centrally generated patterns (Fuchs et al., JEB 2012, Couzin-Fuchs et al., J. Insect Physiol. 2015 and Ayali et al J. Comp. Physiol. A 2015). Lately we've been also studying how are these sensory-motor interactions influenced by descending information from higher brain areas.

In the suggested talk, I would like to introduce the topic in further details, discuss these findings and suggest movement-based feedback in cockroach locomotion as a model system to study bidirectional interactions between motor control and sensory processing in general. This work is based on over 5 years of true collaboration between the groups of Prof. Amir Ayali in Tel Aviv University and Prof. Philip Holmes in Princeton University and myself (initially as a postdoctoral researcher working with both groups and now as a faculty member in Konstanz University, Germany).

Impaired control of movement stability in neurological patients

Mark Latash

Pennsylvania State University, USA

We used the concept of synergy and the framework of the uncontrolled manifold hypothesis for quantitative analysis of stability of actions by motor systems with multiple elements (digits, muscles, etc.) that all contribute to salient performance variables. Recent studies of multi-finger and multi-muscle synergies have shown decreased indices of synergies during steady-state tasks and delayed/reduced anticipatory synergy adjustments (ASAs, a drop in the synergy index in preparation to a quick action) in patients with Parkinson's disease (PD), multisystem atrophy, or multiple sclerosis. In PD, changes in synergies are seen before motor problems with the effectors and tasks can be identified during clinical examination. These impairments in synergies and ASAs are sensitive to dopaminergic drugs and deep brain stimulation. In contrast, stroke is associated with unchanged synergies during steady states while ASAs are delayed and reduced. Taken together, these results point at subcortical structures that are crucial for proper control of movement stability at steady state. It is timely to introduce the concept of *impaired control of stability* as an objective, quantifiable clinical descriptor of movement disorders that can increase our understanding of the neural control of movement with all of its implications for clinical practice.

A multi-dimensional approach to evaluate performance of complex daily activities of young and older adults in a simulated mall

Patrice L. (Tamar) Weiss

University of Haifa, Israel

There is, to date, no clear understanding of why some individuals age successfully and others do not. Recent literature suggests that the use of assessment strategies that focus on body function and/or activity (i.e., isolated tasks) rather than on participation (i.e., complex functional tasks) do not take into account all of the factors that contribute to and detract from successful functioning as a person ages. Moreover, many studies have examined the contribution of isolated factors (e.g., cognition or metabolism) to participation, which compromises the understanding of performance in complex life situation. It is important to understand and characterize the ways in which age-related impairment of cognitive, motor and physiological processes, individually or in combination, impede the ability of elderly persons to accomplish daily tasks in complex life situations. Assessment within a virtual simulation can provide a multidimensional evaluation while controlling for environmental parameters. The purpose of this study was to use a multi-dimensional approach to assess performance of a simulated complex daily activity of older adults compared to young adults.

This presentation will report on a comparison of two groups of healthy adults, young (20-40 years) and older (65-80 years), who performed a shopping task in a real shopping mall and in a high fidelity simulation of the shopping mall that runs in the CAREN™ (Computer Assisted Rehabilitation Environment) Integrated Reality System and is projected onto a 52" wall-mounted monitor. When performing the simulation, participants walked on an interactive, self-paced instrumented treadmill (VGait; Motek Medical B.V.) facing a monitor and navigated through the simulation with a joystick. Data collection included kinematic outcomes via a 12 infra-red camera VICON system and Wearable Technologies APDM system, a portable gait outcome device, and metabolic measures including oxygen consumption (VO2) and respiratory frequency (RF) via a portable K4b2 system. Participants performed the Multiple Errands Test (MET) and a virtual simulation of the same test (VMET) which assesses executive functions during a shopping task.

The results demonstrate that the young adults performed the VMET significantly better than the older group. The use of the simulation enabled a multi-dimensional measurement of this complex task in a controlled setting; without the measurement from the simulation it would not have been possible to identify some of the inefficient strategies made by the older adults' that are evident in their trajectory. Moreover, many of the older adults needed substantial mediation in order to complete the VMET and therefore could not be scored on the test using the standard scoring protocol. The use of measurements from the simulation enabled analysis of their performance despite this limitation. The results of this study provide support for the need to use more realistic virtual environments that truly simulate the challenges experienced by people when engaging in functional tasks. The relative advantages and limitations of simulation for motor control studies will be discussed.

Locomotor Adaptation and Learning after Stroke

Darcy Reisman

University of Delaware, USA

Rehabilitation following stroke is required to make gains beyond those achieved through spontaneous recovery during the first several months after stroke. The gains during rehabilitation are obtained through learning or re-learning of movements that have been disrupted due to damage to the brain. Neuroplasticity is the mechanism by which the brain learns behavior and neuroplasticity and learning can occur after stroke. Yet, the literature provides little information about *the process of relearning movements* after stroke or the mechanisms that facilitate or impede this learning. In particular, very little is known about the process of relearning to walk following stroke, even though recovery of walking is often the primary goal of stroke survivors. In this presentation, results from recent studies that provide insight into the behavioral and neurophysiologic processes that impact post-stroke locomotor learning and their relationship to rehabilitation will be presented.

Optimal Neural Codes for Estimation and Control

Ron Meir

Technion, Israel

Optimal neural codes have been widely studied in the field of neuroscience in the context of perception, leading to explanations of encoding in terms of optimal signal representation. However, in general settings perception subserves action selection leading to behavior through motor control. Motivated by recent results from motor control, we argue that encoding strategies should depend on the task for which they are being used. Given the different requirements of purely perceptual (e.g., object classification) and action-oriented (e.g., object manipulation) tasks, it is expected that sensory adaptation should differ within these domains. We show, based on principles of optimal estimation and control, that sensory adaptation for control differs from sensory adaptation for perception, even for simple setups. This implies, consistently with experiments, that when studying sensory adaptation, it is essential to account for the underlying task. In a broader setting, top-down effects, task-dependent and otherwise, have been shown experimentally to contribute to early sensory processing, thereby inspiring the development of a theoretical framework for such phenomena.

Neural correlates of nonlinear multisensory integration during wrist stabilization

Robert Scheidt

Marquette University, USA

Limb stabilization is a fundamental motor behavior requiring closed loop feedback control. The availability of multiple feedback sources (e.g. vision and proprioception) raises the question of how sensory information is combined to drive feedback compensation for kinematic performance errors caused by environmental perturbations. Here we investigated how the neural mechanisms involved in feedback control of limb position were modulated in response to manipulation of the fidelity between visual and proprioceptive information. Twelve healthy subjects steadied their wrists while resting supine in an MRI scanner. They stabilized against either predictable, constant extensor torque perturbations (**CT**) or unpredictable, pseudo-random extensor torques (**RT**) having the same average extensor torque as the CT perturbation. Direct view of the arm was precluded, although a cursor representing wrist angular deviations from a target was visible via prism glasses. One of 3 types of visual feedback was available: true vision (**TV**), pseudo-random vision (**RV**) and no vision (**NV**). Scanning runs were comprised of 30 s of stabilization in each of the 6 conditions, with 30 s of rest preceding and following each stabilization period. Behaviorally, performance errors accumulated more quickly during trials where the fidelity of visual feedback decreased. Analysis of functional images was conducted in 2 stages. First, a blocked design multilinear regression analysis revealed expected task-related activations in a cerebello-thalamo-cortical circuit previously linked with feedback stabilization. Importantly, we found that BOLD activity within this network varied based on the fidelity of visual feedback. A second regression analysis, performed on residuals from the blocked analysis, evaluated correlation between BOLD signal fluctuations and kinematic performance errors during RTRV stabilization. Importantly, BOLD signals in areas supporting feedback stabilization only exhibited correlation with hand errors, not cursor errors. In comparing BOLD signal correlations with hand errors during the NV and TV conditions, we found that addition of veridical visual feedback caused marked changes in the overall network activity (a drop-out of prefrontal activation as well as dramatic increases in parietal and cerebellar areas engaged in feedback control). These results favor a nonlinear, competitive integration strategy when V and P are in conflict. This nonlinearity is further reflected in the observation that relative to the NV condition, addition of veridical visual information modifies the network structure mediating sensory feedback control.

Computational physiology of Basal Ganglia & Parkinson's disease

Marc Deffains, Liliya Iskhakova, Shiran Katabi, Zvi Israel and Hagai Bergman

The Hebrew University, Israel.

The basal ganglia (BG) are a set of subcortical interconnected structures involved in normal behavior control whose dysfunction leads to BG disorders such as Parkinson's disease (PD). Current computational reinforcement learning (RL) models of the BG divide the BG network into two functionally related subsystems. First, the main axis (or "actor" in machine learning terminology) which corresponds to the BG structures that connect state-encoding cortical areas to cortical and brainstem motor centers. Second, the neuromodulators (machine learning's "critics", e.g., the midbrain dopaminergic neurons and striatal cholinergic interneurons) that encode a prediction error signal (mismatch between prediction and reality) capable of modulating the activity of the BG main axis. The BG main axis is built as three layers neural network, where the striatum and the subthalamic nucleus constitute the BG inputs and together innervate the BG downstream structures using GABA and glutamate, respectively. However, the respective contribution of these two distinct inputs in shaping BG downstream activity in health and parkinsonism is still unknown.

Comparison of the neuronal activity in BG input and downstream structures reveals that subthalamic, not striatal, activity fluctuations correlate with modulations in the increase/decrease discharge balance of BG downstream neurons during temporal discounting classical condition task. After striatal dopamine depletion and induction of parkinsonism with 1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine (MPTP), abnormal low beta (8-15 Hz) spiking and local field potential (LFP) oscillations emerge and resonate across the BG network. Nevertheless, LFP beta oscillations entrain spiking activity of STN, striatal cholinergic interneurons and BG downstream structures, but do not entrain spiking activity of striatal projection neurons. To "close the loop", we found in PD patients undergoing deep brain stimulation (DBS) surgery that beta oscillations and higher neuronal discharge rate were correlated and coexisted in the motor area of the STN compared to its associative/limbic area.

Together, these results highlight the pivotal role of STN divergent projections in BG physiology and pathophysiology and provide rational explanation for the widespread choice of the STN, as the prime target along the BG network for DBS in patients suffering from PD and other BG disorders. Finally, the evidence of STN region-specific higher neuronal discharge rate in PD patients might be used to accurately position the DBS electrodes in the dorsolateral motor area and thus assure an optimal motor benefit while minimizing the emotional and cognitive side effects of the DBS procedure.

Biomechanical energy harvesting from human motion: Theory, design, and results

Raziel Riemer

Ben-Gurion University, Israel

Biomechanical energy harvesters are wearable robots designed to generate electrical energy from human locomotion (e.g. walking), thus providing an alternative to batteries as an electrical power source for portable electronics (e.g. GPS, laptops).

For an energy harvesting device to be useful, it is important that it can generate energy with minimal – or without any additional – effort of the user. Therefore, many of the current devices aim at replacing part of the muscles' work during the phases in human motion where the muscles act as brakes (i.e. negative work). This leads to regenerative breaking, which generates energy similar to a hybrid car. If performed correctly, this in theory could lead to generation of electrical energy while reducing the user's effort (i.e. metabolic power).

In this talk I will explain the theory of an energy harvesting device, discuss the criteria for evaluation of the device, demonstrate the optimization base design approach, and present preliminary results of our device which indicate that it is possible to generate electrical energy while reducing the user's effort.

Finally, I will talk about future directions for research and the implications for designing wearable robots (exoskeletons).

Linking the dynamics of activity in the frontal eye field to the planning of action selection

Mati Joshua

The Hebrew University, Israel

Action selection and its planning are fundamental computations implemented by the brain to control the environment. The neural networks that select action and specify the parameters of movement are intertwined. Neural populations, and even single neurons that encode the parameters of motor commands are also part of the network that chooses from among multiple actions. The motor circuitry controls aspects of movement that are critical to choice, such as direction when choosing between two paths, and other factors that are not crucial to choice per se like latency. One of the key challenges in current research is to specify what is planned during action selection; specifically, how the motor network encodes both selection related and unrelated aspects of movement.

We use the smooth pursuit eye movement system to investigate preparatory activity during target selection tasks. The pursuit system has the advantage of being low dimensional, which makes it possible to relate preparatory neural activity to movement parameters. Furthermore, the kinematics of pursuit eye movements is under experimental control. Given the tight relationship between visual motion signals and the subsequently produced eye movement, the kinematics of planning can be controlled on a trial-by-trial basis. We studied the preparatory activity of neurons in the frontal eye field (FEF) of monkeys performing a pursuit target selection paradigm. The results show that both selection- related and unrelated movement parameters were encoded in parallel by preparatory neural activity in the frontal eye fields. The most common preparatory neural activity in the FEF was ramping preceding target motion onset, which was linked on a trial-by-trial basis to the latency of the upcoming pursuit eye movement rather than its direction. Pursuit selection was encoded by the offset of this ramping response and was commensurate with a discrete selection process.

Taken together, these findings suggest that in the FEF, planning of movement parameters unrelated to selection dominate neural activity. Both selection - related and unrelated movement parameters are multiplexed at the level of single neurons but in ways that are easy to decode by downstream structures.

Posters

Weber's Law during Remote Grasping

Afgin O., Sagi N., Nisky I., Ganel T. and Berman S.

Ben-Gurion University, Israel

Remote operation of robotic devices requires dexterous integration of cognition, perception, and action within and between the human and the robot. Successful teleoperation may be challenging due to difference in kinematics, dynamics, sensations, and inherent delays in the transmission of information between the local and remote site. Examining inherent interrelations between human perception and action in teleoperation conditions may facilitate overcoming some of these challenges along with providing a quantitative assessment framework for telerobotic interfaces. One known factor differentiating cognitively driven semi-motor control from real-world reach-to-grasp visuomotor operation is defined based on the susceptibility to Weber's law. According to this law, in cognitive assessment tasks, the sensitivity of human perception to a change along a physical dimension is linearly related to the intensity of the stimulus, i.e., the just noticeable difference (JND) is larger for larger stimuli. Unlike perceptual assessments, grasping movements, where the JND is measured as the standard deviation of fingers aperture, was found to be invariant with object size, in violation of Weber's law. In the current research we examine whether this dissociation between perceptual assessments and grasping exists in remote robotic manipulation scenarios.

An experiment was conducted using a telerobotic system: the operator controlled a robotic manipulator (UP6, Motoman) equipped with a jaw gripper (Schunk, Germany) using a pair of Phantom Premium haptic devices with finger thimbles (Geomagic, USA), and grasped one of five cylinders. The gripper's aperture was controlled by the aperture between the human fingers, and the tool center point was controlled by the center of the finger aperture. In the experiment, we tested subjects performing either perceptual assessments of object size or reaching and grasping from different orientations with respect to the robot: alongside the robot (aligned-control direction) and facing the robot (mirrored-control direction). In the assessment task, subjects were asked to indicate the width of the cylinder by opening the gripper to an equivalent distance. In the grasping task, subjects were requested to reach and grasp the object and after a short pause raise the object slightly and place it back on the table.

Disruption in Simultaneity Representation in Multi-sensory Integration – a Model for the Hemispatial Neglect Syndrome

Avraham C[1], Avraham G[1], Mussa-Ivaldi FA[2] and Nisky I[1]

1 Ben-Gurion University, Israel

2 Rehabilitation Institute of Chicago, USA

Following brain injury, individuals may demonstrate a spatially behavioral deficit of asymmetric attention and action, also known as hemispatial neglect. This behavioral syndrome is often characterized only in spatial terms, but recent studies have also revealed abnormalities in temporal components. An association between space and time was recently reported in studies of time delay representation in the sensorimotor system of unimpaired participants. Here, we explore the effect of asymmetric sensorimotor delay on state representation.

Towards this goal, we asked participants to perform reaching movements to left and right targets, and applied a visuomotor delay between the hand and the cursor only to leftward movements. We examined the effect of adaptation to this unilateral delay on the amplitude of the reaching movements, and in random trials, we examined transfer of adaptation to a blind circle-drawing task without visual feedback. We hypothesized that adaptation to delay that is applied only to the leftward and not to the rightward reaching movements would influence the state representation of the arm to be asymmetric, and that this asymmetry would transfer to the blind drawing circles task.

During the reaching task, the adaptation to the delayed feedback affected the amplitudes of only leftward movements, and did not generalize to rightward movements. Furthermore, we saw transfer of adaptation to the leftward- and not rightward-initiated blind circles: their symmetry was distorted.

Our results provide the first evidence that adaptation to delay in healthy participants can cause asymmetric drawings, similarly to the drawings performed by hemispatial neglect patients. We believe that this is an important step in revealing the neural mechanisms that underlie the emergence of hemispatial neglect following stroke.

Representation of a Delayed Feedback as a Combination of Current and Delayed States

Avraham G[1], Mawase F[2], Karniel A[1], Shmuelof L[1], Donchin O[1], Mussa-Ivaldi FA[3] and Nisky I[1]

[1] *Ben-Gurion University, Israel*

[2] *Johns Hopkins University, USA*

[3] *Rehabilitation Institute of Chicago, USA*

Our sensorimotor system can adapt to deterministic force perturbations that depend on the current state of the hand. To do so, it builds internal representations of causal relations between experienced forces and hand's motion. However, information from multiple modalities travels at different speeds, resulting in intermodal delays that need to be compensated to develop internal representations.

To investigate the compensation for such delays, we added an external delay to the force feedback, and presented participants with forces that depend on hand velocity a certain time beforehand. In force-channel trials, we measured the forces they apply to cope with the perturbations. To adapt to such delayed force field, the participants can apply a force that would be similar to a delayed velocity profile, based on a delayed velocity primitive, or build a prediction by approximating the delayed velocity as a combination of current state movement primitives. We tested these representation options by comparing simulations for each representation model to participants' force profiles in force channels at the end of adaptation. We also examined how the representation is influenced by the delay magnitude, and how it generalizes from slow to fast movements.

The best model for the forces that the participants applied was based on current and delayed velocity primitives, with more prominent separation between these primitives for larger delays. Furthermore, following adaptation, when participants were asked to move faster in force-channel trials, they applied forces that were also a combination of current and delayed velocity primitives. This generalization strengthens our conclusion that participants used a delayed velocity primitive and not its approximation using current state primitives.

Our results indicate that, contrary to earlier claims, the sensorimotor system represents delayed state. Interestingly, in the presence of delayed force perturbations, both delayed and current states are used for adaptation. These findings significantly advance the understanding of sensory integration and movement control in the presence of inherent feedback delays.

ROBOT MOTION LEARNING AND ADAPTATION

Davidowitz I., Berman S.

Ben-Gurion University, Israel

Programming by Demonstration (PbD) allows direct transfer of human knowhow regarding task and motion requirements to a robotic system. The ability of the robotic system to autonomously adapt previously learned motion profiles facilitates important reduction in required training cycles and Reinforcement Learning (RL) methods are commonly used to achieve such adaptation. However, RL require notoriously long convergence lags, especially in multi-dimensional spaces which are typically encountered in robotic applications. Therefore, improving learning efficiency is of importance, especially in scenarios where the robot must adapt to changes in the environment during run-time. Zhang et al. (2015) proposed using Principal Component Analysis (PCA) of PbD profiles for decomposition of task dimensions, and then application of RL using the non-principal dimensions as an initial search space. To ensure algorithm convergence, the search is re-initiated using a search space with additional dimensions in case a solution is not found in the reduced space. In the current study, we propose a modification of this algorithm based on using a dynamically growing space rather than the previous abort-and-re-learn methodology. The two algorithms were compared for learning a reach-to-grasp task. A human operator demonstrated the task using a telerobotic system (Sagi et al, 2015). The trajectories were transformed to robot coordinates (Mitsubishi RV-2F) and the principal component space was computed along with a representative trajectory in this space. Five new targets to which the robot was required to adapt the initial trajectory were defined. Both learning algorithms were executed 10 times for each target. Algorithm efficiency was measured by number of iterations until convergence. Results showed that learning required significantly more iterations when reaching the target required changing the trajectory in the principal space compared to when change was required only in the non-principal space. Using a dynamically growing space required considerably less iterations compared to the abort-and-re-learn algorithm when reaching the target required changing the trajectory in the principal space. When change was required only in the non-principal space the performance of both algorithms was similar.

Bayesian estimation of spatial configuration distribution

Duani R., Berman S.

Ben-Gurion University, Israel

Grapability maps are a spatial representations of endpoint configurations that lead to successful grasps. Such maps can be generated using simulation or physical demonstration (robotic or human). They have been used for analysis of both grippers and grasps and for reach-to-grasp motion planning. The graspability map samples can be used for establishing spatial distributions. In such cases, as most objects can typically be grasped using several grasp types, a mixture model, e.g., a Gaussian mixture model (GMM) is used. Previous research used Expectation Maximization (EM) for estimating model parameters. In EM the number of model components must be set a-priori and the best model is typically selected based on a cost criteria, e.g., the Bayesian Information Criterion (BIC). In contrast using non-Parametric Bayesian estimation, e.g., the Infinite Gaussian Mixture Model (IGMM) (Rasmussen, 2000), the number of components is among the estimated parameters and need not be a-priori set. Additionally over-fitting and local minima are avoided.

We applied IGMM to evaluate the distribution of endpoint configuration of successful grasps of three objects: a sphere, a cup with a handle, and a frying pan for which graspability maps were generated based on a physically validated simulation. We compared the generated models to GMMs generated using EM. With IGMM, the sphere's model had four components each encompassing different grasp orientations angles; For the pan the model generated included two components, one for grasps about the rim of the pan's body and the other for grasps about the handle; Similarly for the cup the model included two components, one for grasps about the cup's body and one for grasps about its handle. The models, especially for the pan and cup comply with our intuitive impression of suitable grasp types. Using EM more clusters were generated for each object (sphere 7; pan 10; cup 10) and their correspondence to grasp types was less evident.

In the future we intend to develop a non-parametric Bayesian estimation procedure for models with cyclic distributions. This is expected to reduce the number of artificial clusters, which may be the case in the model generated for the sphere.

Motion analyses for a robotic functional upper limb rehabilitation system

Eizicovits D., Edan Y., Tabak I., Raanan Y., Silverman Y., Duvdevani T., and Levy-Tzedek S.

Ben-Gurion University, Israel

Rehabilitation studies show that exercise repetition is essential, but difficult to sustain. Increasingly, robotic devices are investigated as a means to advance upper limb rehabilitation. In this research a 3D human - robot gaming system for upper limb rehabilitation was developed using physical objects and a KINOVA arm manipulator rather than video games, to generate a more realistic training of everyday activities. The system uses image processing to recognize the game status and the Kinect 2.0 for extracting the motion performance measures.

The research objective was to encourage long arm reaching movements with full functionality of the upper limb which requires the impairment of the arm and the hand. Hemiparesis patients might use trunk bending and increased shoulder elevation during reaching movements to compensate for their lack of the desired motor pattern. One way of measuring the compensation in the reaching movement is finding the maximal angle generated during the motion between the upper right arm and the torso which is defined as the arccosines equation between the two vectors formed by the arm and spine:

$$\theta = \max\left[\arccos\left(\frac{\mathrm{Arm}_{\mathrm{vec}} \cdot \mathrm{Spine}_{\mathrm{vec}}}{\left|\mathrm{Arm}_{\mathrm{vec}}\right| \cdot \left|\mathrm{Spine}_{\mathrm{vec}}\right|}\right)\right]$$

Data was collected from 6 subjects (ages: 25.5±0.75) in a preliminary experiment aimed at evaluating the effects of the gaming system on the human upper limb motion. Each subject played five games against the robotic system while using only their right arm. Objective quality measures were obtained based on the Kinect 2.0 and subjective quality measures were obtained based on the Godspeed questionnaire.

Results show that the robotic system challenged the participants to perform large repetitive motions which are important for the rehabilitation process. The maximal angle between the upper right arm and the torso was above 70 degrees in 81% of the trials. Results from the Godspeed questionnaire show that most subjects found the system safe (an average of 4.2 out of 5), however they were not entirely satisfied with the interaction as the average results of likeability was 3.2 out of 5. A potential solution for that might be a more human-like interface. Future work would focus on improving the gaming artificial intelligence, adding more personalization features and evaluating the effects of the system on different populations.

Disassociation between the effect of stiffness on accuracy of perception and action in teleoperated interaction with virtual elastic objects

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In bilateral teleoperation, users interact with a master manipulator to move a remote robot and sense environment forces. Teleoperation can improve many minimally-invasive medical procedures, in which the physician has to move accurately to avoid tissue damage (action), but also perceive delicate differences between the tissues to make appropriate decisions (perception). The forces that the physicians feel may greatly influence their perception and action.

It is well documented that perception of stiffness obays Weber's law – the sensitivity to small changes decreases when the stimulus intensity increases. However, the effect of stiffness on the accuracy of probing movements and the grip force that users apply on the tool remains unclear. In grasping, where perception of object size obays Weber's law, the accuracy of grasping action does not depend on the size of the object. We hypothesized that similar disassociation would exist in teleoperated interaction with elastic objects, and the accuracy of movement and grip force adjustment would not depend on object stiffness.

To test this hypothesis, we combined an adapation and a forced-choice paradigms. Participants made out-and-back movements to invisible targets inside elastic objects, and received feedback after each trial to achieve a desired movement magnitude. We measured the displacement of their hand and the grip force that they applied. We assess action by: (1) peak displacement variance, and (2) variance of the parameters of regression between grip force and load force. We assess perception by verbal judgement of stiffness.

In contrast to our expectation, we found that the accuracy of the movement and the accuracy of adjustment of the grip force to anticipated load force improved as stiffness increased.

Understanding the effect of stiffness on action and perception is important for determining the parameters of teleoperation control laws that will optimize the presentation of force information to users.

Effect of Training Duration on the Acquisition and Generalization of Motor Acuity

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A central component in motor skill acquisition is improvement in motor acuity, which can be captured by a shift in the speed-accuracy trade-off function (SAF) of the task. Using the Arc Pointing Task (APT), which requires performance of finely controlled wrist movements, we show that the acuity gains depend on the duration of training, and that duration further affects the prevalence of same-hand generalization to a different task.

Using their left, non-dominant, hand, subjects trained on a counter-clockwise (CCW) APT in an intermediate speed for two (group T2) and for three days (group T3), and tested, in separate days before and after training, on the performance in a clockwise (CW) and CCW task variants, in both hands, at four different speeds. A control group (Cr) that did not do any training between the test sessions was also examined.

Both T2 and Cr groups showed improvement in the trained and untrained tasks when performed with their left hand. However, two days of training (T2) did not lead to a significant improvement in the trained task when compared to the gains due to the test sessions alone (Cr). Additionally, both T2 and Cr did not show generalization to the other tasks. Nevertheless, training for three days (T3) lead to a significant improvement with respect to the Cr group and to a generalization to the CW task when performed with the same hand. This result suggests that while familiarization to the task elicits a shift in SAF, improvement in motor acuity requires at least three days of training. We suggest that only this additional improvement is generalized to another task, when performed with the same hand. Intermanual transfer was not found in any of the groups. Our results are consistent with previous fMRI results pointing to selective representational changes in the contralateral motor cortex following motor acuity acquisition.

Trouble with the curve: Variances and Invariances in the representation of end-point target and shape of curved trajectories during motor planning and execution

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Cortical areas that are directly involved in driving motor actions are active prior to movement onset. This activation is thought to reflect neural processes that are involved in motor planning. Little is known about qualitative differences in the patterns of activation during periods of planning and execution, and how the motor system distinguishes between the two in order to prevent premature motion. Furthermore, does planning account for the entire upcoming trajectory, or does it reflect a selection of an end-point target, and the trajectory is a consequence of following a control policy? We addressed these questions by studying fMRI activation patterns, recorded during the production of intentionally curved movements, a process that is associated with increased planning effort compared to straight point to point movements. We hypothesized that planning a curved trajectory requires generating a kinematic motor plan for the action, and that the plan will be invariant to rotations and active during both the phases.

Using a slow event related fMRI design, subjects performed 4 delayed memory-guided wrist reaching trajectories to one of two targets by making one of two curved shapes, indicated by a target and a single via point. Our multivariate analyses reveal a vast network of occipital, parietal and frontal areas that show selectivity to movement conditions during both the planning and execution phases. Additionally, we found representation patterns in occipital and parietal areas that share common condition representation during both planning and execution. Interestingly, activation patterns in the parietal and frontal areas differ between planning and execution in terms of end-point and shape invariance, hinting at a possible shift in functionality. For example, activation patterns in the primary motor cortex were invariant to end-point target during planning, and to trajectory's shape during execution. Overall, our results provide evidence for the existence of both common and separate functional processes during planning and execution of intentionally curved movements. The similarity in patterns of representation between planning and execution further suggest that intentionally curved trajectories are generated based on a kinematic plan.

Relating neural and kinematic trial-by-trial variability

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Trial-by-trial kinematic variability is a hallmark of human motor behaviors. While variability is detrimental for accurate behavior, many models of motor control stress the advantages of such variability: it is essential for motor learning/flexibility and enables exploration of alternative motor solutions through trial-and-error. We asked whether behavioral motor variability is a stable characteristic of the individual subject and whether we can identify neural sources that generate behavioral motor variability in humans.

Here we present evidence from several fMRI experiments, which demonstrate that: 1. Behavioral variability of individual subjects is correlated across targets and effectors (behavior of some subjects is "noisier" than others). ; 2. Brain response variability is correlated across targets and effectors (neural responses in some subjects are "noisier" than in others). ; 3. Brain response variabilities are correlated with behavioral variability of specific kinematic variables (subjects with "noisier" brain responses have "noisier" behavior). Specifically, variability in movement extent and peak velocity were correlated with brain response variability in parietal cortex (for both hands movements) and premotor cortex (for the right hand only). Directional variability was correlated with brain response variability in the left PMd for the right hand movements, and in the right SPL for the left hand movements.

We, therefore, conclude that the intensity of kinematic and neural intertrial variabilities are relatively stable individual traits and speculate that this may predispose individuals to exhibit different motor proficiencies and learning capabilities.

Trust in haptic assistance: Reliability-based weighting of visual and haptic cues

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Humans rely on multiple sources of information to effectively interpret and interact with the world. Through years of experience, the statistical properties of sensory information inherent to various tasks can be observed and learned, resulting in near-optimal integration of sensory cues via reliability-based weighting. However, can such behavior also be applied to an artificial cue from an unnatural source? Artificial cues may be presented by advanced assistance systems, where guiding forces or visual aids are computed by an intelligent, autonomous source and displayed to the user. This study investigated whether people can learn to appropriately rely on a haptic cue from an intelligent assistance system, even if it is not always accurate. Subjects held a haptic device and made reaches to a hidden target using a visual (Gaussian distributed dots) and haptic (force channel) cue. There were two levels of visual uncertainty, determined by the dot distribution and thus inherent to the stimulus. There was one level of haptic uncertainty, determined by the variance in target error over trials. Despite the artificial nature of the haptic cue, subjects learned to estimate the target location in a near-optimal manner, weighting the visual and haptic cues based on their relative reliabilities. This resulted in improved or equal performance with both cues compared to task performance with a single cue. These results provide evidence that the brain can learn to incorporate artificial cues from unnatural sources and weight them in a near-optimal manner, similar to what has been previously observed with sensory integration of naturally occurring cues. The implications of these results are favorable for haptic assistance and other augmented feedback systems under practical conditions; haptic assistance does not need to be perfect, as people can appropriately adjust their trust in an intelligent, autonomous assistive system depending on its relative reliability.

The Effect of Gripper Scaling on Grip Force Adjustment in Robot-Assisted Surgery – a Preliminary Study

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In robot-assisted minimally-invasive surgery (RAMIS) the surgeon teleoperates surgical instruments using robotic manipulators. Many RAMIS instruments have a gripper for grasping tissue and surgical equipment. When manipulating an object with a precision grip, we apply a grip force that is slightly larger than needed to not drop the object, and its magnitude is (predictively) adjusted to the load force of the object. Incorrect grip force in surgery may cause excessive fatigue, and may cause iatrogenic injuries to the patients when applying too much grip force, or slippage of tissue from the grasp when not applying sufficient grip force.

State of the art RAMIS systems do not present the surgeon with force feedback, and do not provide grip force information from the grasped objects, except from passive pseudo-grip force feedback from two physical springs in the gripper of the master manipulator. Hence, the surgeons must rely on visual cues from the environment to decide how much grip force to apply.

To provide surgeons with force feedback it is important to acquire the force information from the surgical environment, and present it reliably to the surgeon. Here we bypass the former problem by using image processing to compute a virtual load force, and focus on the latter.

We studied the effect of the scaling between manipulator and instrument gripper angles on grip force-load force adjustment in RAMIS. We hypothesized that although not necessary for holding the load, a larger gripper scaling will cause larger grip forces for similar load forces.

We constructed a custom RAMIS setup which consists of the RAVEN II surgical research platform, a SIGMA7 haptic device and a 3D vision system. Using the custom setup, subjects were asked to perform object lifting trials at the surgical environment by manipulating a haptic manipulator, controlling the surgical tool. Subjects received 3D visual feedback and image processing-based load force feedback, corresponding to the size of the object that was lifted, from the haptic manipulator. We recorded subjects‘motions and grip forces in each trial.

We show that the relation between grip force and load force is as in natural object grasping and that larger scaling caused some of the subjects to apply larger grip forces. We also show that subjects have a learning process during the interaction with our setup.

Volitionally enhanced beta-band oscillations by operant conditioning affects behavior in primates

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Beta frequency band oscillatory activity is prevalent in the motor cortex. Previous studies demonstrated that it increases during hold periods, attenuates during voluntary movement and re-emerges thereafter. However the exact role of beta oscillations in the planning and execution of motor action is still not understood.

In this work, we implanted an array of 96 microelectrodes in the motor cortex of two macaque monkeys. The monkeys were trained to volitionally enhance the neuronal oscillatory activity in the beta band (20-30Hz) at local selected sites by neural operant conditioning, using a real time brain machine interface (BMI) platform. At the same time, the monkeys had to perform a sensorimotor task involving color discrimination.

We show that the monkeys learned to robustly increase beta band cortical oscillations and that many neurons were phase locked to the oscillations. Furthermore, we found that the LFP beta-power before the execution of the motor action was positively correlated with the reaction times, and negatively correlated with behavioral performance (success rate).

Our results suggest that during high beta epochs new motor actions take longer to initiate and the perception of sensory inputs is impaired. These findings may support the widely accepted hypothesis that beta oscillations are tied to preservation of current motor state and help in unraveling the functional role of cortical oscillations and their effect on neural synchrony.

Differential contribution of temporal cues to optimal trajectory prediction in elite baseball and non-baseball players

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Elite athletes have shown to possess superior predictive, perceptual, and decision-making skills. However the concomitant distinction and interactions between perception, cognition and motor control in general have remained unclear. For example, the tight coupling between pursuit eye movements and perception has been challenged and is supported by evidence for the importance of subcortical pathways for implicit perception at early stages of visual processing. We aimed to investigate relative roles of internally (endogenous) and externally (exogenous) generated implicit temporal cues in optimal trajectory prediction between elite baseball (experts) and non-baseball players (controls). We predicted elite baseball players would better optimize the use of both temporal cues for accurate decision-making during trajectory prediction. While observing a ball moving vertically across a touch screen towards a visible square target, seated subjects had to predict within the trial time whether the ball would end up inside the target by touching a specific locus on the screen prior to the end of its trajectory. We varied duration of the fixation cross display before the ball moved (endogenous) and the speed and expansion of the ball once it moved (exogenous). We measured eye movements, pupillary response, hand movements, and screen touches and found that experts were more successful than controls when temporal cues were most challenging. When preparatory time is short experts exhibit faster arousal activation. When stimulus speed is fast, experts exhibit optimal voluntary saccadic eye movements at the early stage of the task, accompanied by subsequent superior decision-making and performance levels. During longer preparation times experts show slower arousal activation but similar performance levels. These results indicate that experts utilize internally generated temporal cues while controls do not and experts utilize externally generated cues better than controls. We propose subjects tune psychophysical responses for optimal performance. In experts, the neural pathways facilitating these responses have been optimally trained for short periods. At slower trajectories and longer preparation times when constraints allow it, slower top-down attentional processing and the temporal cues that trigger them are enough for optimal performance in both expert and normal groups equalizing performance.

Learning to use supplemental kinaesthetic feedback for enhancing reach performance

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Proprioception is critical for effective planning and real-time control of movement. Unfortunately, proprioception can be impaired after stroke. Our long-term goal is to develop sensory substitution technologies that provide supplemental sensory feedback, via vibrotactile stimulation, to restore closed-loop control of the arm in stroke survivors who lack proprioceptive integrity. As a first step, we evaluated the ability of unimpaired people to learn how to use two forms of vibrotactile feedback – limb state information or hand position error - to enhance performance of a goal-directed reaching task. Fifteen neurologically intact subjects participated in two experimental sessions performed on separate days. In both sessions, subjects grasped the handle of a planar robot and performed 10 blocks of center-out, out-and-back, reaching movements with their dominant hand to sixteen targets distributed around a central target. They received supplemental kinaesthetic feedback via a vibrotactile display fixed to their non-dominant arm. In one session, subjects trained to reach without vision using supplemental feedback that encoded an optimal combination of hand position and velocity information, whereas in the other session, the tactors encoded hand position error. We used root-mean-square (RMS) target capture error as our primary measure of performance. We found that all subjects captured all targets accurately when initially provided concurrent visual feedback of the target and a visual cursor representing hand position. Performance degraded dramatically when cursor feedback was subsequently removed. Reaches to all radial targets were hypermetric whereas return movements to the central target exhibited large systematic and variable errors. Errors were subsequently reduced rapidly – largely within the first training block - with supplemental vibrotactile feedback. For both forms of supplemental kinaesthetic feedback, target capture errors decreased progressively throughout the entire training session suggesting the involvement of both fast and slow learning processes (i.e., a dual-exponential decay model). For state feedback, the fast learning rate time constant averaged 1.7±1.1 trials (mean±SD), whereas the slow time constant averaged 162.1±135.9 trials. For error feedback, the fast time constant averaged 1.0±0.4 trials, whereas the slow time constant averaged 16.3±14.6 trials. Because subjects learned to use both forms of feedback to enhance the accuracy and precision of reaches made in the absence of visual feedback, we conclude that both are viable encoding schemes for improving closed-loop control of reaching movements, although error feedback appears easier to learn. Future studies should explore the ability of state and error feedback to enhance closed-loop control over the insensate arm post-stroke.

Weber's Law during Remote Reach-to-grasp Demonstration

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Object manipulation is a major component in many robotic tasks, yet programming a robot to grasp and manipulate an object is a non-trivial task. Researchers have been developing methods for alleviating the difficulties of robot programming trying to make robot programming accessible to individuals that are not knowledgeable in robotics. One such interface is Programing by Demonstration (PbD), where the operator demonstrates the required motion to the robot rather than explicitly programing it. A major issue in PbD is the interface used by the operator for demonstrating the task. Interfaces closely linked to robot dynamics, such as a kinesthetic teaching or tele-control of the robotic system simplify the human-robot correspondence mapping required, yet may make the task difficult for the operator obstructing the system's ability to exploit his or her natural manipulation abilities. We suggest using the inherent differences in human compliance to Weber's law in grasping and in perceptual assessments conditions for evaluating the naturalness of robotic interfaces. According to Weber's law, for perceptual assessment scenarios the just noticeable difference (JND) of a stimulus is proportional to the stimulus intensity. Unlike perceptual assessments, grasping movements, in which the JND is measured by the variability of fingers aperture, remains invariant with object size, thus violating Weber's law.

In the current research we examine the conditions which provide natural interface for PbD of robotic manipulation by assessing the adherence to Weber's law in different remote demonstration conditions. A data-centric telerobotic system was constructed based on a robotic manipulator (Motoman, Japan), a controlled jaw gripper (Schunk, Germany), two Phantom Premium haptic devices with finger thimbles (Geomagic, USA), and five cylinders. The robotic gripper aperture was controlled by the operator's finger aperture and the tool center point was controlled by the center of the aperture. Subjects were asked to remotely control or to demonstrate reach-to-grasp movements to the robot using the phantom device without moving the robot. Prior to the demonstration, subjects practiced remotely controlling the robot for several minutes.

Effect of braking elbow rotation on the kinematics of reaching movements. Perspectives for rehabilitation.

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The redundancy of the body and motor equivalence allow the kinematic invariance of the working point of the body specified by the task. In particular, the trajectory of the hand remains invariant during trunk assisted reaching even if the trunk is blocked (Ma and Feldman 1995). This was also the case when the elbow was unpredictably restrained before the movement (Mattos et al. 2011). We used a braked elbow or thesis to apply unpredictable perturbations during pointing movements. Twelve right handed healthy subjects performed two series of 42 pointing movements with a stick to targets placed in front of them, so that pointing involved flexion then extension elbow rotation (vision occluded at the onset of movement). The 6 first movements were controls, then the perturbations were triggered in a pseudorandom sequences (9 movements in each of 4 conditions : control, permanent viscous brake or hard brake triggered at two levels of elbow flexion). The perturbations modified the elbow and shoulder range of motion, increased the duration of the movements and delayed and lessened the velocity peak but did not increase the final pointing error nor modified the final trunk position. Rather it seems that the adaptation occurred mainly during the movement with modifications of the trunk rotation and shoulder-elbow coordination. Since the partial restraint of elbow rotation does not perturb the trajectory and final position of the working point this demonstrate the automatic adaptation of shoulder elbow coordination thanks to motor equivalence. The braked orthosis was developed in the perspective to mimic « pathological coordination » in order to develop sound feedback for rehabilitation (demo movies will be presented). However, the present results show that the coordination in healthy subjects is particularly robust and that the braked orthosis can hardly be a model of upper-limb motion in hemiparesis patients.

Analysis of surgeon hand and instrument orientation in robot-assisted and open needle driving

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Successful surgery requires procedural knowledge – knowing what to do, and motor skill – knowing how to do it. Quantitative characterization of surgical movements may help to improve the control of surgical robots and to optimize the training of novice surgeons. Today, surgical skill assessment is mainly performed by observation of an expert surgeon, yielding potentially subjective estimation. Robot-assisted surgery systems allow for monitoring of various parameters of the movement and developing new objective metrics of skill. Characterizing the movement of surgeons also opens a window to studying motion coordination in natural contexts.

So far, angular motion was not thoroughly examined in surgical skill assessment. We hypothesize that in order to perform surgical procedures successfully, the range and the rate of change of hand orientation are important. Using instrument's orientation, we developed a new metric: *normalized angular displacement,* which is the cumulative sum of the change of instrument orientation, normalized by the path length. We used the new metric and a classical metric (path length) to compare the performance of experienced robotic surgeons and novice users in open and teleoperated needle driving task. In the teleoperated task, we found that the new metric correlates with experience, and in contrast to the classical metric, shows statistically significant difference between novices and experts at the end of short training. Therefore, we think that the new metric can improve skill assessment.

A preliminary analysis of the open task revealed that the new metric does not show a difference between novices and experts. These results suggest that in the open task, in which the participant had all the sensory information, the angular motion that required for success in the task is done naturally. However, when some sensory information is missing, such as force feedback in the teleoperated task, the required angular motion is obtained only after long training.

Robotic Mirror Game to Encourage Movement for Physical Therapy Applications

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Due to the increasing affordability of robots and rising cost of healthcare, robots are becoming viable physical therapy tools. Robots currently assisting in upper-limb physical therapy can be classified into two general categories: exoskeletons and end-effectors. Exoskeletons, like ReWalk, are wearable robots that support the user and make contact throughout the limb. End-effectors, like Wood way Lokohelp, guide the wearer's limbs' from their endpoint.

Although these devices have vastly different means of assisting in the patient's recovery, both restrict the patient's mobility. Combining an assistive robot with a tracking system, we developed a "hands off" prototype for physical therapy. Our interactive system focuses on patients regaining functionality without restricting their movements.

We use a Kinova MICO robotic arm to interact with the patients and a Microsoft Kinect to track the their movements. Our adaptive algorithm enables the robot to interact with the patient in 3D, without direct contact between robot and patient. The Kinect tracks the relative location and movement of the patient, performing real time evaluations of the patient's performance and adapting the treatments' parameters accordingly. With these capabilities we built a robotic physical therapy tool that allows the patient to move freely in three dimensions, while maintaining a reciprocal real-life interaction with the physical robotic entity.

Assistive robots have greatly increased the independence of people with severe disabilities. They have enabled patients to, literally, travel and reach places beyond their physical limitations. We plan to build on this process and use assistive robots to assist in the patients' physical therapy process. We will present preliminary comparing this novel platform to a 2D projection.

A comparison of some linear methods for studying hand posture classification and reconstruction

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Kinematic synergies (or movement primitives) of hand have been widely used in studying abundance in human hand. Dexterity in humans is believed to be due to the presence of excess degrees of freedom than required for a task. Different algorithms have been used in classification and reconstruction of postures of human hand. In this study, we compare two such linear methods (PCA and U-LDA) in their performance of classification and reconstruction of hand postures.
Seven subjects (3 females) performed 70 different postures including daily life postures, ASL (American Sign Language) and aesthetic postures (Indian dance form Bharatnatyam). Each posture was performed 5 trials (a total of 350 trials). Sixteen (15+1 reference) 1.8 mm Liberty Electromagnetic tracking sensors (Polhemus, USA) were placed on each finger phalanx and we measured linear and angular displacement data at 120Hz. We considered the hand as a 21DOF system and computed 21 joints (4 DoFs for the digits and 5 DoF for the thumb). We applied linear dimensionality reduction techniques (Principal component analysis and Unsupervised Linear discriminant analysis) for extracting kinematic synergies which projects higher dimensional data to lower dimensional subspace. Our results shows that PCA gives better cluster purity compare to U-LDA in reduced dimension space. Also, we found that some postures are wrongly classified in LDA but not PCA. In addition first two principal components (PCs) explains more than 95% variance. However, scree plot for LDA showed that we require more than five eigen vectors for explaining about 95% of total variance. In addition, we computed contribution of each joint angle to make particular posture using PCA and LDA. Our preliminary results shows that using PCA we can explain joint angle contribution better compare to LDA technique. One of the reasons behind this results is fundamentally, LDA focuses classifying a single posture from pool of hand postures data correctly. We observed that there are more joint angles in PCA space which gives significant contribution (>5%) in comparison with LDA space. Our results may help in Robotics or Animation industry for reducing joint angles and making postures with reduced degree of freedom model. We suggest that analysing joint angle contribution with Non-linear dimensionality reduction techniques such as kernel PCA and Auto-encoder may help understanding abundance of human hand better.

Does the archer fish use motor adaptation to correct for light refraction?

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The archer fish is unique in its ability to hunt by shooting a jet of water from its mouth that hits insects above the water surface. To aim accurately, it needs to overcome the problem of light refraction at the air-water interface as there is a considerable difference between the actual and visible location of the insects as seen from below the water surface. Nevertheless, archer fish can still hit the target with high success rate from various angles and positions. Is the ability to compensate for the refraction a built-in mechanism or is it achieved by trial and error through motor adaptation?

As a first step towards this question, we determined if the fish can adapt to perturbations in the environment and make appropriate adjustments to its shooting method. We trained archer fish to shoot at a target situated above the water surface. If the hit was successful, it was rewarded with a food pellet. After several shots, an air flow applied horizontally to the water surface perturbed the fish's shot. The shots were recorded using a high speed camera and measured the fish's ability to deal with the perturbation.

We found that fish have the ability to adapt to our perturbation. Immediately after the introduction of the air flow perturbation, there was an increase in aiming error. Then, over the course of several trials, the error got smaller and, eventually, plateaued. On the first trials after the air flow perturbation was removed, the error was in the opposite direction, and this was washed out after several trials. This indicates that the fish was generating motor command that anticipated the perturbing air flow.

Our next step is to characterize in greater detail the fish behavior during adaptation and to record brain activity in the cerebellum and the optic tectum to reveal the mechanism of archer fish aiming.

Intermanual transfer of visuomotor adaptation depends on awareness

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In previous studies, intermanual transfer after gradual and sudden sensorimotor adaptation were compared to find out whether transfer depends on awareness of the nature of the perturbation. The results of these experiments, however, were contradictory. Furthermore, the results of our own recent study suggest that awareness depends on perturbation size. Thus, we hypothesize that if intermanual transfer is indeed related to awareness, we should find it only after sudden adaptation to a large perturbation but not after sudden adaptation to a small perturbation or after gradual adaptation.

To confirm this idea, four groups (S30, G30, S75, G75) of subjects performed centre-out-and-back pointing movements with their right arm. In a baseline block, they received veridical visual feedback about their movement. In the subsequent adaptation block, feedback was rotated by 30° (S30, G30) or 75° (S75, G75). This rotation was either introduced suddenly (S30, S75) or gradually in steps of 3° (G30, G75). After the adaptation block an awareness test consisting of an exclusion and an inclusion condition was conducted. The experiment concluded with an intermanual transfer block, in which movements were performed with the left arm under rotated feedback, and a washout block again under veridical feedback. We determined adaptation, awareness, unawareness, transfer and washout indices from the subjects pointing directions.

Analysis of variance (ANOVA) of the adaptation indices revealed no significant difference between groups for the end of adaptation block. Further ANOVAs of the awareness, unawareness, transfer and washout indices each yielded significant effects of Group. Post hoc analyses revealed the same significant pattern for awareness and transfer index and for unawareness and washout index, respectively. While awareness and transfer was larger in S75 than in all other groups, unawareness and washout was smaller in G75 than in S30 and S75, and was even smaller in S75 than in G75. Our results suggest that intermanual transfer does depend on the awareness of the visuomotor distortion and, thus, on the explicit process of motor adaptation.