The Eighth Computational Motor Control Workshop at Ben-Gurion University of the Negev

June 5, 2012, W.A. Minkoff Senate Hall, BGU Marcus Family Campus, Beer-Sheva, Israel

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

The Eighth Computational Motor Control Workshop at Ben-Gurion University of the Negev

June 4-6, 2012, W. A. Minkoff Senate Hall, BGU
Marcus Family Campus, Beer-Sheva, Israel
Website: http://www.bgu.ac.il/cmcw

Zlotowski Center for Neuroscience

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

Program:

Tuesday, June 5

- 8:30-8:50 Registration, poster placement and coffee
- 8:50-8:55 Greetings **Opher Donchin**, Head of the organizing committee, Ben Gurion University of the Negev, Israel
- 8:55-9:00 Opening Remarks **– Alon Fridman**, Chair, Zlotowski Center for Neuroscience, Ben-Gurion University of the Negev.

*Focusing the eyes: **Ehud Ahissar***

- 9:00-9:30 **Maarten Frens** - Erasmus MC,
- The Netherlands -
  " The Role of Cerebellum in Human Saccadic Learning**"**
- 9:30-10:00 **Brian Corneil** - University of Western Ontario in London, Canada.
  "An animal model for TMS of the frontal eye fields"
- 10:00-10:10 Discussion
- 10:10-11:00 Coffee Break & Posters

*Machines and Reward: **Armin Biess***

- 11:00-11:30 **Daniel Braun –**
  Max Planck Institute for Biological Cybernetics in Tübingen, Germany -"Risk-sensitivity in sensorimotor control".
- 11:30-12:00 **Jan Peters** - University of Darmstadt, Germany - "Towards Motor Skill Learning for Robotics."
- 12:00-12:30 **Sethu Vijayakumar** - University of Edinburgh, UK - "Explaining and Exploiting Impedance Modulation in Motor Control"
- 12:30-12:40 Discussion
- 12:40-14:30 Lunch & Posters

*Coordination: **Maarten Frens***

- 14:30-15:00 **Esther Adi-Japha** - Bar-Ilan University, Israel - "Motor learning in developmntal disabilities."
- 15:00-15:30 **John Rothwell** -
  University College London, UK -
  “The importance of movement variability during skill learning”
- 15:30-15:40 Discussion
- 15:40-15:50 Poster awards
- Sensegraphics, NanInsturments, AlphaOmega
- 15:50-16:20 coffee break & Posters

*Limb movement's: **Avi Karni***

- 16:20-16:50 **Sandro Mussa-Ivaldi** - Northwestern University, USA -
  "Optimal control, motor learning and the degrees of freedom problem: Is reaching targets all that matters?"
- 16:50-17:20 **Amir Karniel** –
  Ben Gurion University of the Negev, Israel -
  "The Turing-like Handshake test and the Active Sensing Principle"
- 17:20-17:50 **Marco Davare** –
  University College London, UK -
  "Effect of visuo-haptic conflicts on grasping movements"
- 17:50-18:00 Discussion
- 18:00-20 :00 Rest
- 20:00-22:00 Dinner

***Wednesday, June 6*:**

Alon Building Numb' 37, auditorium 202.

- 9:00-12:00 Lab Visits

*Rehabilitation Robotics: **Amir Karniel***

- 13:00-14:10 - Opening Remarks
- 14:10-14:50 BME Seminar:
  Sethu Vijayakumar –University of Edinburgh, UK - "Machine Learning for Robotics and Sensorimotor Control".
- 14:50-15:40 Panel about rehabilitation Robotics
  Miriam Zacksenhouse – Technion, Haifa
- 15:40-16:10 Coffee break
- 16:10-17:00 - Zlotowski Seminar:
  John Rothwell - University College London, UK - “Is theoretical motor learning important for practical rehabilitation therapy?”
- 17:00 – Pizza break

Invitation Letter and Call for Posters CMCW June 4-6, 2012

Dear Colleagues,

In what has now become a tradition, we wish to invite you to participate in the sixth annual Ben-Gurion University Workshop on Computational Motor Control on June 5th 2012, in the W. A. Minkoff Senate Hall at Ben-Gurion University of the Negev, Beer-Sheva, Israel. The following information is also available on our website: http://www.bgu.ac.il/cmcw

Thank you for your attention,

Opher Donchin and Amir Karniel
donchin@bgu.ac.il; akarniel@bgu.ac.il

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.

Call for Posters: The posters will be available throughout the day near the lecture hall to facilitate fruitful discussions.Please submit a one-page abstract of up to 400 words by May 1 through the website or by email to cmcw@bgu.ac.il with the subject heading "CMCW registration form". An email should clearly contain your name and affiliation. Notification of acceptance and abstract books will be mailed out **until May 15** . In addition, all accepted abstracts will appear on our website prior to the conference. Poster's should have a maximum width of 90 cm and a maximum height of 120 cm.

Best Poster Award:The award committee will choose the best poster(s) which will be announced at the end of the day.
The Best Poster Award Committee will be chaired by Amir Karniel, Ben-Gurion University.
To be considered for the best poster award, authors must submit a file with their poster to the Best Poster Award Committee by June 1, 2012. The poster can be submitted in PDF, TIFF, or Power Point formats by e-mail to cmcw@bgu.ac.il. Please use the subject heading "CMCW best poster submission" and include in the text of the message the name of the main author.
The Best Poster Award Committee members: Amir Karniel, Ronnen Segev and Sandro Mussa-Ivaldi.

The Best Poster Award Sponsors:

- Alpha Omega
- SenseGraphics
- NanInsturments
- Geomagic/SensAble Group

Travel Award: In special cases we will also consider a travel award to partially cover the expenses of international researchers/students. The criteria for the travel award will be: (i) The scientific quality of the proposed poster and its relevance to the topic of the workshop (ii) An interest in pursuing a PhD, post doc or faculty position at Ben-Gurion University. Those interested in receiving a travel award should submit an abstract for the poster they will submit and a short description of their circumstances by May 1 by e-mail to cmcw@bgu.ac.il with the subject heading "CMCW travel award."

Dinners: We will have a festive welcome dinner on the evening of June 4, before the workshop.Speakers and chairmen will be guests of the workshop at the dinner. For others wishing to join us, the dinner will be subsidized and will cost no more than 90 NIS per person. We will also have a more modest dinner and discussion in the evening following the workshop. Subsidized cost (other than speakers and chairmen) will be no more than 50 NIS per person.

Trip to the Negev: On monday, June 4th , we plan a trip to the Negev. Cost per-person will be no more than 150 NIS (approx. $40), registration and payment (cash only) to the trip will be done during the morning of June 4th at the workshop registration desk. Price includes the cost of lunch.

Registration: Please register before May 20. Registration is mandatory but free. Space may be limited, so please register early.Please register on our website or by email to cmcw@bgu.ac.il with the subject heading "CMCW registration form". Please indicate in your registration whether you are interested in particpating in the welcome dinner, the discussion dinner or the desert hike.

Sponsors:
- The President, Ben-Gurion University
- The Zlotowski Center for Neuroscience, BGU
- The Dean of the Faculty of Health Sciences
- The Dean of the Faculty of Engineering

***"The Tastes of the Desert"* – the first Day of the Conference**

A trip dedicated to Encounters between the ancient & the modern life in the Negev Desert

11:00 – We will leave from the parking lot of Building 72 in the University (please see the attached map at the end of the book).

11:15 – The second place of gathering the Leonardo- Hotel.

11:45-12:15 - The Monument to the Negev Brigade, situated on a hill overlooking the city of Beer- Sheeva from the east and a recognized symbol of the Neveg and Beer Sheeva. The place constitutes Historical & Geographical Orientation to the south of Israel for our trip.

13:00- 14:00 – lunch in Drijat the farmer's village has a fascinating story of a unique non-nomad population in desert landscape.

14:00- 15:15 - Tour the village and visit "the cave" This remote village, looks like it belongs in another time and place. In the cave traditional coffee & tea will be served, our host Gabber will tell us the way of his ancestors who used to live in these caves.

16:00- 17:00 – A visit to the Archeological site of "Tel Beer Sheeva", an ancient city focusing the "Iron age" through this visit we will explore the inspiring connection between the findings to stories of the Bible.

17:15 – Visit the farm "Bat- Hamidmar" at the Bedouin (the nomads of the Negev and Arab deserts) town Tel-Sheeva.

"Bat Hamidbar" (the Daughter of the desert) is a farm owned by Miriam a Bedouin woman who manufactures soaps, lotions etc' out of the desert's vegetation. She will tell us about her life and as a working woman in the Bedouin Society and how she is producing her merchandise.

18:30 – The Festive Dinner in the farm "Bat- Hamidmar" authentic Bedouin food will be served.

Bring with you: hats, comfortable clothes and shows for a warm day, camera, and sun's cream

All the best!

Looking forward to see you all

Eitan -the guide of the trip

Talks Tuesday

Computational Motor Control Workshop, BGU,

June 5, 2012

The Role of Cerebellum in Human Saccadic Learning

Maarten Frens

Erasmus MC, the Netherlands

Saccade adaptation (SA) is a paradigm that has been extensively studied for several decades. Although much is known about SA on a behavioural levelm almost all of our knowledge about its neural representation is based on work in non-human primates, whose adaptation behaviour is substantially different. We set out to systematically investigate the representation of SA in human cerebellum. To do so we conducted a series of imaging and stimulation experiments. From this the image emerges that SA is represented over several areas in the cerebellum. Activity depends on the size and the direction of the induced error. Stimulation over Crus II with the proper timing could enhance the adaptation process.

An animal model for TMS of the frontal eye fields

Brain Corneil

University of Western Ontario, Canada.

The oculomotor system, which rapidly moves the line of sight, is one of the best- understood motor systems. Although typically studied head-restrained, this system evolved to control the gaze axis in space with the head free to move. In my laboratory, we pair recordings of neck muscle activity with neurophysiological techniques. Recent results demonstrate that volitional or imposed signals that appear “covert” since the gaze axis remains stable culminate in overt motor recruitment at the neck. We speculate that these results arise because of brainstem circuits that tightly govern the initiation of saccades without exerting a similar level of control on the initiation of neck muscle recruitment. This line of thinking led us to investigate neck muscle responses evoked by transcranial magnetic stimulation (TMS) of the FEF. In both humans and non-human primates, TMS-FEF evokes a brief, state-dependent neck muscle response. Such neck muscle responses provide an objective measure that motivate and guide predictions about exactly what TMS is doing within the oculomotor system, and support the suitability of the non-human primate as an animal model for TMS-FEF.

Risk-sensitivity in sensorimotor control

Daniel Braun

Max Planck Institute for Biological Cybernetics, Germany.

Recent advances in theoretical neuroscience suggest that motor control can be considered as a continuous decision-making process in which uncertainty plays a key role. Decision-makers can be risk-sensitive with respect to this uncertainty in that they may not only consider the average payoff of an outcome, but also consider the variability of the payoffs. Although such risk-sensitivity is a well-established phenomenon in psychology and economics, it has been much less studied in motor control. In fact, leading theories of motor control, such as optimal feedback control, assume that motor behaviors can be explained as the optimization of a given expected payoff or cost. Here we discuss evidence that humans exhibit risk-sensitivity in their motor behaviors, thereby demonstrating sensitivity to the variability of "motor costs." Furthermore, we discuss how risk-sensitivity can be incorporated into optimal feedback control models of motor control. We conclude that risk-sensitivity is an important concept in understanding individual motor behavior under uncertainty."

Towards Motor Skill Learning for Robotics

Jan Peters

Technical University of Darmstadt, Germany

Autonomous robots that can assist humans in situations of daily life have been a long standing vision of robotics, artificial intelligence, and cognitive sciences. A first step towards this goal is to create robots that can learn tasks triggered by environmental context or higher level instruction. However, learning techniques have yet to live up to this promise as only few methods manage to scale to high-dimensional manipulator or humanoid robots. In this talk, we investigate a general framework suitable for learning motor skills in robotics which is based on the principles behind many analytical robotics approaches. It involves generating a representation of motor skills by parameterized motor primitive policies acting as building blocks of movement generation, and a learned task execution module that transforms these movements into motor commands. We discuss learning on three different levels of abstraction, i.e., learning for accurate control is needed to execute, learning of motor primitives is needed to acquire simple movements, and learning of the task-dependent "hyperparameters" of these motor primitives allows learning complex tasks. We discuss task-appropriate learning approaches for imitation learning, model learning and reinforcement learning for robots with many degrees of freedom. Empirical evaluations on a several robot systems illustrate the effectiveness and applicability to learning control on an anthropomorphic robot arm.

Explaining and Exploiting Impedance Modulation in Motor Control

Prof. Sethu Vijayakumar

University of Edinburgh, UK

Variable Impedance refers to the ability to change stiffness and damping during task execution. Humans have an excellent capacity to modulate impedance in response to task demands. Is there some systematic optimality principles underlying this modulation? With novel prototype robotic actuators capable of fast impedance modulation, another obvious question is how we can maximally exploit this capability in an automatic and data driven manner? This talk will aim to elucidate principles that can be used to study and explain impedance modulation in a consistent manner, explaining stiffness adaptation from first principles of minimizing uncertainty. I will also describe an MPC based optimal control formulation for optimizing both the temporal profile of movement and impedance modulation in a way that is tuned to the dynamics of the plant. Implementation of dynamically energetic tasks such as throwing and brachiation will serve to highlight the benefits. This talk will draw upon concepts of stochastic optimal feedback control, dynamics representation and incremental learning.

<u>Motor learning in developmental disabilities.</u>

Esther Adi-Japha

Bar-Ilan University, Israel

The cognitive processes and neural substrates that mediate our capacity to acquire new motor skills have been studied in recent years among the adult human population, and among school-age children. It was shown that following a training experience, significant training- dependent gains in performance can appear hours after the termination of training, for example 24 h post-training. These gains were maintained for weeks and months. It has been proposed that these delayed gains reflect neuronal memory consolidation processes that require time, and in some cases sleep, to reach completion.

Traditionally, the acquisition of new motor skills (for example, handwriting) is typically cited to demonstrate learning that is supported by the procedural memory system. Ullman (2004) highlighted the fact that the procedural memory system is involved in the acquisition of language skills and habits, such as the implicit knowledge of language rules and suggested an atypical procedural memory system in individuals with language impairment (LI, Ullman & Pierpont, 2005). Following this line of study, Nicolson and Fawcett (2007, 2011), suggested that an atypical procedural memory system is involved in a range of developmental disabilities, including ADHD and LI. In this talk we will focus on skill acquisition in children with LI who learned to produce a simple written letter (study 1, Adi-Japha, Strulovich-Schwartz, & Julius. 2011) and a more complex letter (study 2, ongoing work). We will briefly discuss skill acquisition in adults with ADHD (Study 3, Adi-Japha, Fox, & Karni, 2011).

In study 1, 5-year-old children with language impairment and their peers matched for age and visual-motor integration skills practiced the graphic production of a new symbol and were tested 24 h and two weeks post-practice day. Differences in performance speed emerged between the groups: children with LI showed a later onset of rapid learning in the practice phase, and only the comparison group exhibited delayed, consolidation, gains 24 h post-training. At two weeks post-training, children with LI improved, closing the gap in performance speed. In study 2, 5-year-old children with language impairment and their peers matched for age and IQ practiced the graphic production of a complex new symbol for 4 consecutive days and were tested two weeks post-practice day. Children with LI forget more than their peers between sessions, but also learned more within sessions, showing only some of the expected characteristics of long-term memory formation. In study 3, Thirty-two participants, 16 with ADHD, were trained on a sequence of finger movements using a well-established training protocol, and tested before training and immediately, 24 h and 2weeks after training. Both groups showed similar within-session gains in speed; additional, delayed gains were expressed at 24 h, but less robustly in ADHD, and at 2weeks post-training. However, while controls showed significant delayed gains in accuracy at 24 h and 2 weeks post-training, accuracy deteriorated in ADHD from pre-training to 24 post-training and was only at pre-training levels by 2-weeks post-training.

<u>The Importance of Movement Variability for Skill Learning</u>

John Rothwell, Joe Galea, James Teo and Orlando Swayne.

UCL Institute of Neurology, UK

There is a large body of experimental and theoretical work on model-based adaptation learning. However there is much less information available about processes involved in skill learning, which is often defined as a shift in the speed-accuracy trade off. In effect, this requires the motor system to explore new ways of performing a task outside the range of its past experience. To do this may require a model-free approach in which task variables are explored and chosen based on success or failure (reward). We explored this idea in two experiments.

In the first we artificially manipulated the trial to trial variability of motor cortical (M1) output by pre-treating M1 with a single session of intermittent theta burst transcranial magnetic stimulation (iTBS). This increased the variability of thumb movements evoked by subsequent single TMS pulses applied to the hand area of M1. In a separate experiment, iTBS was applied prior to learning a ballistic thumb abduction task in which participants have to maximise the initial acceleration of the movment. Compared with sham TMS, iTBS increased the rate at which participants improved their acceleration, and the amount of improvement correlated with the increase in trial to trial movement variance. We suggest that increased exploration of task space allowed individuals to maximise the rate at which they acquired the new skill.

In a second experiment we explored the role of reward/punishment on the variability of movement. We argued that if a model-free, reward based system was important in optimising movement parameters, then reward would reduce variability (since it signals success) whereas punishment would require variability of movement to increase. To assess this, participants performed a repetitive finger movement and were instructed that reward was based on maximal acceleration, when in fact the feedback was deterministic. This allowed us to investigate whether punishment increased behavioural variability, as a result of the motor system searching for a more rewarding outcome, within the boundaries of the same action. Two experimental sessions involved either the administration of a dopamine D2-antagonist or placebo. Throughout the task, transcranial magnetic stimulation (TMS) was used to read-out whether any DA-dependent changes in behavioural variability might be paralled by neurophysiological variability in primary motor cortex (M1). Relative to reward, behavioural and neurophysiological variability was greater during blocks biased towards punishment. D2-antagonist administration reduced the variability associated with punishment and abolished the correlation between behavioural and neurophysiological variability. We propose that dopamine has a critical role in shaping behavioural variability during action execution, with a neurophysiological analogue in M1 which is specific to the muscle involved in behaviour.

Optimal control, motor learning and the degrees of freedom problem: Is reaching targets all that matters?

Ferdinando A. Mussa-Ivaldi

Northwestern University, USA

Theories of optimal control applied to the analysis of motor behavior have suggested that the motor control system learns to optimize the accuracy of reaching movements by shifting the variance associated with motor noise to the degrees of freedom that are not affecting the final accuracy of a movement. Here, I will present a different view, according to which the purpose of motor learning is not to increase movement accuracy in order to maximize some immediate reward. I will discuss evidence that motor learning aims at acquiring operational knowledge about the geometrical and mechanical properties of the space in which movements take place. In recent experiments, human subjects were asked to control a simulated kinematic linkage by continuous finger motion, a completely novel sensory-motor task. This paradigm removed all biases arising from influences of limb dynamics and past experience. Subjects were exposed to two different types of visual feedback; some saw the entire simulated linkage and others saw only the moving extremity. Consistent with our hypothesis, subjects learned to move the simulated linkage along geodesic lines corresponding to the geometrical structure of the observed motion. These findings do not invalidate the theory of optimal control per se. If indeed the motor system is optimal attaining some goals, these must include the ability to operate according to the geometrical and physical structure of the environment and cannot be reduced to minimizing final reaching errors or neuromuscular effort.

The Turing-like Handshake test and the Active Sensing Principle

Amir Karniel

Ben-Gurion University of the Negev, Israel

The Turing-like handshake test, has been designed to measure our progress in understanding the motor control system in units of human likeness, under the assumption that being able to simulate the motor control system is a prerequisite for understanding it.

In this talk I will describe the test and our measures of human likeness as well as the recent Tournament between three handshake models: (i) Tit-for-Tat model, proposed by G. Loeb (ii) λ model inspired by A. Feldman; and (iii) a Machine Learning model proposed by K. Kording et al.

Considering various handshake we came up with an hypothesis asserting that facing passive handshake leads to active handshake and vice versa. We have formulated this idea, called it the active sensing principle and demonstrated it by proving it analytically for a second order linear system. I will briefly present this study and refer the audience to the poster by Furmanov and Karniel about this study in this very workshop.

I will conclude this talk by discussing the scientific and technological implications and future applications of studying motor control of human handshake and measuring our progress by the model human likeness grade developed as part of the Turing-like handshake test.

Effect of visuo-haptic conflicts on grasping movements

Marco Davare

UCL Institute of Neurology, UK

Grasping and manipulating objects with high dexterity requires the brain to extract useful information from multiple sensory sources, in particular vision, touch and proprioception. The integration of multiple sensory modalities that convey signals to the brain at different times during movement is a major challenge. Here, we investigated how the motor system uses information from vision and haptics (i.e. touch and proprioception) to plan grip-lift movements. When lifting a series of objects, the planning of fingertip forces relies on the integration of a sensorimotor memory acquired from previous lifts and visual cues from the present object. We tested whether a conflict between vision and haptics in the previous lift has an effect on the fingertip force planning of the next lift. To do so, we used a virtual reality environment that allowed subjects to grasp a haptic object simulated by two Phantom robots while they received online visual feedback via a 3-D screen. Subjects were instructed to grasp and lift the object using their thumb and index finger, which were attached to the robot's arm with a thimble. We varied the object size and weight. In 20% of trials, the size and weight of the object were incongruent (i.e. small&heavy or large&light). We quantified the grip force (GF) rate peak as a behavioural read-out of force planning. First, we found that subjects (n=10) overall used object size to scale their GF even if size and weight were incongruent in 20% of trials. GF rate peak was significantly higher (24% increase) for large objects with respect to small ones. In addition we also quantified the sensorimotor memory effect by comparing lifts preceded by heavy relative to light objects when size and weight were always congruent. As expected, we found significantly higher GF rate peaks (13% increase) when the object previously lifted was heavy compared to light. We also assessed whether a visuo-haptic conflict in the previous trial changes the sensorimotor memory effect. Interestingly, we showed that GF rate peaks were significantly lower (8% decrease) when the previous object was large &light compared to small &light. Conversely, there was a significant increase in GF rate peaks (15%) when the previous object was small &heavy compared to large &heavy. In conclusion, our results show that the motor system is capable to bias the sensorimotor memory by rapidly learning a new size-weight relationship.

Talks - Wednesday

Panel Discussion Robotics For Rehabilitation

Computational Motor Control Workshop, BGU,

June 6, 2012

Machine Learning for Robotics and Sensorimotor Control

Sethu Vijayakumar

University of Edinburgh, UK

Humans and other biological systems are very adept at performing fast, complicated control tasks in spite of large sensorimotor delays while being fairly robust to noise and perturbations. There are various components involved in achieving such levels of robustness, accuracy and safety in anthropomorphic robotic systems. Broadly, speaking challenges lie in the domain of robust sensing, flexible planning, appropriate representation and learning dynamics under various contexts. Statistical Machine Learning provides ideal tools to deal with these challenges, especially in tackling issues like partial observability, noise, redundancy resolution and scalability.

I will talk about some of the large scale machine learning techniques we have developed for: (a) real time acquisition of non-linear dynamics in a data driven manner, (b) automatic low-dimensional (latent space) representation of complex movement policies and trajectories and (c) planning methods capable of dealing with redundancy (e.g. variable impedance) and adaptation. Exciting videos of learning in high dimensional movement systems like anthropomorphic limbs (KUKA robot arm, SARCOS dexterous arm, Touch Bionics iLIMB etc.) and humanoid robots (HONDA ASIMO, DB) will serve to validate the effectiveness of these machine learning techniques in real world applications.

Panel Discussion Robotics for rehabilitation

Moderator: Miriam Zacksenhouse,

BCI for rehabilitation Laboratory, Technion. Israel

Panelists:

1. **Zeev Meiner**, MD, Dept. of Physical Medicine & Rehabilitation, Hadassah University Hospital

2. **Gabi Zeilig**, MD, Dept. of Neurological Rehabilitation, Sheba Medical Center.

3. **Dario Liebermann**, PhD, Dept. of Physical Therapy, Faculty of Medicine, TAU

4. **John Rothwell**, PhD, Univ. College London, Institute of Neurology, UK

5. **Sandro Mussa-Ivaldi**, Phd, Northewestern Univ. Rehabilitation Institute of Chicago, Chicago, USA

Abstract:

Rehabilitation requires extensive re-training for regaining both cognitive and motor function. Recent developments resulted in rehabilitation robots, which assist disabled patients to perform repetitive motor training tasks. The panel discussion will address issues related to how well robot-assisted rehabilitation is performing and what is needed to improve and enhance their success and integration. Specifically:

Zeev Meiner will present the experience in Hadassah rehabilitation department using robotic-assisted gait orthosis (RAGT), the LOKOMAT, in the treatment of patients with neurological diseases. Their studies showed that in 3 different populations the treatment with RAGT was beneficial. In stroke patients, 6 weeks of locomotor therapy using RAGT combined with regular physiotherapy was superior to regular physiotherapy alone in achieving functional walking ability. In SCI patients the combination of assisted treadmill training and partial body-weight support allows severely affected SCI patients to perform locomotor training efficiently and in MS patients RAGT is feasible and may be an effective therapeutic option**.** Although some of the results were encouraging, there is still uncertainty regarding proper patients' selection, timing and protocol for RBWTT treatment following neurological diseases.

Gabi Zeilig will introduce his personal vision regarding the role of the clinician in the multidisciplinary cooperation that should include also partners from rehabilitation engineering and basic neurobiological research as well as people living with disabilities.

Dario Liebermann will argue for the need to create an "integrative stage" in the evolution of a robot-based rehabilitation approach, whereas knowledge acquired from basic science (understanding mechanisms), clinical research (characterization of neuro-motor pathology and evaluation of robot-based interventions) and engineering (solution-oriented research and development), all become tailored to the actual needs of patients and practitioners.

John Rothwell will discuss the problem of the missing "expert coach" in robotic therapy. He will argue that people often need to employ cognitive strategies to move in the most effective way and these depend on environmental factors.

Sandro Mussa-Ivaldi will discuss a new approach to the task of interfacing the human body with external devices, which is based on (1) developing programmable maps between body motions and their functional and sensory consequences, and (2) organizing these maps so as to combine the access to assistive devices with the development of functional exercises for the recovery of motor functions.

Miriam Zacksenhouse will discuss the potential importance of integrating the brain-in-the-loop during stroke rehabilitation. She will argue that this can enhance timing and adaptation of robotic intervention and provide a diagnostic and monitoring tool.

Is theoretical motor learning important for practical rehabilitation therapy?

John Rothwell. UCL Institute of Neurology, UK

Rehabilitation is a long, slow process in which the brain has to learn how to produce movement with a damaged motor system. In recent years, a great of work in motor control has provided important insights into, for example, process and principles of adaptation learning; the importance of neuroplasticity for learning; and the importance of repeated massed practice. Yet many clinical trials that were based on sound scientific principles such as these have often been unsuccessful. Good examples are the recent large trials of robotic gait training and weight supported treadmill training, both of which show no improvement over over-ground training. Clearly something is missing about our understanding of motor learning that is highly important when it comes to practical application of that knowledge. I will try to highlight some of our own experience with failed trials which were based on excellent science, and explore some of the reasons why this may occur. I will also discuss what we can learn from successful therapies about the missing links in our logic.

Posters

Shaping of arm configuration space by prescription of non-Euclidean metrics with applications to human arm movements

Armin Biess*

Max-Planck-Institute for Dynamics and Self-Organization, 37073 Göttingen, Germany

We endow arm configuration space with different non-Euclidean metrics and study the predictions of the generalized minimum-jerk (MJ) model in the resulting Riemannian manifold for different types of human arm movements. The prescribed metrics encode different distance measures on the manifold and are derived from the movement dynamics and the hand and elbow displacements in task space, respectively. For each metric space the optimal solution of the generalized MJ-model is given by re-parametrized geodesic paths (geodesic model). Using this differential geometric approach we analyze three-dimensional unconstrained movements of a four degree of freedom arm between pointlike targets as well as constrained movements where the end-effector location is confined to a surface (e.g., a sphere) or a curve (e.g., an ellipse). For the latter speed-curvature relations are derived and the compatibility with the empirical two-thirds power law is shown. We hypothesize that the sensorimotor system may shape arm configuration space by learning
metric structures through sensorimotor feedback.

* Currently at General Motors, Advanced Technical Center, 7 HaMada Street, Herzlyia 46733

Motor control during speech articulation at the single neuron level

Ariel Tankus [1,2], Itzhak Fried[1,3,4] and Shy Shoham[2]

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Abstract

Human speech sounds are produced through a coordinated movement of structures along the vocal tract. Because it is unique to humans, little is known about the neural representation of speech articulation at the single cell level[1,2], and how it relates to the coding of other motor and cognitive processes. This study shows that the neuronal encoding of vowel articulation in two speech areas in human temporal and frontal lobes is highly structured at both the single-unit and the neuronal population levels. At the single neuron level, we find signatures of two structured coding strategies: highly specific sharp tuning to individual vowels (in medial-frontal neurons) and non-specific, sinusoidally-modulated tuning (in the superior temporal gyrus), analogous to the tuning of motor cortical neurons during the control of directed movement. At the neuronal population level, we find that the encoding of vowel generation appears to be organized according to a functional representation of a spatial-anatomical axis: the position of the highest point of the tongue during articulation. Our results thus demonstrate that a parameter important for articulatory motor control is encoded at the population level activity. This structured encoding enables accurate decoding of volitional speech segments and could be applied in Brain-Machine Interfaces for restoring speech in paralyzed individuals[3,4].

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Can Time Delay between Visual and Proprioceptive Feedback during Tracking be Represented by a Mass-Spring-Damper System?

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Usually, external events issues simultaneous sensory feedback, e.g. the sound and vision of a shattering glass will always seem simultaneous; however, there are events where this simultaneity is broken like the sound of a thunder that will always delayed the vision of the lightning. Even in what is seem to be simultaneous sensory feedback, as in the first example, there is a temporal difference due to different neural propagation delays which needs to be processed to seem simultaneous. Evidence of difficulty to employ temporal representation may suggest that the system tries to obtain an equivalence representation with a plausible candidate which is a mechanical equivalence.

We hypothesized that the motor system adapts to delay between visual and proprioceptive feedback during 1-D tracking task using an equivalence mechanical representation derived from time delay operator Taylor approximation.

The task involved tracking a virtual target moving in sinusoidal manner by moving a virtual cursor which follows the hand position by either 250 ms delay (D) or through mechanical system which corresponds to the first two elements in the Taylor series of the time delay operator (M). We recruited subjects to participate in one of two experiments: in the first experiment subjects tracked the target using the delayed cursor (D) for 8 trials lasting 2 minutes each and proceed for another 8 trials of tracking using the mechanical cursor (M). In the second experiment the subjects did exactly the opposite, i.e. started with 8 trials of tracking using the mechanical cursor (M) and continued to another 8 trials of tracking using the delayed cursor (D).

We show that subjects continued reducing the error between target and cursor while switching from the delayed tracking task to the mechanical tracking task (D->M) (P=0.0043) one-way repeated measures ANOVA with Bonferroni correction for multiple comparisons) while during the opposite order, i.e. (M->D), improvement is not significant (P=0.0855). We also show that although the mechanical tracking (M) required longer and faster movements than delay tracking (D), subjects were still able to perform better during mechanical tracking.

We suggest that during first encounter with the perturbed tracking task, subjects construct a mechanical representation to the cursor moving behavior. Since the representation was not aligned with the cursor motion during the delayed tracking, subjects were not able to improve their performance in contrast to the mechanical tracking where representation was closer to the actual cursor behavior.

State Representation of Time Delay during Motor Learning

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A recent study[1] found clear adaptation to delayed velocity-dependent force perturbations during reaching movements. However, the way in which the nervous system represents the presence of delays in reaching movements is not yet well understood.

In this study, we explored this question by exposing three groups of subjects to delayed, non-delayed and combination of delay and non-delayed velocity-dependent force perturbations. In the delay trials, the force lagged the current velocity by 70 msec. Each subject performed three phases of movements: baseline, adaptation and post-adaptation. In the first baseline phase there were 100 trials, in which no force field was applied. The second phase was an adaptation phase of 200 trials, during which subjects performed reaching movements in a velocity-dependent force field. Finally, the third phase was a post-adaptation phase of 100 trials, in which no force field was applied. Learning capability was assessed by measuring the lateral perpendicular forces profiles that subjects generated during movement in force-channel trials. In the experiment with combined delayed and non-delayed perturbations, the force-channel trial was always presented after two consecutive delay and non delay perturbation trials. The results of the previous study were reproduced, demonstrating clear adaptation to the delayed force perturbations; however, the lateral forces applied by the subjects during force-channel trials in the delay group were not shifted in time compared to in the lateral forces of the non-delayed group. Instead, the forces against the channel start in phase with the current velocity, without a lag of 70 msec. Moreover, the lateral forces of the third group was identical - at least in the first part of the movement- to the state-force average of the forces from the first two experiments

These results suggest that the motor system develops a state-based representation of time delayed forces.

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Moving curiously on the way to reaching

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An agent attempting to reach a moving target must be able to perform several subtasks, such as motion detection, visual-to-arm coordinate transformations and directed motion of the arm towards the visual target. We investigate an agent, driven by curiosity, such that it moves in an optimal manner in order to autonomously learn all the required transformations. The hierarchical curiosity loop architecture implemented in a robot results in a sequence of complex emergent behaviors: alternation of motion/no motion of the eye for motion detection; periodic motion of the arm for learning the inverse model and synchronized motion of the arm and eye for visual self-recognition. These autonomously learned behaviors facilitate the rapid appearance of a reaching motion.

A Biologically Inspired Controller For Dynamic Biped Locomotion

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In recent years there has been a growing interest in the field of dynamic walking and bio-inspired robots. However, most works focus on walking or running on a flat surface and few deal with the issue of walking over terrains with different slopes. In this work, we develop an open-loop controller based on a Central Pattern Generator (CPG) and apply it to a Compass-Gait biped walker. The bio-inspired controller generates a stable walking gait over a small range of slopes. This range is greatly increased by applying a once-per-cycle feedback to the CPG controller. The bio-inspired controller enhanced with minimal feedback allows the dynamic walker to traverse terrains with slopes ranging from +10 to -10 degrees. We use numerical simulations to investigate the resulting gaits and verify stability. The stability of the obtained limit cycles is demonstrated through the system's Poincare Map.

Handedness and the perception of delayed stiffness

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Handedness is defined by unequal distribution of fine motor skills between left and right hand. Can that hand asymmetry influence the way we perceive mechanical properties such as stiffness? The human perception of stiffness has been studied as subjects probed virtual elastic spring-like fields using their dominant hand only. It was found that a delay between force and position (force lags position) has a significant influence on our perception. Subjects overestimated delayed stiffness and that overestimation increased monotonically with the increasing of the delay [1]. The boundary of the field also plays an important role, while the hand remains in a continuous contact with the elastic force field, subjects tend to underestimate the delayed stiffness and overestimate it when they move across the boundary. It was suggested that the differences in perception are originated from a difference in the control strategy [2]. In addition, a proximo-distal gradient in the amount of underestimation of delayed stiffness was found in the transition between probing the field with shoulder, elbow and wrist joint, supporting the force-position control hypothesis [3]. Sainburg suggested the existence of different control strategies between hands [4], we suggest that different control strategies result in a different perception of stiffness, and thus we hypothesize differences in the perception of stiffness between hands. To the best of our knowledge, no one has yet examined possible differences between the perceived stiffness while probing with the dominant and non-dominant hand.

In this study, subjects were presented with two virtual elastic fields and were asked to choose which one was stiffer after probing it with their dominant/non-dominant hand. At the next day they repeated the task, using their other hand. Psychometric curves were derived from the responses of the subjects in this forced-choice task, according to their probability to answer: 'delayed field was stiffer'. The Point of Subjective Equality (PSE), indicating the stiffness difference that was perceived to be zero, has been extracted from a logistic function fitted to the answers of each subject. Initial results showed a significant ($p<0.05$) difference between PSE values of right and left hand of each subject individually. This result is discussed in light of the current models of the perception of stiffness and possible future models that would include the effect of the probing hand.

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ADAPTED VISUOMOTOR MAPPINGS DECAY TO PREVIOUSLY REINFORCED BEHAVIORS

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When subjects adapt to a visuomotor perturbation they decay back to their baseline behavior when error feedback is removed or when they are provided with false feedback that shows zero error. What is so special about baseline that makes subjects decay back to it? We show that subjects can be manipulated to decay towards a different behavior if that behavior is first reinforced with binary reward in the absence of error feedback.

We examine the time course of decay of adaptation through a "visual error clamp"– trials in which subjects receive false visual feedback showing perfect performance, regardless of the movements they actually made. These error-clamp trials revealed a rapid reversion to baseline behavior following initial visuomotor adaptation. Following a period of reinforcement of a new behavior, however, performance in clamp trials instead decayed to the previously reinforced action. When both binary reward and vector error were present over a comparable training duration, we observed a mixture of behaviors across subjects, with some exhibiting rapid decay to baseline and some reverting to the repeated action. We propose that learning can be decomposed into two components – a fast-learning, fast-forgetting adaptation process that is sensitive to vector errors and insensitive to reward, and a second process driven by reward rather than by error that learns more slowly but is less susceptible to forgetting. Understanding this balance and exploiting the long-term learning properties of reward-dependent learning is likely to be essential for successful neuro-rehabilitation strategies.

Developmental aspects of skill learning: A comparison of the acquisition of a graphomotor learning task in three age groups

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Memory that is acquired through repeated experiences is termed procedural memory. Motor skill acquisition is a subtype of this memory system. Through extensive research on adults it has been shown that additional robust gains in performance of a trained task appear hours after the initial training experience. These gains reflect neuronal memory consolidation processes.

It is still unclear which aspects of skill acquisition are developmental and at what age they reach maturity. Some researchers have focused on the early maturation of brain regions associated with skill acquisition (Bremner, Mareschal, Destrebecqz, & Cleeremans, 2007, Reber, 1993; Vinter & Perruchet, 2000), which support adult-like learning (Dorfberger, Adi-Japhe, & Karni, 2007, Savion-Lemieux, Baily & Penhue 2009), while other studies suggest that age differences relate to other maturational effects as late maturation in locomotor adaptation or perceptual learning in children compared to adults (e.g., Huyck & Wright 2011, Vasudevan, Torres-Oviedo, Morton, Yang, & Bastian 2011).

Research comparing young children to adults presents many challenges due to an array of developmental considerations. Some studies include older children or tasks that allow adults to reach a ceiling effect, making it difficult to reach valid conclusions. However, young children practice a variety of skills. For example, prewriting, graphomotor skills are practiced by young children from as early as kindergarten; this ability contains a procedural learning component.

The aim of the current study is to characterize the developmental aspects of skill acquisition using a graphomotor task in three age groups: kindergarten children, grade two students, and young adults. All groups were tested four times (three consecutive days and after two weeks for retention) in order to examine initial learning, consolidation, and preservation of acquired gains. The task was performed using a digitizer tablet allowing exact measurement of parameters of speed and accuracy.

The uniqueness of our study is in that graphomotor skill acquisition was examined using a simple letter like task with ecological validity that is natural for children. Preliminary findings demonstrate similar learning and consolidation in both children and adults.

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Development and Validation of the First Robotic Scale for the Clinical Assessment of Upper Extremity Motor Impairments in Stroke Patients

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Purpose. We aimed to develop and validate the first robotic-based instrument and procedure for assessing upper extremity motor impairments in stroke patients, and to test its discriminative power.

Methods. The ReoGo robotic rehabilitation platform was used to design a novel, upper limb functionality assessment tool, the Reo Scale Assessment (RSA). We evaluated 100 stroke patients with the RSA. The RSA items were tested for internal consistency and submitted to factor analysis. The Fugl-Meyer (FM) motor test, the Wolf Motor Function Test (WMFT) and the Action Research Arm Test (ARAT) were used to examine the validity of the RSA. RSA scores were compared and correlated with the scores of the three scales. The discriminative power of the RSA was tested against the FM impairment levels by analysis of variance.

Results. The total RSA score correlated closely with the upper extremity scores of the FM, WMFT and ARAT (r = 0.95, 0.93 and 0.90, respectively).

The RSA was able to discriminate between low, moderate, and high functioning patients (86% agreement with FM).Principal component analysis revealed that the RSA coefficients loaded on three tested components: proximal, distal and force.

Conclusions. Our results provide strong evidence that the validity of the Reo Scale Assessment is comparable with that of the FM, WMFT, and ARAT. The objective measuring and scoring systems of the robotic RSA make it an efficient tool for assessing motor function of stroke patients in clinical and research settings. Additional studies are needed to test the reliability and sensitivity of the RSA.

Strategies in sequential finger task and their dependence on the type of training: What is learned in motor skill acquisition?

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Many motor skills, such as typing or piano playing, evolve with the ability to articulate finger movements into novel sequences that are executed faster and smoother with practice. We explored the nature of the between-session improvements in a finger tapping sequence task in terms of movement kinematics and timing. Specifically, we tested how the type of training, self-generated repetition vs. cued repetition of a given amount of sequences, affected the effectiveness, representation and the time-course of learning. Two indices were assessed as contributing to improvement in performance: movement duration (the speed with which each single movement is produced), and transitions (the duration of the gap between individual movements).

Participants practiced a five-element sequence of finger presses on a keypad using their left, non-dominant hand. Key press information including timing, as well as the movements of the fingers was recorded. Training sessions, performed on two consecutive days, included pre- and post-training tests of continuous tapping of a given sequence and either Cued (externally initiated) or Uncued (self-initiated) training. On the third day performance of the trained sequence and three transfer conditions were tested: performance of the trained sequence with the untrained hand and of a reversed sequence of identical component movements with both the trained and untrained hand.

Training resulted in significant multiple improvements in performance in both groups. These gains were sequence-specific, indicating a qualitative change in the representation of the task post-training. However, Uncued group participants showed significantly higher relative learning gains in terms of the number of sequences completed, as compared to the Cued group. The main factor of improvement in both groups was the minimization of gaps; approximately half due to reducing gaps within the sequence, and about half due to reducing gaps between the sequences. Subjects also increased movement amplitude and velocity; these changes approximately cancelled out contribution to performance improvement, but possibly improved the tactile feedback available. Individual data analysis showed that different characteristics of the finger movements independently change following training and exhibit specific time-course of learning-related modifications, as well as generalization abilities.

Our findings indicate that reorganization of a sequence representation may rely mainly on modification of gaps between the individual finger movements within and between sequences. We suggest that rather than being the product of a single mechanism, the general improvement in performance arises from distinct processes, whose behavioural expressions are presumably supported by partially segregated brain networks.

Evidence of size-invariance in motor planning of writing movements

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Some geometrical features of human handwriting are invariant across size and effectors. This observation suggests that movements may be represented in the central nervous system in an abstract form, independently of their implementation by actions of specific effectors and muscles. In order to test this hypothesis, subjects were asked to write three English letters (a, s and n) in two different sizes on a digitizing tablet, while their brain activity was recorded using functional MRI (fMRI). Using Generalized Procrustes Analysis (GPA), we were able to show the previously reported similarity between the spatial paths of the different repetitions of each letter, across the different scales. Moreover, we performed a multivariate pattern classification analysis (MVPA) to identify several cortical regions that responded in a trajectory-selective manner to each letter type. In these identified areas we found unique voxel-by-voxel response patterns during the execution of each letter such that we were able to decode the identity of the performed letter from the area's response with significantly larger-than-chance accuracy. Most importantly, two brain areas – primary motor cortex (M1) and anterior intraparietal sulcus (aIPS) – enabled accurate identification of letter type across different sizes. This suggests that these brain areas contain neural populations that encode an abstract path shape regardless of its precise dynamics or scale. This result was evident in both a region of interest analysis and using a whole-brain searchlight analysis. Our findings suggest that motor planning of handwriting is carried out by M1 and aIPS in a manner that is invariant to size.

The consolidation and retention of a motor skill in young female adults with ADHD: shorter practice is better?

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The learning and practice of a given sequence of movements can produce robust procedural memory for the learned sequence. The acquisition of this memory develops in two distinct phases that are largely dependent on the amount of practice and the time elapsed from practice: i. gains in speed that emerge concurrently with training (within-session, on line, gains) and ii. Additional gains in speed and accuracy that evolve during the hours and days following the termination of practice (between-session, delayed, Off-line gains). This delayed improvement in task performance is considered a manifestation of procedural memory consolidation processes, and results in long-lasting retention of the task. A recent study (Adi-Japha, Fox & Karni, Res. Dev disabilities, 2011) suggests that young adults with Attention Deficit Hyperactivity Disorder (ADHD) may show a slower procedural memory consolidation phase after training in the task

Research objectives: 1. To study the time-course of learning a sequence of movements in young adult females with ADHD. 2. To investigate the effect of shortening the practice session on the learning and consolidation of the skill.

Method: 64 female collage students, 32 with ADHD (but no stimulant medication) and 32 typically developing (controls), were trained and tested in the finger-to-thumb opposition sequence (FOS) learning task. In the FOS task, participants are instructed and shown (including full explicit knowledge) a five element sequence of finger opposition movements, practice the task and are then tested on its repeated execution in terms of speed and accuracy. Half the participants of each group practiced using the standard protocol (160 repetition on the task), and the other half were given shorter training (80 repetition). Speed (number of sequences performed in a given test interval) and accuracy (number of ordering errors) were recorded before and after the practice session and again at 24 hours and two weeks after the termination of the practice session.

Results and implications: The participants with ADHD were able to acquire and retain the practiced sequence of movements, however, compared to controls performance was slower and accuracy failed to improve. The shortening of practice resulted in as effective speed gains in the ADHD group but the costs in accuracy during the consolidation phase were smaller. On the other hand, the shortening of practice had no effect on the typical group although a trend towards inferior retention of speed gains was noted.

Altogether, these results show a robust consolidation phase (i.e., expression of delayed gains) is more likely after a shorter training experience in young female adults with ADHD. This is apparent in the gains in accuracy with no costs in speed. Procedural memory consolidation may be atypical in ADHD; a shortening of the practice session, however, may be effective in improving motor skill acquisition.

Clustering cerebellar interneurons according to their spontaneous spiking activity

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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. Recent studies have searched for physiological signatures of those morphological types in the statistical measures of spontaneous activity. While spontaneous activity may reflect morphology, it is also possible that spontaneous activity reflects other aspects of a cells function. We used unsupervised clustering method to identify groups of cerebellar cortex interneurons' with similar spontaneous activity, and then asked how these groups map onto different cell types.

We recorded extracellular spontaneous activity of cerebellar cortex interneurons in anesthetized cats. Since earlier studies had failed to find well-separated groups using standard parameterizations of the spontaneous activity, we used a non-parametric approach. We applied an fuzzy C-means based Clustering algorithm on the ISI distributions using Kullback-Leibler distance, and found different functional groups. When we classified juxtacellular labeled cells into those 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.

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Act or Absorb? Probing active system with passive sensors and vise versa will lead to enhanced sensitivity

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"Perceptual activity is exploratory, probing, searching… we do not just see, we look" (Bajcsy R. 1988)

Over the last three decades many mission specific active sensing algorithms have been crafted and implemented [1-3]. Nevertheless, there is a lack in systematic theoretical approach to analyze the interaction between two dynamic systems of a sensor and the probed dynamic environment.

We propose an extremely simple hypothesis for a general 'Active Sensing Principle' asserting that in order to optimally extract information from the probed system, the sensor should act according to the following basic principle: If the probed system is passive the sensor should be active and when the probed system is active the sensor should be passive.

We formulate the active sensing principle in the context of classification problem. We argue that sensitivity to specific parameter can be directly proportional to the classification performance. We rigorously formulate and prove an active sensing theorem for a simple linear mechanical system and sinusoidal force generators, using phasor sensitivity analysis to frequency and amplitude of the power source in the probed system.

The principle demonstration is complemented by testing the active sensing principle and classification performance in a more realistic interaction of two nonlinear time varying dynamic systems of human handshake, using data of humans interacting with simulated software models [4-5].

The principle of active sensing has enormous applications in the growing field of human robot interaction, user verification and in many other cases where active sensing is used.

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Adaptation of the limb dynamics during walking on a split-belt treadmill

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Recent studies measured lower limbs kinematics during split-belt locomotion adaptation. However, the neural mechanisms and the limb dynamics during such adaptation paradigm are not fully understood.
In this study, we used a novel split-belt treadmill with build-in force plate to monitor and evaluate the adaptation process. The use of a split-belt treadmill, where the belt beneath each foot is independently controlled, allows for the systematic manipulation and study of adaptation to novel walking environment. The experiment is consists of three parts; Initially subjects walk in similar speed for each belt (baseline), then each belt moves with a different speed for each leg (adaptation) and again similar speeds (post-adaptation). Walking kinematic parameters (step symmetry and double support time) and dynamic parameters (ground reaction force and center of pressure) were measured and analyzed. We found that ground reaction forces for each leg and center of pressure changed adaptively and showed aftereffects during post-adaptation session. We also found step symmetry adaptation in the coronal plane in addition to the sagittal plane.
These results suggest some dependence of neural motor control of inter-limb and intra-limb walking parameters. Adaptation of the center of pressure and the ground reaction forces as parameters of stability and as intra-limb parameters reinforce the hypothesis that stability drive split belt adaptation.

An optimal control model of the compensatory eye movements system

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Compensatory eye movements (CEM) maintain a stable image on the retina by using visual and vestibular input to drive eye movements that cancel movements of the head and the surroundings, thereby preventing retinal slip. The optokinetic reflex (OKR) and the vestibular ocular reflex (VOR) compensate for low and high velocity stimuli, respectively, and are complementary in the CEM system. Frens and Donchin (Front Cell Neurosci, 2009) proposed a new scheme of forward models and state estimation through the CEM system stating that this system could be explained using a state-predicting feedback control (SPFC) framework. They proposed the SPFC framework of CEM as a control system consisting of three essential components: a forward model, a state estimator and a feedback controller. To test the model, we collected behavioural data from C57Bl6 mice in four different CEM conditions: vestibulo-ocular reflex (VOR, head movement in the dark), opto-kinetic reflex (OKR, moving visual field and fixed head), visually enhanced VOR (VVOR, head movement with fixed visual field), and suppressed VOR (sVOR, head movement and visual field movement cancel each other). We used sinusoidal stimuli containing a wide range of frequencies (0.1 - 3.2 Hz) and amplitudes (0.5 - 8.0°), and tested in most of the frequency/amplitude combinations. Identical stimuli were also used to drive the simulation for the model and we compared the behaviour of the simulation with the experimental results. Results of the behavioural experiments are such that the OKR compensates the stimulus at low frequencies but has low gain and phase lag at high frequencies; VOR compensates at high frequencies but has low gain and phase lead at high frequencies; VVOR successfully compensates at all frequencies; and SVOR behaves like VOR at high frequencies but shows even lower gains at low frequencies. The model simulation reproduces these main properties of the CEM system. Also in line with experimental data, the saturation of the visual input signal, led to non-linear responses of the OKR during large amplitude, high frequency simulation. From this matrix of frequencies and amplitudes, we have thoroughly tested the compensatory eye movement system (CEM) with our computational model and now have an in-depth comparison into CEM's. The SPFC model correctly predicts non-linearities in OKR responses at higher frequencies and amplitudes. It also responds well to recreate eye movement traces of CEM physiology in all conditions: OKR/VOR/VVOR/SVOR and it reproduced accurately the gain and phase of the behavioural responses. Model simulations also provide potential a resolution to the ongoing debate about the role of the nucleus prepositus hyopglossi (NPH) in eye movement generation which argues that the NPH is a neural integrator for eye velocity [Cannon and Robinson, J Neurophysiol 1987] or that it provides efference copy of the motor command to cerebellum [Green et al. J. Neurosci. 2007]. Simulated forward model produces output that is nearly synchronous with the occulomotor output: Both correlations peak at t=0 and have the same width i.e. output of the forward model (identified with the cerebellum, Frens and Donchin, 2009) is correlated to movement with zero lag. Effects of simulated flocculus lesion are also in line with occulomotor literature which states that floccular lesions reduce the gain of the OKR but not the VOR (Van Alphen, Schepers et al 2002; Rambold, Churchland et al 2002). Mapping the Frens/Donchin model onto CEM physiology through the SPFC framework may reveal similarities in the cerebellar circuitry used in goal directed movements and CEM. Presently, we are conducting electrophysiology experiments recording from the flocculus and vestibular nucleus to further strengthen the suggestion of the SPFC model as a control system and a plausible framework for understanding the CEM system.

Maps

Getting to BGU
Marcus Family Campus
Northern Entrance
to Beer Sheva
Vehicles Entrance
Gate A
Vehicles Entrance
Gate of the Future
Train
Station
Ben-Gurion
University
Soroka
Medical
Center
Utel

אוניברסיטת בן-גוריון בנגב
Ben-Gurion University of the Negev
קריית האוניברסיטה ע"ש משפחת מרקוס
Marcus Family Campus
מתל-אביב
FROM TEL AVIV
AABGU DORMITORY COMPLEX
RAGER BOULEVARD
BEN-GURION BOULEVARD
שדרות בן-גוריון
URI ZVI GREENBERG BLVD.
DEICHMANN PLAZA
CUMMINGS PLAZA
KAYE MALL
UNDER CONSTRUCTION
SPORTS CENTER
ZLOTOWSKI DORMITORY COMPLEX
JOYCE AND IRVING GOLDMAN MEDICAL SCHOOL
SOROKA UNIVERSITY MEDICAL CENTER