The 14th KCMCW

Karniel Computational Motor Control Workshop
Ben-Gurion University of the Negev

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

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

The organizers:

Dr. Ilana Nisky - conference chair
Dr. Lior Smuelof – program chair
Prof. Opher Donchin
Orit Cohen-Rothman
Avia Lavon

Program committee:

Prof. Opher Donchin, Ben-Gurion University of the Negev
Dr. Ilana Nisky, Ben-Gurion University of the Negev
Dr. Lior Shmuelof, Ben-Gurion University of the Negev
Prof. Sandro Mussa-Ivaldi, Northwestern University
Prof. Ehud Ahissar, Weizmann Institute of Science
Prof. Eilon Vaadia, Hebrew University
Dr. Nicole Malfait, Aix-Marseille Université, France

Sponsors:

Ben-Gurion University of the Negev – President
Ben-Gurion University of the Negev – Rector
Ben-Gurion University of the Negev – Faculty of Engineering
Ben-Gurion University of the Negev – Faculty of Health Sciences
Zlotowski Center for Neuroscience

Program

Tuesday, March 13

Lab visits 14:00 – 15:50

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**

Cognition

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

Lab tours will start from Student Center (near bank Hapoalim) at 14:00

Evening Special Talk

Student House Teaching Hall (Behind Barkan Auditorium)

- 16:00 – 17:00 – "Evolution Of Response" **Miles Kessler**
- 17:00 – 18:00 – Reception

18:30 **Festive dinner** (*speakers, session chairs, and guests by invitation*) at *Kapara Restaurant, Smilansky St., Old city*

(cars will start leaving Utel parking or campus at 18:00)

Wednesday, March 14

Minkoff Senate Hall

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

Session 1 – Motor control

Chair: Eilon Vaadia, Hebrew University, IL

- 09:00-09:30 **Andrea d'Avella**, University of Messina , IT
  "Sensorimotor control of limb movements: dynamic knowledge for coordination and prediction"

- 09:30-10:00 **Elizabeth Torres,** Rutgers University, USA
  "New Frontiers in Behavioral Neuroscience: Dynamic and Personalized Biomarkers to Habilitate Autonomy in Neurodevelopment and Beyond"

- 10:00-10:30 **Maura Casadio**, University of Genova, IT
  "The Body-Machine Interface: a new tool for basic and clinical neuroscience"

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

Session 2 – Oscillatory activity in motor control

Chair: Oren Shriki, Ben-Gurion University of the Negev, IL

- 11:20-11:50 **Bernadette van Wijk**, University College of London, UK
  "Dynamic causal modelling of cortico - basal ganglia interactions in Parkinson's disease"

- 11:50-12:20 **Simon Little**, Oxford University, UK
  "Towards a computational understanding of beta oscillations in motor control for health and disease"

- 12:20-12:50 **Nicole Malfait**, Aix Marseille Université, FR
  "Pre- and post-movement β-band error-related modulations: different functions and distinct neural substrates"

- 12:50-13:00 Discussion
- 13:00-13:30 Lunch
- 13:30-14:30 **Posters**

Session 3 – Keynote session

Chair: Abraham Zangen, Ben-Gurion University of the Negev, IL

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

- 14:40-15:10 **John Rothwell**, University College of London, UK
  "What is happening in the primary motor cortex before a movement starts?
  Non-invasive TMS studies in humans"

- 15:10-15:40 Prof. Amir Karniel Memorial Young Researcher Lecture
  Avital Hahamy, Weizmann Institute of Science, IL
  "What can sensorimotor deprivation teach us about typical neural functions? Examples from the study of one-handed individuals"

- 15:40-16:10 **Tony Prescott**, University of Sheffield, UK
  "The robot vibrissal system: Understanding mammalian sensorimotor co-ordination through biomimetics"

- 16:10-16:20 Discussion
- 16:20-16:40 Coffee break and posters

Session 4 – Motor learning

Chair: Roy Mukamel, Tel-Aviv University, IL

- 16:40-17:10 **Opher Donchin**, Ben-Gurion University of the Negev, IL
  "Characterizing (some) of the processes underlying our ability to adapt"
- 17:10-17:40 **Carsten Mehring**, Albert-Ludwigs-University Freiburg, DE
  "Enhanced manipulation abilities in humans with 6-fingered hands"
- 17:40-17:50 Discussion
- 17:50-18:00 Best poster awards

19:00 Drinks and light dinner at *Coca Bar*

Thursday, March 15

Hike in the Negev 08:30-18:00

Talk Abstracts

Session 1 – 14.3.18
09:00-10:40

Motor control
Chair: Eilon Vaadia
Hebrew University, Israel

Sensorimotor control of limb movements: dynamic knowledge for coordination and prediction

Andrea d'Avella

Department of Biomedical and Dental Sciences and Morphofunctional Imaging,

University of Messina, IT

Successful performance of many daily living or sport activities, such as reaching for a static object or intercepting a moving object, requires solving complex coordination and prediction problems. Storing and re-using knowledge of the dynamic behavior of the musculoskeletal system and of the environment might be a general strategy employed by the CNS to simplify coordination and prediction. Muscle synergies, coordinated activation of groups of muscles, may represent a small set of building blocks whose combinations allow to generate all the muscle activation patterns required to perform a motor task, thus capturing the essential knowledge of the dynamic behavior of the arm and of the task constraints. Internal models of the dynamic behavior of flying objects, such as the effect of gravity acceleration on object motion, may allow to make accurate predictions even in the absence of accurate sensory information. Recording EMG signals from many muscles during reaching and isometric force generation in multiple directions has allowed us to investigate how the CNS organizes and combines muscle synergies and to test the prediction that, if the CNS relies on muscle synergies, it must be harder to adapt to a perturbation that requires new or modified muscle synergies than to a perturbation that can be compensated by recombining existing synergies. To investigate the role of an internal model of gravity in predicting the location and time of interception, we have recorded arm, finger, and eye movement during catching of flying balls. When subjects were free to choose where to intercept a horizontally approaching ball we observed a large inter-individual variability in movement kinematics. Differences in catching performance across individuals were related to the ability of accurately time the closing of the fingers on the ball rather than on ability to intercept the ball trajectory and on the oculomotor strategy used to gather information on ball motion. When approaching balls were simulated in an immersive virtual environment, participants achieved a better performance when intercepting accelerated than non-accelerated balls and they made spatial errors indicating they used a priori knowledge of the dynamic effect of gravity to predict when to intercept a moving object. In sum, these results indicate that the CNS stores and exploits dynamic knowledge of the body and of the environment when mapping sensory information into motor commands.

New Frontiers in Behavioral Neuroscience: Dynamic and Personalized Biomarkers to Habilitate Autonomy in Neurodevelopment and Beyond

Elizabeth Torres

Department of Psychology, Computer Science and Cognitive Science
Rutgers University, USA

Precision Medicine (PM) has emerged as a new platform for personalized targeted treatments of disease. In the medical field, this platform is poised to accelerate drug-discovery and rapidly advance scientific research; but the translation of its tenets and concepts to areas of mental health is far from obvious. Part of the problem rests on the disconnect between opinion-based clinical scores and the genomic layers of the PM knowledge network. In mental health, objective behavioral outcomes are missing; yet, they are a fundamental link required for the development of pharmacological and behavioral interventions and for the longitudinal tracking of treatments' outcomes.

In this talk, I introduce a reconceptualization of behavior as biorhythmic motion across different levels of functionality of the nervous systems, from deliberate to spontaneous autonomy, extended also to dyadic social exchange. Further, I describe new data types coined "*micro-movements*" to provide standardized ways to acquire and integrate multi-modal signals in tandem, from multiple functional layers of the nervous systems. These data types convert into spike trains the moment-by-moment fluctuations in the amplitudes and timings of peaks that are present in time-series of biophysical activities, as continuously harnessed, non-invasively from the nervous systems. Unlike discrete binary cortical spike trains from the central nervous system, the peripheral bodily spikes convey information along continuous real/complex number scales, amenable to offer a new unifying analytical framework to quantify information transfer across the CNS and the PNS. We do so in ecologically valid settings, during activities of daily living using wearable biosensors and defining parameter spaces relevant to the tasks and contexts.

I introduce ways to empirically estimate probability landscapes of biophysical parameters across the human spectrum. I show that the stochastic signatures of nervous systems biorhythms shift with age in a non-linear manner with age-group and pathology specificity. As such, this empirically-informed model offers a new way to measure departures from neurotypical (normative) stages along the human life continuum. The results have implications for animal models of drug development; the tracking of treatment outcomes required for legislation tied to insurance coverage of interventions and more generally, they have implications in the scientific arena, for any attempt to apply machine learning methods and neural-network models in data-driven approaches using biophysical signals. Brain-inspired computing will have to be extended to a new level of ***brain-body*** inspired computing if autonomous control of the brain over the body in motion is to be achieved within AI settings.

The Body-Machine Interface: a new tool for basic and clinical neuroscience

Maura Casadio

Department of Informatics, Bioengineering, Robotics and Systems Engineering, University of Genova, IT

A distinct feature of the neuromotor system is its abundance of muscles and degrees of freedom, which allows it to attain any specific motor goal in a variety of different ways. This "motor redundancy" is at the same time a resource, providing for a high level of dexterity, and a computational challenge, requiring the ability to solve a classical family of "ill-posed problems", characterized by a lack of uniqueness in its solutions. We focus on the challenge posed by motor redundancy from the perspective of learning. How does the central nervous system learn to perform a novel task when multiple alternative solutions are available? This learning problem has a particular clinical relevance, when a person with paralysis must learn to operate an assistive or a rehabilitative device - such as a wheelchair or a robotic system - via a dedicated interface mapping the available body motions into device motions. In this scenario, the learning process is bi-directional, i.e., also the interface has to adapt to the user ability and its need. What are the requirements for this kind of interfaces? We propose a 'Body-Machine Interface' based on three key concepts:

- Highly personalized remapping the user's residual movement ability into the space of controls for a machine that typically has fewer dimensions of movement
- Adaptively matching this control space to the evolving skills of the user
- Gradually challenging the user to involve increasingly body motions in the operation of the interface

By manipulating the maps between body signal space and devices control space, we selectively and adaptively targeted the specific physical abilities, deciding how to exercise each part of the body, switching between configurations that promote exercising specific body abilities and configurations that simplify the control of assistive devices (e.g. wheelchairs). This blurred the boundary between assistive and rehabilitative methods, as the interface adapt to the actual subject's residual abilities and preferences. Thus, it is possible to use a unique personalized interface capable to adapt both to the need of exercising motor ability and of controlling assistive devices. This feature has a high potential in cases that require both a rehabilitative intervention and the use of assistive tools, whereas often both these type of devices follow a one-fits-all approach.

Talks

Session 2 – 14.3.18
11:20-13:00

Oscillatory activity in motor control
Chair: Oren Shriki
Ben-Gurion University, Israel

Dynamic causal modelling of cortico - basal ganglia interactions in Parkinson's disease

Bernadette van Wijk

Department of Neurology, Charité - University Medicine Berlin, Germany

Wellcome Trust Centre for Neuroimaging, University College London, United Kingdom

The basal ganglia are considered essential for action selection and reinforcement learning. In combination with their connections from and to cortex and thalamus, they form a distributed and intricately connected network that is difficult to fully capture with electrophysiological recordings. Computational modelling could therefore be highly valuable in studying the functional roles of the classical direct, indirect and hyper-direct pathways within the network. Here, we take the approach of dynamic causal modelling (DCM) where each brain structure in the network is represented as a neural mass and model parameters are estimated using Bayesian inference. Neural dynamics are described with second order convolution-based equations. We implemented a network consisting of motor cortex, striatum, external and internal pallidum, subthalamic nucleus and thalamus, and used this to study the pathophysiology of Parkinson's disease in humans. The motor impairments observed in the disease are closely associated with the occurrence of strong beta band oscillations (13-30Hz) in electrophysiological recordings. We therefore used the model to infer how these oscillations arise within the cortico-basal ganglia network. Simultaneous magneto-encephalography recordings (from cortex) and local field potentials from the subthalamic nucleus were collected in 11 Parkinson's disease patients who received deep brain stimulation treatment. Model parameters were estimated from power- and cross-spectral densities that were obtained from recordings before and after patients took dopaminergic medication. A significant reduction was observed in both clinical symptoms and beta oscillation amplitude after medication. Our modelling results indicate that this finding could be explained by a reduced synaptic efficacy within the circuit between the subthalamic nucleus and external pallidum, as well as a reduced synaptic efficacy for hyperdirect and indirect pathway connections leading to this circuit. Excessive beta band oscillations in Parkinson's disease might hence occur via altered synaptic coupling between multiple structures within the cortical-basal ganglia circuit. A network perspective is therefore essential in order to understand how movement impairments arise.

Towards a computational understanding of beta oscillations in motor control for health and disease

Simon Little

Nuffield Department of Clinical Neurosciences, Oxford University, United Kingdom

Motor control has often been analysed at the level of single unit recordings or via advanced computational models. Population level signals such as local field potentials or EEG, MEG signals may provide a vital intermediate level of analysis to help bridge the gap. Beta oscillations and their modulation in advance of movement have been known about for nearly 100 years and yet their precise computational role is still disputed. This is complicated by standard analysis methods that generally average over trials and theorise at this level. Here I will present recent work that suggests that beta is actually rapidly dynamic at the single trial level. This has notable implications for our interpretations of these population level signals for movement in health and also diseases such as Parkinson's where beta is now being used as a control signal for adaptive intelligent stimulation. The next challenge is to now delineate the functional role of these short lasting beta bursts within a formalise computational framework that can unify this across movement periods in health and disease.

Pre- and post-movement β-band error-related modulations: different functions and distinct neural substrates

Nicole Malfait

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

While β-band activity has been extensively studied in relation to voluntary movement, its role in sensorimotor adaptation remains uncertain. Recently, it has been shown (Tan et al. 2014) that the increase in EEG β-power typically observed after a movement above sensorimotor regions (β-rebound) is attenuated when movement-execution errors are induced by visual perturbations. I will present data extending and refining this finding. Along with the β-rebound, we examined the modulation of the β-activity during the preparation of reaches immediately following perturbed movements. We found that both pre- and post-movement β-activities are parametrically modulated by the sizes of kinematic errors, but with critical functional differences. While the error-related modulation of the β-rebound seems to reflect error salience processing, independent of sensorimotor adaptation, the modulation of the pre-movement β-activity seems to relate to adaptive processes activated after movement-execution errors are experienced. Furthermore, we show that the two types of error-related oscillatory responses arise from distinct neural substrates and do not reflect efferent signal processing.

Talks

Session 3 – 14.3.18
14:30-16:20

Keynote Session
Chair: Abraham Zangen
Ben-Gurion University, Israel

What is happening in the primary motor cortex before a movement starts? Non-invasive TMS studies in humans

John Rothwell

UCL Institute of Neurology, University College of London, United Kingdom

At rest and prior to a movement, there is lots of neural activity in M1, but no motor output emerges (i.e. no change in EMG activity). One possibility is that movement output occurs when the level of M1 activity reaches some sort of threshold. In fact, it is often imagined that the rate of rise towards threshold determines the reaction time in a simple task. Another possibility is that motor output is prevented because of active inhibition, which is released prior to movement. Lots of TMS experiments in humans seem to fit these possibilities. For example, at the time of an expected imperative stimulus, MEPs are usually inhibited and as movement onset approaches, short interval intracortical inhibition (SICI) is reduced.

I will present some new experiments that show that MEP suppression does not occur because of direct inhibition of corticospinal output neurones. Instead, inhibition affects the inputs to corticospinal neurones. Furthermore, only some of these inputs are suppressed. Others are unaffected. The MEP appears smaller because TMS preferentially excites those inputs that are suppressed. The more obvious this suppression, the faster the reaction time. We argue that lack of motor output during movement preparation is the result of a balanced amount of inhibition and excitation onto presynaptic inputs to corticospinal neurones.

Other experiments suggest that the rate of corticospinal lexcitability (as probed with TMS) does not necessarily reflect individual reaction times. If participants are told that they might have to stop after receiving a “go” command, then the RT in that trial is delayed. But this is not because the rate of rise of corticospinal excitability is slower: in fact it is unaffected. The implication is that in those trials, participants insert a delay that prolongs RT beyond the usual minimum.

Final experiments suggest that measuring the trial-to-trial variability of MEP amplitude can give some additional insight into motor cortex changes during the reaction period.

Prof. Amir Karniel Memorial Young Researcher Lecture:

What can sensorimotor deprivation teach us about typical neural functions? Examples from the study of one-handed individuals

Avital Hahamy

Department of Neurobiology Weizmann Institute of Science, Israel

Individuals born without one hand (hereafter, one-handers) provide a unique model for exploring the relation between focal reorganization in the sensorimotor cortex and everyday behavior. Here we use this model to answer two questions, tested using fMRI. We first asked what information is reflected in the patterns of synchronization seen in spontaneous brain activity (functional connectivity) of resting participants. We demonstrated that the more symmetrical the daily limb-use of one-handers, the higher the synchronization between the spontaneous activity of their bilateral hand areas. This suggests that functional connectivity observed in the resting brain represent the statistics of habitual daily behaviors (Hahamy et al. , 2015).

We next asked what drives deprivation-related reorganization in the sensorimotor cortex. Specifically, we aimed to test whether reorganization is topographically-related (such that cortical neighbors will be represented in the deprived hand area) or behaviorally-related (body-parts used for compensatory purposes will be represented in the missing-hand area). To that end, we characterized the full repertoire of ecological compensatory behaviors of one-handers and related them to activity and functional connectivity in the missing-hand area. We first found that one-handers use multiple body-parts (residual arm, lips, feet but not the intact hand) to compensate for the absence of a hand. We next demonstrated that although only the representation of the residual arm cortically neighbors the hand area, all of the body-parts used for compensatory purposes were represented in the missing-hand area of one-handers. Importantly, the representation of the intact hand, which is not used for compensation, did not map onto the deprived hand area (Hahamy et al. , 2017). This activity-based reorganization in the missing-hand area of the sensorimotor cortex was replicated across three independently acquired datasets of participants, attesting to the robustness of this phenomenon. Moreover, two datasets which included coverage of the cerebellum demonstrated that the cerebellar missing-hand area also represents the residual arm, lips and feet, but not the intact hand. The similarity in reorganization across the cerebrum and cerebellum, despite differences in functional topography between these brain areas (Manni and Petrosini, 2004), provides further evidence that functional topography does not restrict brain reorganization. These findings also propose that if multiple body-parts share the same functionality (in this case, a hands' functionality - manipulating objects), they may all be represented in the same brain-area, hinting that the sensorimotor homunculus may represent general motor functions rather than specific body-parts.

The robot vibrissal system: Understanding mammalian sensorimotor co-ordination through biomimetics

Tony Prescott

Director of Sheffield Robotics Department of Computer Science, University of Sheffield, United Kingdom

This talk will consider the problem of sensorimotor co-ordination in mammals through the lens of vibrissal touch, and via the methodology of embodied computational neuroscience—using biomimetic robots to synthesize and investigate models of mammalian brain architecture. I will consider five major brain sub-systems from the perspective of their likely role in vibrissal system function—superior colliculus, basal ganglia, somatosensory cortex, cerebellum, and hippocampus. With respect to each of these sub-systems, the talk will illustrate how embodied modelling has helped elucidate their likely function in the brain of awake behaving animals, and will demonstrate how the appropriate co-ordination of these sub-systems, within a model of brain architecture, can give rise to integrated behaviour in life-like whiskered robots.

Talks

Session 4 – 14.3.18
16:40-17:50

Motor learning
Chair: Roy Mukamel
Tel-Aviv University, Israel

Characterizing (some) of the processes underlying our ability to adapt

Opher Donchin

Department of Biomedical Engineering, Ben-Gurion University of the Negev, Israel

The motor control community coalesced around the study of adaptation in part because it provided a model for a simple process in the motor system that could be studied in a controlled manner and related to specific neurophysiological mechanisms. In 20 years of study, "simple" motor adaptation has proved to be anything but simple. I will discuss a modern perspective on the different processes underlying motor adaptation and present our own efforts to dissociate the effects of these different processes and explore their underlying neurophysiological substrates. Specifically, I will discuss 'fast' and 'slow' adaptation and 'explicit' and 'implicit' adaptation and the correlation of adaptation with behavioral and neural noise. Specifically, I will present results showing that random variations in reaching movements can be decomposed into a planning component and an execution component and that the planning component is correlated with the rate of adaptation but the execution component is inversely correlated with it. I will show that the noise in the planning component is specifically correlated with the level of noise in posterior parietal cortex. I will address how this planning component can be decomposed into 'fast' and 'slow' adaptation. While recent work by others indicate that the fast component reflects a strategic, aware component of adaptation while the slow component reflects implicit learning, I will complicate this picture. Our results show that the both the aware and unaware aspects of learning can be further decomposed into at least two dissociable components. I will focus on the idea that awareness can be partially decomposed into the ability to report what is happening and the ability to control it. We will show that these two aspects of awareness can be dissociated and the hypothesize that these two components are comparable to the 'what' and 'where' streams of visual processing. This leads to the final, unsupported, claim that parietal cortex will be shown to be specifically related to aware control of motor adaptation and not to our ability to describe our own behavior.

Enhanced manipulation abilities in humans with 6-fingered hands

Carsten Mehring

Institute for Biology III, Albert-Ludwigs-University Freiburg, Germany

Neurotechnology attempts to develop supernumerary limbs, but can the human brain deal with the complexity to control extra limbs and yield functional advantages from it? To address this question we analyzed for the first time the neuromechanics and manipulation abilities of polydactyly subjects with 6-fingers per hand. The results reveal unique hands with five fingers as in common hands and a supernumerary finger (SF) with extra muscles and nerves that can move independently from them. Neural resources dedicated to the SF enable our polydactyly subjects to coordinate it with the other fingers for more complex movements, and so carry out with only one hand tasks normally requiring two hands. These results demonstrate that a body with significantly more degrees-of-freedom can be controlled by the human nervous system without motor deficits or impairments, and can provide superior manipulation abilities.

Posters

Action Semantics Modulates Action Kinematics, Regardless of Sensory Outcome

Aberbach S.[1, 2], Mudrik L. [1, 2*], and Mukamel R.[1, 2*]

1. *Sagol School of Neuroscience, Tel-Aviv University, Israel*
2. *School of Psychological Sciences, Tel-Aviv University, Israel*

Introduction: Depending on context, similar motor schemes are used to achieve different (sometimes even opposite) goals. Such different end-state goals and future intentions, for the same action, can affect its kinematics (Ansuini et al., 2006). Moreover, at the neural level, several sensory-motor regions are sensitive to intended outcomes, so that different activations are found for the same action depending on its expected outcome (Krasovsky et al., 2014). However, these differences may represent the sensory outcomes of the action rather than its different goals. In the current study, we examined whether movement kinematics are modulated by semantic goals without sensory outcome. Specifically, we examined whether response force is differentially modulated when intending to affirm (i.e. responding “yes”) or to negate (i.e. responding “no”) and whether such modulations depend on hand identity (right/left).

Results: 25 right-handed subjects reported if they saw an image of a face or a vase, using “yes”/’’no” answers. In half the blocks, subjects pressed with their right and left index fingers to respond “yes” and “no”, respectively, and vice versa in the other half. Results showed that using the right hand, button-press force levels were higher for “yes” than “no” responses ($p<0.01$) while the opposite was observed for the left hand ($p<0.01$). Furthermore, for response time, there was a main effect of response type ($p<0.01$); “yes” responses had, overall, shorter latencies than “no” responses, and a main effect of percept type was also found ($p<0.01$), so that face perception latencies were overall shorter than vase perception. No correlation was found between force and RT measurements.

Conclusions: Our results suggest that action semantics are embedded in the movement’s kinematics, regardless of sensory outcome. Furthermore, semantic content differently modulates action execution, depending on hand identity. These findings are in line with the *body specificity* hypothesis and expand it by showing that hemispherical bias is triggered not only by the perception of stimuli of different valence but also by the intention to affirm or to negate (i.e. responding “yes” vs “no”). Alternatively, right and left spatial locations of the keys might be associated with “yes” and “no” responses, respectively. Thus inducing a conceptual bias even when using the same hand (same hemisphere). Finally, since no correlation was found between response latency and force, we suggest that the first is more indicative of cognitive processes and not related to action execution per se, while the latter is kinematic in nature.

The Effect of *Gaga* Movement Language on Penché Dance Movement Kinematics, Somatic Awareness, and Imagery Use in University-Level Dance Students

Amit Abraham, B.P.T, MAPhty, PhD [1,2], Loren Davidson, *MFA* [3], Tom Welsh, *PhD* [3], Bethany Nelson, *B.ed* [2], Tamar Flash, PhD [4], Madeleine E. Hackney, *PhD* [1]

1. *Department of Medicine, Division of General Medicine and Geriatrics, Emory University School of Medicine, USA*
2. *Department of Kinesiology, University of Georgia, Athens, USA*
3. *School of Dance, USA*
4. *Department of Mathematics, Weizmann Institute of Science, Israel*

Background: Dance students constantly seek to improve physical and aesthetic levels of performance, including lower extremity range of motion (ROM). The effectiveness of dance and other training methods (e.g. stretching, strengthening) in enhancing ROM while maintiaing dancers' well-being is questionnable. Thus, there is a need for exploring novel training approaches. Gaga is a movement language that seeks to enhance participants' physical, emotional, and cognitive aspects of dance and motor performacne. Gaga combines improvisational movement, mental imagery (MI: i.e., the cognitive process of creating and using images and metaphors for enhancing physical performance), and physical and cognitive body awareness. Penché is a multi-segmental ballet movement that entails high levels of dynamic balance, postural alignment, and maximal pelvic and lower extremity ROM. The current study explored the effect of Gaga training intervention on penché performance quality and kinematics, somatic awareness, and dance-specific MI use in university-level dance students.

Methods: Nineteen university-level dance students (M age = 21.63P+P3.88 years, M dancing experience = 15.89P+P4.63 years) gave informed consent and were measured in the dance studio 24 hrs pre- and post-intervention, while performing a single repetition of penché. The intervention consisted of 5 x 120-min Gaga classes over 5 consecutive days. Data were collected from the gesturing leg using 3-dimensional motion capture (Ariel Performance Analysis System, APASP®P), self-reported somatic observations, and the Dance Imagery Questionnare. Desctiptive statistics and paired-samples t tests were used with a significance level of .05.

Results: Significant improvements were detected following the *Gaga* intervention in performance quality ($p < .01$), somatic awareness [physical sensations and movement efficiency ($p < .01$) and pleasure ($p < .05$)], and dance-specific MI use ($p < .05$).

Discussion: This study is the first to demonstrate potential benefits of Gaga training on technical and aesthetic qualities as well as on MI use in dancers. Further research employing experimental controls is needed to confirm these results. Investigating Gaga's neural and motor control mechanisms of effect is also warranted.

Performance based approach for movement artifact removal from EEG signal recorded during locomotion

Evyatar Arad[1], Ronny P. Bartsch[2], Jan W. Kantelhardt[3], Meir Plotnik[1,4]

1. *Center of Advanced Technologies in Rehabilitation, Sheba Medical Center, Israel*
2. *Department of Physics, Bar-Ilan University, Israel*
3. *Institute of Physics, Faculty of Natural Sciences II, Martin-Luther-University, Germany*
4. *Department of Physiology and Pharmacology, Sackler Faculty of Medicine, Tel Aviv University, Israel*

Movement artifacts (MA) in EEG signals originate from mechanical forces applied to the scalp electrodes, inducing small electrode movements relative to the scalp which, in turn, cause the recorded voltage to change irrespectively of cortical activity. These mechanical forces, and thus MA, may have various sources (e.g., ground reaction forces, head movements, etc.) that are inherent to daily activities, notably walking. In this paper we introduce a systematic, integrated methodology for removing MA from EEG signals recorded during treadmill (TM) and over-ground (OG) walking, as well as quantify the prevalence of MA in different locomotion settings. In our experiments, participants performed walking trials at various speeds both OG and on a TM while wearing a 32-channel EEG cap and a 3-axis accelerometer, placed on the forehead. Data preprocessing included separating the EEG signals into statistically independent additive components using independent component analysis (ICA). MA was identified and quantified in each component using a novel method that utilizes the participant's stepping frequency, derived from a forehead-mounted accelerometer. We then benchmarked the EEG data by applying newly established metrics to quantify the success of our method in cleaning the data. The results indicate that our approach can be successfully applied to EEG data recorded during TM and OG walking, and is offered as a unified methodology for MA removal from EEG collected during gait trials.

Rhythmic movements of the upper limb improve motor UPDRS scores

Dan Arbelle*[1], Dan Forman*[1], Y. Zlotnik[2], S. Levy-Tzedek[1, 3]

* equal contribution

1. *Recanati School for Community Health Professions, Department of Physical* Therapy, *Ben Gurion University of the Negev, Israel*
2. *Neurology Department,Soroka Medical Center, Israel*
3. *Zlotowski Center for Neuroscience, Ben Gurion University of the Negev, Israel*

Background: Parkinson's disease (PD) is a progressive neurodegenerative disease, often characterized by tremor, bradykinesia and rigidity. These symptoms often develop to be highly debilitating, preventing participation in many activities of daily living. Our main objective in this pilot study is to determine whether fast-pace rhythmic movements of the upper limb affects clinical symptoms of PD, thereby making it a useful tool for rehabilitation.

Methods:

Participants - Ten PD participants were tested after an overnight withdrawal from Dopaminergic treatment (age 71.0±6.5 years; 7 women, 3 men).

Protocol:

Participants were asked to perform a rhythmic horizontal flexion-extension movement of the forearm which controlled a marker on a computer screen in front of them. Each trial included alternating segments with and without visual feedback. The goal of removal of feedback during the trials was to induce fast-paced rhythmic movement of the arm. The location and speed of the forearm were recorded. Each participant performed a 40-minute "Rhythmic movement exercise" with both hands in alternation. The MDS-UPDRS motor score was recorded for each patient before and after the exercise by a blinded tester.

Results:

A significant improvement in upper-limb MDS-UPDRS motor score following the exercise session was found by using a two-sided Wilcoxon signed rank test ($p=0.0234$).

Conclusions:

The preliminary results shown here indicate a benefit for using a high-intensity exercise program of the upper limb. Such exercise might pave the way for a new rehabilitation tool for PD patients. Further analysis is needed to understand the underlying mechanism of the improvement. In this study, participants were OFF medication; Further research is needed to examine the effects of such an exercise session while ON medication.

Integration of kinesthetic and cutaneous information during force-field adaptation

Avraham C. and Nisky I.

Department of Biomedical Engineering, Ben-Gurion University of the Negev, Israel

When interacting with the external environment, our sensorimotor system constantly integrates information from multiple sensory streams. An important sensory stream is force information, allowing us to estimate accurately contact and interaction forces when manipulating objects. There are two kinds of force sensing modalities in our body – *kinesthetic* and *tactile*. Recent studies have investigated the role for each of the sensory modalities in mediating our internal representation of the environment; however, their dissociable roles in force field adaptation are unknown.

In this study, we set out to investigate the integration of kinesthetic and tactile information for the control of manipulation and grip forces during adaptation to force perturbations. We exposed a group of participants to a velocity-depended force field perturbation during performance of reaching movements from start point toward a target with a robotic device. To examine the changes in the manipulation forces that the participants applied, throughout the experiment, we incorporated force channels in randomly selected trials. We also recorded the grip force that the participants applied on the device throughout the entire experiment. Another group of participants performed the same experiment but with the added information of velocity-depended skin deformation in the same direction of the applied force field.

We found no difference between the performed trajectories of two groups, but nevertheless, the skin-stretch affected the applied manipulation and grip forces. During early adaptation, the correlation coefficient between the manipulation and load forces was smaller in the group with skin-stretch, but this difference vanished as adaptation developed. In addition, we saw that throughout adaptation the grip force was larger in the presence of skin stretch - the baseline magnitude was larger, and with adaptation the modulation between grip force and load force was higher for the skin stretch group. Therefore, we conclude that additional tactile information affected the applied grip force, and surprisingly, had initial deteriorating effect on the force-field adaptation process which was compensated possibly by increasing arm stiffness.

Our study shows how the human sensorimotor system combines kinesthetic and tactile information. Understanding sensory integration can be necessary for effectively integrating the sense of touch within prosthetic devices. Furthermore, intelligent integration of tactile, kinesthetic and proprioceptive information is essential to teleoperation technologies that require skillful control of interaction forces and motions.

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Surgeon-centered analysis of robot-assisted needle driving under different force feedback conditions

Lidor Bahar, Yarden Sharon, and Ilana Nisky

Department of Biomedical Engineering, Ben-Gurion University of the Negev, Israel

Robot-assisted minimally invasive surgery (RAMIS) refers to minimally invasive surgical procedures aided by robots in which the surgeons use a local robotic manipulator to operate robotic instruments inside the patient's body. The surgical instrument follows the movement of the local manipulator, often with different motion scaling and filtering. One major challenge in the field of RAMIS is the absence of haptic (force) feedback. As a consequence, surgeons have to estimate the forces based only on visual information and prior knowledge, this can cause the surgeon to apply substantial forces on the tissue ending in unwanted injuries. Understanding the effect of different conditions of force feedback on the surgeon (i.e. the movement of the operator) is a necessary step for optimizing force feedback in RAMIS.

Studies on needle driving task showed that haptic feedback reduces the forces applied on the tissue during the task, consequentially reducing tissue damage, but there is no conclusive result on the benefits (or disadvantages) of haptic feedback in teleoperation. In this study, we aim to assess the effect of haptic feedback on the sensorimotor control of inexperienced surgeons in RAMIS, focusing on teleoperated needle driving task. We use the needle driving task as an example of a complex movement which is widely used in general surgery using RAMIS systems. The participant is requested to drive a surgical needle through an artificial tissue made of silicone molded homogenous piece using (1) surgical forceps and (2) teleoperation under one of three different haptic feedback conditions with the da-Vinci Research Kit: no feedback, direct feedback, and position exchanged based feedback.

We characterize the movements and the forces that are applied on the artificial tissue. We use classical and new, motor control grounded, metrics for performance evaluation and discuss the pros and cons of each of the force feedback methods in terms of surgeon task performance.

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cCHAI3D: CHAI3D+Unity3D made easy

Nicolò Balzarotti [1,2], G. Baud-Bovy [2,3]

1. *DIBRIS, Università di Genova, Italy*
2. *Robotics, Brain and Cognitive Sciences Unit, Istituto Italiano di Tecnologia, Italy*
3. *Faculty of Psychology, Vita-Salute San Raffaele University & Unit of Experimental Psychology, IRCCS San Raffaele Scientific Institute, Italy*

CHAI3D [1] is a powerful open-source cross-platform C++ simulation framework for haptic applications (Modified BSD License). It implements state-of-the-art algorithms to render object geometries and material properties such as weight, friction and texture. CHAI3D also integrates graphical rendering (Open GL) and physical simulation engines to develop full-fledged virtual reality applications. Despite its rich set of features, CHAI3D is not used as a general-purpose game engine because game developers tend to prefer other alternatives that offer features such as state machines, animation support, and Graphical User Interfaces (GUIs) that simplify the development of games [2].

In this poster, we present a haptic plugin for Unity3D (https://unity3d.com/), a popular choice for game development. Previous attempts to integrate CHAI3D with Unity3D are either incomplete [3], [4] or no longer available [5]. At the lowest level of the plugin, we wrote cChai3d, a C wrapper around a lightweight version of CHAI3D that included only the force-rendering algorithms. The wrapper has C bindings to facilitate the integration with any programming language and framework. It also includes a high-frequency thread that handle all haptic rendering computation.

Full integration between Unity3D and CHAI3D is achieved via Unity3D `C#` scripts that give haptic properties to Unity3D GameObjects with simple `drag-and-drop` operations. The position and orientation of the haptic device in the world is configurable and handled transparently. Haptic properties supported by CHAI3D such as stiffness, friction, viscosity and textures can be set via the Unity3D GUI and changed in real time while the simulation is running. Haptic interaction with moving objects is supported within the limits allowed by the update rate of Unity3D main loop. The plugin is compatible with any haptic device supported by CHAI3D.

The haptic plugin has been used to implement a study on the haptic perception of virtual textures in Unity 3D ([6] (submitted)) and is currently used to implement a serious game to teach 3D geometry to young children ([7], [8]).

The *authors declare* that there is *no conflict of interest.*

Modeling explicit learning in hand movement adaption using eye tracking

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

1. *Dept. of Biomedical Engineering, Ben-Gurion University of the Negev, Israel*
2. *Zlotowski Center for Neuroscience, Ben-Gurion University of the Negev, Israel*
3. *Dept. of Bioengineering, Imperial College London, United Kingdom*

Motor learning driven by error correction from one movement to the next consists of two components: one explicit and the other implicit. While the total amount of learning is the combination of these two components; measuring the relative contribution of each component still poses a challenge. The present research is based on a study by Taylor et al., (2014) where they assessed the magnitude of explicit learning by asking subjects to verbally report their aiming direction. Here, we investigated whether eye movements can provide a valid measure of the explicit component.

Subjects performed a standard visuomotor learning adaptation task where the cursor movement was rotated 45º relative to the hand. One group of subjects did the task in the same way as in Taylor's study: reporting the intended direction every movement. The other group did not report their direction of movement. In both groups, we recorded eye movements during the task.

We found that eye movements followed a general pattern whether the subjects are asked to report their aiming direction or not. The eyes initially fixate the origin of the reaching movement. After target appearance, the eyes saccade to the target. However, immediately before movement, the eyes saccade again. This second saccade is in the direction the hand will need to move to correct for the cursor rotation.

We hypothesize that this second saccade reflects the subjects' explicit intention. We base this claim on three aspects of this eye movement. First, during the reporting sessions, there was a close match between the learning curve of the reporting and the learning curve of the eye movements. Second, for subjects in both groups, the eye movements learning curves showed the basic pattern of explicit learning: a rapid rise early in the rotation phase followed by a gradual decline over the course of the learning set. Last, subjects showed similar savings in both eye movement and hand movement when performing the experiment a second time. Taking all of this evidence into consideration, we propose that eye fixation at movement initiation reflects the subjects explicit aiming direction.

Vision and gravity in inclined planes: a VR study of perception and action coupling

Desiderio Cano[1, 2], Rivka Inzelberg[2, 3], Yotam Bahat[1], Gabriel Zeilig[2, 4], Meir Plotnik[1,2,3]

1. *Center of Advanced Technologies in Rehabilitation, Sheba Medical Center, Israel*
2. *Faculty of Medicine, Tel Aviv University, Israel*
3. *The Sagol School of Neuroscience, Tel Aviv University, Israel*
4. *Rehabilitation Department, Sheba Medical Center, Israel*

Introduction: Functional locomotion is mostly a visually guided behavior. Besides the *on-line* visual control of locomotion, strategies integrating multisensory inputs (e.g. visual, proprioceptive, and vestibular) are imperative to adapt gait in constrained environments and daily tasks. Previous studies using virtual reality environments (VE) suggest that variations of visual feedback modulate balance and locomotion in healthy individual and in neurological patients with gait deficits. However, the mechanisms regulating locomotion to accommodate to environmental changes in inclined planes remain unclear.

Objective: To characterize the role of vision in locomotor adaptations when walking on inclined planes.

Methods: Fifteen young healthy participants (mean ± SD: 27.2.1±3.9 y, 9 female) walked in a self-paced treadmill (TM) synchronized with a VE (i.e. a one-lane road) projected over a 360° dome-shaped screen in a room-size virtual reality facility (CAREN High End, Motek Medical, The Netherlands). Here, we report on seven walking conditions. [1]: congruent VE-TM level, [2] congruent VE-TM uphill (+10°), [3] congruent VE-TM downhill (-10°), [4]: only VE switches to uphill, [5]: only VE switches to downhill, [6] only TM switches to uphill and [7] only TM switches to downhill. To characterize locomotor adaptations among conditions, we compared walking speed, postural adjustments and spatiotemporal parameters. To estimate the temporary contribution of vision, we implemented a weighted average linear model.

Results: Incongruent visual input (conditions 4 and 5) induced locomotor adaptations that were consistent with expected effects of gravity in congruent conditions. VE downhill decreased speed by 21% at 7.65±1.99s, while VE uphill increased speed by 11% at 12.4±4.50s (adaptation intensity and timing were different, $P<0.05$). Changes in the range of motion of trunk, knee, ankle and elbow determined postural adjustments in VE downhill. Spatiotemporal gait parameters were consistent with changes of walking speed. The contribution of vision was mainly relevant in the initial 10s after environmental changes and substantially decreased afterwards.

Conclusion: Expected effects of gravity regulate locomotor adaptations in inclined planes. To accommodate environmental changes, the on-line visual control of locomotion relies on the anticipated characteristics of the environment. When exposed to incongruent sensory information, a mechanism of sensory reweighting seems to gradually reject vision and predominantly rely on body-based cues (e.g., proprioception) for locomotor adaptation. Further research might explore the possible advantage of these findings in rehabilitation.

Terisa: Telerobotic Intelligent System for Patients with ALS

D. Dajles, F. Siles

Pattern Recognition and Intelligent Systems Laboratory, Department of Electric Engineering, Universidad de Costa Rica, Costa Rica

Recent years have seen a growing interest in the development of robots for helping people in everyday tasks. This is of particular relevance for those with reduced mobility, including patients with neurological degenerative diseases, such as ALS. For example, providing those patients with a way to interact with other people, and having a robot perform simple tasks for them, might allow them to regain some independence.

The interest in our lab is to devise and implement a Telerobotic Intelligent System for patients with ALS, that is, a computational platform embodied in a humanoid robot to perform telepresence, based on the idea that a human is an effective interface to interact with other humans.

To achieve our goal, we have integrated several available technologies, including controlling arms and head movements of a NAO robot using a sensor hub in an OSVR, hand gestures captured through LeapMotion, body movements by means of a Motion Capture System, as well as evoked potentials from EEG based BCI using P300 paradigms and motor imagery, while allowing the patient to observe the world through the robot’s cameras, via the OSVR.

Our preliminary results have shown over 70% accuracy in controlling the robot, with up to seventeen different routines. Current routines include walking in a specific direction selected using P300 signals by focusing on arrows on a screen; imitating user’s head movement with OSVR; standing or sitting after a key tap with the left or right index finger respectively.

Additional research is being conducted to join all the available technologies into a system that allows multiple commands depending on the patient’s disability; as well as adding the option for the robot to vocalize what the patient spells through the BCI, using a P300 spelling system.

Transfer of learning between eye and hand tracking when adapting to a visuomotor rotation

James Mathew[1], Pierre-Michel Bernier[2], Cedric Goulon[3], Frederic Danion[1]

1. *Institut de Neurosciences de la Timone, CNRS, Aix-Marseille University*
2. *Département de* Kin*anthropologie, Université de Sherbrooke, Sherbrooke, Québec, Canada*
3. *Institut des Sciences du Mouvement, CNRS, Aix-Marseille University*

Skilled motor behaviour relies on the brain learning both to control the body and predict the consequences of this control (Flanagan et al., 2003). Prediction turns motor commands into expected sensory consequences, whereas control turns desired consequences into motor commands (Kawato, 1999). Here, using adaptation to a 90° visuomotor rotation, we investigated how the update of predictive mechanisms involved in eye tracking might influence the update of hand movement control, and vice versa. To achieve this goal we tested the transfer of learning between two tasks. In the first task participants had to track with their eyes a self-moved target whose displacement was driven by means of random hand motion (Landelle et al., 2016). This eye tracking task allowed testing the ability of participants to predict visual consequences arising from their hand actions. In the second task participants had to move a cursor with their hand so as to track an externally moved target (Ogawa & Imamizu, 2013). This hand tracking task allowed testing the ability of participants to control a cursor along a desired trajectory. A key issue was to determine whether adaptation to visuomotor rotation in one task could transfer to the other task. To achieve this goal we compared the performance of one group of participants who first adapted to eye tracking and then to hand tracking, with the performance another group who first adapted to hand tracking and then to eye tracking. Comparison between groups showed an asymmetrical transfer of learning between the eye and hand tracking tasks. Namely although prior adaptation of hand tracking favoured the adaptation of eye tracking, prior adaptation of eye tracking did not benefit to hand tracking. Based on these observations we conclude that the update of hand movement control is accompanied by an update in eye predictive mechanisms, but the update of eye predictive mechanisms can be performed in isolation of hand movement control. Within the internal model approach, a possible scheme to account for these results is that visuomotor adaptation in the hand tracking task requires both the update of a forward and an inverse model of the hand, whereas adaptation in the eye tracking task relies solely on the update of a forward model of the hand. At a more general level these results indicate that an improvement in the ability to predict movement consequences does not necessarily convert into a greater ability to control movement.

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Spinal circuits controlling interlimb coordination and speed-dependent gait expression

Simon M. Danner, Natalia A. Shevtsova, Ilya A. Rybak

Department of Neurobiology and Anatomy, Drexel University College of Medicine, USA

To effectively move in the environment, limbed animals use different gaits depending on the desired locomotor speed. Mice, for example, transition from walk to trot and then to gallop and bound with increasing speed. Each gait is characterized by a distinct pattern of limb movements, which in turn is defined by neural interactions between spinal circuits controlling each limb. These interlimb pathways are mediated by short projecting commissural interneurons (CINs) that control left-right interactions at the lumbar and, presumably, cervical levels, and descending (cervical-to-lumbar) and ascending (lumbar-to-cervical) long propriospinal neurons (LPNs) that control homolateral and diagonal interactions. We present a computational model of the spinal locomotor circuits and investigate the potential role of CINs and LPNs in the control of gaits and their speed-dependent expression. The model consists of four rhythm generators, one for each limb, that interact via several bidirectional pathways mediated by CINs (left-right) and LPNs (homolateral and diagonal). Brainstem drive acts on the rhythm generators to control locomotor speed and on CINs and diagonal LPNs to affect interlimb coordination. The model reproduced speed-dependent gait expression of mice with intact nervous system and speed-dependent disruption of hind limb coordination after deletion of cervical-to-lumbar LPNs, while exhibiting the correct loss of gaits after removal of genetically identified V2a, $V0_V$ and all V0 neurons. Brainstem drive to CINs and LPNs affected the balance of two competing pathways which in turn caused the gait transitions. The model proposes the following roles for CINs and LPNs: diagonal $V0_D$ LPNs supports walk, diagonal $V0_V$ LPNs together with local $V0_V$ CINs stabilize trot, and homolateral LPNs ensure fore-hind alternation present in all gaits. External inputs to CINs and LPNs can affect interlimb coordination and gait expression independent of speed. We suggest that these interneurons represent the main targets for supraspinal and sensory afferent signals adjusting gait to different environmental and behavioral conditions.

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Danner SM et al. J Physiol 2016,594(23), 6947–67.

Social Robots as Physical Curiosity Assessment Tools

Matan Epstein, Goren Gordon

Curiosity Lab, Department of Industrial Engineering, Tel Aviv University

A novel use of social robots is introduced, namely, as assessment tools for cognitive and social characteristics of human subject. Social robots convey objectivity, repeatability and robustness which are highly important in assessment tools, and lacking in human and interaction-based tools.

Here, we implement a fully autonomous social robot for the purpose of assessing physical curiosity of human subjects, namely, how do people explore novel social and physical scenarios. The complex interaction enables us to disambiguate learning, exploration and curiosity-based behaviors, where we show that correlation between self-reported personality traits and physical curiosity computed measures. More specifically, we show that conscientious people do not initiate un-prompted exploration, whereas imaginative people learn how to explore faster. Our results suggest that this novel experimental paradigm can be implemented in a host of social and physical assessment tasks.

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Differences between Young and Older Users when Interacting with a Humanoid Robot: a Qualitative Usability Study for Rehabilitation

Feingold-Polak Ronit[1], Elishay Aviatal[1], Shahar Yonat[2], Stein Maayan[2], Edan Yael[2] and Levy-Tzedek Shelly[1]

1. *Department of Physical Therapy*, *Faculty of Health Sciences, Ben-Gurion University of the Negev, Israel*
2. *Department of Industrial Engineering and Management*, *Ben-Gurion University of the Negev, Israel*

Background: The number of seniors in the world is growing and it is expected that there will be a growing need for home and nursing care services. For this purpose, robots are expected to perform tasks of providing personal assistance and social care for the elderly. Socially assistive robots (SAR) are a natural category for this endeavor. In order for robots to be effective assistive tools, they must be accepted by the intended user population.

Aims: To test how age, location of touch interaction, and embodied presence of a humanoid robot affect the preferences of different age-group users when performing a cognitive-motor task.

Methods: A total of 60 subjects participated in two experiments. The participants played a memory game of reach to grasp task using real physical cups with an SAR. In the first experiment, 10 young (24.6+2.6, 5 females) and 10 older adults (70.8+5.7) played 12 trials of the game with the robot. In the second experiment, 20 young (24.75+2.2) and 20 older adults (69.4+5.64) randomly played 10 trials with the robot and 10 trials with a computer screen. When finished, they completed a questionnaire.

Results: In both experiments participants preferred a real human-like interaction with an SAR (In experiment 1: 70% $p=0.115$; In experiment 2: $p=0.0022$ for petting the hand vs touching the tablet in the older group), as they found it more "human-like" and "intimate". We found a significant preference for interacting with a robot over a screen in the young group ($p<0.0001$, vs. $p=0.157$ in the older group). Participants mentioned the robot was more "engaging", "interesting " and "human-like".

Conclusions: Both age groups preferred the interaction with a robot over a screen, this preference was stronger in the younger group. Specifically, real human-like interaction with a robot, this preference was stronger in the older group. The slow reaction time of the robot compared to the computer screen influenced the preferences of the participants. The preferences of different populations, i.e. stroke, will be investigated in a future study.

Planning of intentionally curved trajectories requires a time-consuming generation of a kinematic plan

Gil Feinstein and Lior Shmuelof

Department of Brain and Cognitive Sciences, Ben-Gurion University of the Negev, Israel

The processes of issuing a motor movement can be described as a three stage process: 1. Perception of stimuli 2. Action selection 3. Motor planning. While the effect of action selection on reaction time (RT) is well established, the reaction time costs associated with motor planning are not well known. We hypothesized that unlike planning of straight point-to-point movements, where the trajectory is likely to be an automatic outcome of a control policy, when subjects are required to perform a curved trajectory, they have to generate a kinematic plan of the trajectory, in a time consuming process.

18 subjects performed reaching movements with their wrist in a reaction time task. We manipulated the action selection component of planning by comparing RT between a condition where subjects had to move to one of 2 possible targets with a condition where they had to move to one of 8 targets. Motor planning RT cost was measured by comparing RTs of curved and straight trajectories. The curvature of the movements was indicated using a via-point (presented between the origin and the target in the straight condition and shifted to the left in the curved condition).

We found a significant action selection effect (28 ms, $p=0.0001$) and a significant motor planning effect (13 ms, $p=0.01$). there was no interaction between the two effects ($p=0.536$).

We propose that the increase in RT for curved trajectories indicates that motor planning involves a trajectory planning stage. The existence of a trajectory planning stage for straight trajectories should be further examined using brain imaging experiments and neuropsychological studies.

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Unexpected balance perturbation training for ABI patients improves dynamic balance and is associated with functional connectivity changes in cortical and cerebellar networks

Katherin Joubran[1, 3], Simona Bar-Haim[2], Lior Shmuelof[1]

1. *Brain and Cognitive Sciences, Ben-Gurion University, of the Negev, Israel*
2. *Physical Therapy Department, Ben Gurion University of the Negev, Israel*
3. *Reuth Medical Rehabilitation Center, Israel*

Background: Acquired brain injury is a major cause of impairment and functional disability and is often characterized by a deterioration of locomotion and balance. The aim of this study was to evaluate the effect of long-term unexpected constant balance perturbation training on dynamic balance and on functional connectivity (FC) in the brain.

Methods: In an exploratory clinical interventional trial, 34 subjects with chronic ABI received 22 sessions of long-term unexpected constant balance perturbation training using Re-Step™ technology (Step of Mind-Israel). Before and after training we assessed dynamic balance for all subjects and resting state FC using functional MRI. Analysis of the neural data was conducted at three levels: (i) Regions of interest (ROIs) analysis focusing on the representation of the lower limbs in the primary motor cortex (M1) and cerebellum, (ii) seed based analysis from the predefined ROIs, (iii) model free Independent Component Analysis (ICA).

Results: Training led to a significant improvement in dynamic balance (p=0.001). The improvement in dynamic balance was correlated with changes in connectivity between the cerebellar ROIs in the two hemispheres (r=-0.553, p=0.002, N=30). No significant change in connectivity following training was found between the cerebellar and cortical ROIs. Seed-based analyses from right M1 showed an increase in connectivity with the sensorimotor cortex. FC from left M1 showed a reduction in connectivity with areas in the frontal lobes. ICA analysis detected a reduction in the strength of the sensori-motor and cerebellar networks following training.

Conclusion: Unexpected balance perturbation training improves dynamic balance control in ABI subjects. The correlation between FC and dynamic balance changes suggests that the cerebellum plays a role in dynamic balance. Whole brain seed-based and ICA analysis results indicate that improvement in dynamic balance is associated with connectivity changes in cortical and subcortical networks.

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Robots prime human movement: evidence from two experiments

Shir Kashi, Danny Eizicovits, Iris Tabak, Yael Edan, Shelly Levy-Tzedek

Departments of Information systems engineering, Industrial engineering and management, Education, Industrial engineering and management, and Physical Therapy, Ben Gurion University of the Negev, Israel

When designing human-robot interactions (HRI), it is important to understand the implications of the interaction in multiple respects: time to completion of the task, success rates, levels of engagement of the human, etc. One under-studied aspect in HRI is how the movement of the robot affects the movement of the human.

In two different experiments, we studied how the movement of a robotic arm (MICO by Kinova, Canada) primed the movements of the human participants in the context of an interactive game.

In Experiment 1, 22 young participants played the mirror game, a leader-follower imitation game with the robotic arm. In that game, one player (person or robot) follows the movements of the other. Each partner (person and robot) was leading part of the time, and following part of the time.

In Experiment 2, 62 participants (40 young, 22 old) played a game of 3D tic-tac-toe with the robotic arm. Each player (person or robot) had to place a sequence of three cups of the same color along a column, a row or the diagonal of a 3D grid, in order to win. Each participant played half of the time with the robot as an opponent, and half of the time with a non-embodied opponent (a computer-controlled lighting system).

In Experiment 1, Priming of the human movement by the robotic arm manifested itself as an increase in the volume of movement ($t21 = -3.201$, $p < 0.05$) and a decrease in the number of movement reversals ($t21 = 2.219$, $p < 0.05$) after the participants followed the robot's movements. That is, the movements of the robotic arm primed the subsequent movements performed by the participants.

In Experiment 2, participants (both young and old) moved significantly slower ($p=0.001$) when they played against the slower robotic opponent, compared to their speed when they played against the faster computer-controlled lighting system.

The accumulating evidence for the priming effect by robots on the movements of humans should be considered when designing interactions with robots in a variety of contexts.

Balance Strategy Used by Panic Disorder Patients Under Computerized Static and Dynamic Measurements

Shani Kimel Naor[1]; Revital Amiaz[2,3]; Asaf Caspi[2,3]; Efrat Czerniak[2,3]; Yotam Bahat[1]; Meir Plotnik[1,5,6]

1. *The Center of Advanced Technologies in Rehabilitation, The Chaim Sheba Medical Center, Israel*
2. *Psychiatry Department, The Chaim Sheba Medical Center, Israel*
3. *Sackler Faculty of Medicine, Tel Aviv University, Israel*
4. *The School of Psychology Science, Tel Aviv University, Israel*
5. *Sagol School of Neuroscience, Tel Aviv University, Israel*
6. *Department of Physiology and Pharmacology, Sackler School of Medicine, Tel Aviv University, Israel*

Objectives: Several studies have shown an association between panic disorder (PD) and reduced balance abilities, mainly based on functional balance scales. This study aims to investigate and characterize the balance abilities of persons with PD (PwPD) using computerized static and, for the first time, dynamic balance measurements and to compare these results to scale.

Methods: Twelve PwPD and 11 healthy controls were recruited. PD diagnosis was confirmed using the DSM-IV, and symptoms severity was evaluated using the HAM-A PDSS and PAS. Balance was clinically assessed using the ABC scale and physically by the Mini-BESTest. Dizziness was evaluated using the DHI scale. Postural balance was evaluated statically by measuring body sway and dynamically by measuring body reactions to rapid unexpected perturbations.

Results: PwPD had higher scores on the HAM-D, PDSS and PAS questionnaires and lower scores on the balance scales compared to the controls (ABC: 156.2±5.9 vs. 160±0.0, P=0.016; Mini-BESTest: 31.4±0.9 vs. 29.4±2.1, P=0.014; DHI: 0.09±0.3 vs. 5.3±4.4, P<0.001). In the static balance tests, PwPD showed smaller ellipse area and higher body sway velocity (N.S), whereas in the dynamic balance tests, PwPD reacted more steadily to perturbations, and their recovery time was faster in comparison to controls (1.56±0.91s vs. 2.09±1.19s, P=0.018).

Conclusions: The computerized balance results point to an adoption of a ‘postural rigidity’ strategy by the PwPD, which is characterized by reduced flexibility of the balance system in the face of postural challenges. This may reflect a non-secure compensatory behavior. Further research is needed to delineate this strategy.

Mismatch between visual feedforward and proprioceptive feedback increases prefrontal activity. A pilot fNIRS study

Yogev Koren[1], Yisrael Parmet[2], Simona Bar-Haim[1]

1. *The laboratory for rehabilitation and motor control of walking, Department of Physical Therapy, Recanati School for Community Health Professions, Faculty of Health Sciences, Ben-Gurion University of the Negev, Israel*
2. *Department of Industrial Engineering and Management, Ben-Gurion University of the Negev, Israel*

Background: Walking is a natural human behavior. Although traditionally regarded as highly automatic, this behavior requires higher-level cognitive resources.
Until recently, research of the underlying neural network was done “offline”. Recent advances in neuroimaging technology make it possible to measure brain activity during real-time walking.
There are indications to the involvement of the prefrontal cortex in human walking. These include increased activity in complex walking conditions, as well as, alteration in prefrontal activation pattern in individuals with neurological deficit and old age, that suffer from gait disturbances. However, the nature of this activity is still unclear.

Purpose: The aim of this pilot study was to evaluate the activity of the prefrontal cortex while walking in a visually unpredictable environment.

Methods: Re-Step system (RS) is a technology for the training and rehabilitation of individuals with brain damage. It is able to generate perturbations which cannot be predicted using vision. It served as the model in this study.
Brain activity in the prefrontal cortex was measured, using near infrared spectroscopy, in three walking conditions: walking shoes, RS unperturbed and RS perturbed, in 20 young healthy adults.
Results: Results of this study demonstrated increased activity of the prefrontal cortex, as well as increased stride time variability, when subjects walked with perturbations compared to the other, predictable, conditions. While this finding was true for both hemispheres, increase in the right hemisphere was significantly larger than in the left.
Conclusions: These observation further support previous findings, linking prefrontal cortex activity to walking. The nature of this activity is unclear, however, laterality observed in this study, may expand our understanding to the role of the PFC in walking. Future investigation of the relation between PFC activity and vision during walking is guaranteed.

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Conflict of interest

Dr. Simona Bar-Haim holds equity positions in Step of Mind, the company that developed the Re-Step system.

The effect of kinesthetic and tactile information on predictive grip force control during object lifting

Raz Leib, Mor Farajian, Amit Milshtein, and Ilana Nisky

Department of Biomedical Engineering, Ben-Gurion University of the Negev, Israel

Estimating the weight of an object weight is essential to securely lift and manipulate the object. This estimation is used by the sensorimotor system to control the applied grip force needed to efficiently grasp the object, avoiding producing insufficient or excessive forces. Interestingly, while lifting a series of increasing weights, the grip force is adjusted to the next weight based on the prior series of weights in a predictive manner. It is well established that when estimating the object's weight we rely on two major force sensing modalities, kinesthetic and tactile; however, how information coming from these two sources is combined to form weight estimation, is yet unknown.

Here, we study how each force sensing modality affects grip force control. To do so, we designed an object lifting task in which we manipulated the tactile information using an artificial skin stretch device, without affecting the kinesthetic information. Using a virtual reality setup, we asked participants to lift a series of objects. In the first experiment, the weights of the objects randomly changed between trials, while keeping the magnitude of the artificial skin-stretch constant. In this random series we embedded series of four objects with increasing weights followed by a fifth object with a weight equal to the average weight of the prior four objects. In the second experiment, we changed the magnitude of the artificial skin-stretch randomly between objects while keeping their weight constant. Similar to the first experiment, we embedded series of objects with increasing magnitude of skin stretch followed by an object with the average skin-stretch magnitude.

Using maximum grip force and grip force rate metrics we show the predictive nature of grip forces for the increasing series of weights and the increasing series of artificial skin-stretch magnitude. We discuss how these results shed light on our understanding of the way the brain integrates kinesthetic and tactile information to form weight estimation, and how this integration can be modeled and tested in a Bayesian estimation framework.

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The Value-Complexity Trade-off for Reinforcement-Learning-based BCI

Hadar Levi Aharoni[1], Michal Moshkovitz[1], Stas Tiomkin[2], Naftali Tishby[1,2]

1. *The Edmond & Lily Safra Center for Brain Sciences, The Hebrew University of Jerusalem, Israel*
2. *The School of Computer Science and Engineering, The Hebrew University of Jerusalem, Israel*

Several studies in recent years have shown that the reinforcement learning (RL) paradigm can be used for training robotic devices (agent) via a brain-computer interface (BCI), as a more efficient BCI paradigm for controlling device movements. In this control approach an error-related potential (ErrP) is used as a negative reward on the agent's action. An important factor affecting the performance of this control paradigm is the accuracy of the extracted ErrP feature, which may vary across individuals and in different conditions. Thus in order to design an RL-based BCI, one has to address the issue of finding an optimal control strategy under different noise levels.

To handle the issue of a noisy reward in RL-BCI, we suggest to utilize the INFO-RL (IRL) algorithm by Rubin et al. The IRL defines a *free energy* that combines both the *value function* and the *control information* (CI), a measure of the policy complexity, with a trade-off parameter, β. By minimizing this free energy, the IRL finds policies which maximize the value function, while giving preference to "simpler" policies (that require lower CI), where the lower the β, the more important is minimizing the policy complexity compared to maximizing the value. Importantly, Rubin et al. have shown that the IRL optimization finds low-complexity policies which are more robust in the presence of noise in the rewards, and thus, show a better generalization performance under noisy conditions.

In this simulation study we used a gridworld with a 'minefield' area and simulated the noise in the ErrP feature extracted from the EEG by a Gaussian noise in the reward. We then used the IRL algorithm to find the optimal policy, under different levels of noise. The solutions were explored for a range of β values, where high β is equivalent to the standard value maximization RL problem, and low β gives preference to policies with random actions. The typical solution shows two types of policies: at high β a policy that crosses the minefield, and at low β a policy that bypasses the minefield. While the high-β policies achieve high expected value (EV) under low noise levels, the EV drops at higher noise levels. On the other hand, a lower-β policy which bypasses the minefield achieves a relatively high EV even under high noise levels, indicating that the low-β policy, i.e. a simpler policy, is the more robust solution above a certain noise level.

Explicit learning during visuomotor adaptation constitutes of two distinct components: explicit reportable knowledge and explicit control

Jana Maresch, Opher Donchin

Department of Biomedical Engineering, Ben Gurion University of the Negev, Israel

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Objective: Multiple processes operate during adaptation to visuomotor rotations. Explicit aiming strategies and implicit recalibration are two of them, and constitute dissociable and relatively independent learning processes.

Various methods have been used to dissociate explicit from implicit learning, with the most recent approaches employing trial-by-trial reporting and process dissociation, a measure derived from cognitive psychology. While closely related, the former seems to measure the awareness of the perturbation a subject can report, while the latter targets the explicit control a subject has over his movements.

The aim of the present study was to dissociate subjects' awareness of 'what they can report' from 'what they can control' and to, this way, show that different components of explicit learning exist.

Methods: We conducted two experiments, in which subjects performed baseline and rotation blocks of fast center-out reaching movements using a robotic manipulandum. The first experiment comprised two experimental groups, the consistent reporting group and the intermittent reporting group. Dissociation trials were interspersed throughout the blocks in both experiments. The second experiment was designed to enhance explicit control by alternating between washout and adaptation blocks.

Results: The reporting group showed better performance during adaptation with a higher asymptote (group 1: 59.45°, group 2: 53.87°; $p < .01$, CI = 1.93 - 9.24). Comparing the two measures of explicit learning, process dissociation revealed more explicit control in the consistent reporting group as compared to the intermittent reporting group (group 1: 31.88°; group 2: 10.88°; $p < .001$, CI = 16.20 – 25.86). Thus, reporting seems to lead to more explicit control while the intermittent reporting shows the opposite effect. We did not succeed in increasing subjects' explicit control in our second experiment. However, regression analysis of the beginning of the washout blocks showed an increase in slopes throughout adaptation. These results provide evidence for an implicit process that operates on a faster time scale than the cerebellar-based slow component.

Conclusions: Consistent reporting improved subjects' performance to the visuomotor rotation. Moreover, it enhanced subjects' ability to control adaptation more than their ability to report strategy. The time course of explicit learning in the intermittent groups did not reflect the typical time course as seen by previous studies. In our second experiment, we confirmed the findings of previous studies providing evidence for two implicit processes that operate on different timescales. Our results indicate an internal structure of explicit learning that is not well captured by state-space models.

Emotion recognition from movement: Associating specific motor components with basic emotions.

Ayelet Meltzer[1], Tal Shafir[2], Rachelle Tsachor[3]

1. School for Creative Arts Therapies, University of Haifa, Israel, Emili Sagol Creative Arts Therapies Research Center, University of Haifa, Israel,
2. School of Theater &Music, University of Illinois at Chicago, IL, USA

This study probed emotion recognition from movement using the framework of Laban Movement Analysis (LMA). Shafir et al., (2016) identified sets of LMA motor components that when moved, predicted feeling of one of the emotions: anger, fear, sadness, or happiness. The current study aimed to examine whether each set of LMA motor components that enhanced a certain emotion when moved, would also be recognized by observers as expressing that same emotion, even when the mover did not intend to express any emotion when she moved.

Our stimuli included 113 three-second video-clips of five Certified Laban Movement Analysts (CMAs) moving combinations of two to four LMA components from these sets. Each combination was composed of components associated with one emotion. A control set of ‘neutral’ components which were not part of any of the “emotional” sets was also added. The CMAs were asked to move movements composed of only the required components. Each clip showed one combination moved by one CMA. Additional 49 clips of bodily emotional expressions taken from Atkinson et al. (2004) validated set, were tested to confirm participants' ability to recognize emotions from movement.

Sixty-two physically and mentally healthy men (n=31) and women (n=31) ages 18-50 were asked to watch the clips and rate the perceived emotion (forced choice) and its intensity. Results showed that for both stimuli types (our LMA-based stimuli and Atkinson's et al. (2004) stimuli), all emotions were recognized far above chance level. Comparing the two clip types revealed better recognition of anger, fear and neutral emotion from Atkinson’s validated clips, and similar levels of recognition accuracy for happiness and sadness. Looking at each emotion separately, happiness was best recognized with 81.3% of the clips containing movements composed of the “happy components” correctly recognized by participants as expressing happiness. Second was sadness with 78.5% correct recognition, then neutral with 67.4%, fear with 51.1%, and anger with 47.2% correct recognition. Our results indicate that these specific LMA components, not only enhance the associated emotions when moved, but also contribute to the recognition of the associated emotions when being part of an observed movement.

Grip force control and perception during pinch grasping in haptic virtual and remote environments

Amit Milstein, Lidor Bachar, and Ilana Nisky

Department of Biomedical Engineering, Ben-Gurion University of the Negev, Israel

We aspire to develop a transparent human-centered controller for bilateral (haptic-feedback) telesurgery. We define transparent telesurgery in action and perception such that the surgeon interacts with the surgical environment and understands its dynamics as if she was performing an open surgery. We believe that such a controller could enhance surgical performance. Towards this aim, we focus on using haptic interfaces for manipulating of rigid and soft objects and perception of their stiffness in virtual and remote environments.

In the first experiment, we studied grip force modulation in contact with virtual deformable objects. Ten participants performed a virtual lifting and manipulation task of rigid and elastic objects, which were connected to a load spring. We controlled the stiffness of the load spring, the compliance presented at the robotic handle and the visual compliance of the grasped object, and investigated their effect on grip force modulation. Participants partially modulated their grip force with respect to the load force in the first lift of every trial, and the gain of this modulation decreased with repetitions, indicating a non-transparent interaction. In addition, overall modulation gain was larger for the less compliant handle, and was not affected by the stiffness of the load or by the visual compliance of the grasped object.

In the second experiment, we used a stiffness perception task to investigate the effect of gripper scaling on the combination of sensory modalities (haptics and visual) used for stiffness perception in remote grasping. Three participants performed a two-alternative forced choice paradigm experiment in a virtual reality environment. There were three different conditions of gripper scaling: (1) normal – no scaling, i.e. a one-to-one mapping between the local gripper aperture and remote tool gripper aperture, (2) quick – a gripper scaling larger than one, (3) fine – the gripper scaling smaller than one. We also added condition (4) blind – interaction using haptic information only. In each trial, participants chose the stiffer virtual cube of the two presented to them. Preliminary results suggest that that in the blind and fine conditions, the reference cube's stiffness was overestimated. These results hint that the modalities and their combinations, which are used for stiffness perception, might be affected by gripper scaling, but further investigation is needed.

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An experimental investigation of human stabilization of delay-induced instability in haptic rendering

Reut Nomberg and Ilana Nisky

Biomedical Engineering Department, Ben-Gurion University of the Negev, Israel

The effectiveness of teleoperation and haptic systems is limited in the force feedback that can be presented to the human operator, because it can destabilize the system. While many efforts are invested to force feedback controllers, the potential role of the human motor control in improving the stability of the system did not receive sufficient attention.

We define an unstable system that becomes stable with an appropriate human operation, as a coupled-stable system; correspondingly, this system without the intervention of an operator will be called an uncoupled-unstable. Towards developing a human-robot coupled stability theory, we study the human motor performance during interaction with an (uncoupled) unstable system. We designed an experiment in which the participants used a haptic device to probe virtual force fields and evaluate their stiffness under stable and unstable conditions. First, we designed elastic objects with different uncoupled stability conditions by combining stiffness and force feedback delay values, and verified the analytical design experimentally without adding a controller or a human active intervention. Then we studied the stabilization by human participants. We focused on performance in task space and on coordination of the variability in the redundant degrees of freedom in joints space. To analyze the latter we used the UnControlled Manifold (UCM) analysis that divides users' joint angle variability into task-irrelevant and task-relevant manifolds.

Our results show that for certain margins of uncoupled instability the stabilization applied by the participants is natural and immediate. For higher instability margins, the stabilization is not immediate, but can be quickly learned. In both stable and uncoupled unstable conditions, participants did not alter critical movements' characteristics to the operation of exploratory probing, such as depth and speed of the movement. However, oscillations appeared in movement directions that did not interfere with task performance. Such selective behavior may be indicative of an optimal control policy. In contrast to these task space results, the coordination of the joint space variability, as quantified by UCM, was not affected by the instability of the system.

We highlighted the potential importance of introducing the human capabilities into considerations of system stability, and demonstrated a new approach for its analysis. Further studies are needed to fully understand the sensorimotor mechanism that is responsible to the human stabilization of an unstable system. This line of research can eventually push the boundary force reflecting teleoperation systems.

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The effect of a concurrent cognitive task on balance and step recovery during standing and walking in healthy young individuals

Inbal Paran, Hadas Nachmani, Itshak Melzer

Department of Physical Therapy, Faculty of Health Sciences, Ben-Gurion University of the Negev, Israel

Objective: Performing a concurrent cognitive task might have a diminishing effect on stability while walking and dealing with unexpected perturbations. We hypothesized that balance recovery responses to unexpected balance loss are reflex-like responses, i.e. the postural as well as cognitive performance will be similar under single-task and dual-task conditions. We aimed to (1) compare the stepping threshold under single and dual-task conditions, (2) investigate the effect of unannounced perturbations while standing and walking on concurrent cognitive task performance.

Methods: Thirteen healthy young subjects were recruited. Unannounced lateral and anterior-posterior surface perturbations were induced by the BaMPer system in six progressive levels, while standing and walking (i.e. single-task). Concurrently, a cognitive task of serial subtractions by seven was performed (i.e. dual-task). Primary outcome measures were; Stepping threshold (i.e., the minimum disturbance magnitude that elicits a compensatory step) and Cognitive task performance ratio (i.e., the ratio between the amount of numbers counted correctly and the total amount of numbers counted). Secondary outcome measures were stepping strategies and kinematic step parameters. Non-parametric Wilcoxon signed-rank test was performed to analyze differences in stepping threshold and kinematic step parameters. For analysis of cognitive performance differences between test conditions the Friedman test was first performed. Post hoc analysis was performed using Wilcoxon signed rank test. Stepping strategies differences were qualitatively analyzed.

Results: We found no significant differences in stepping thresholds between single and dual-task conditions. Friedman test did not reveal a significant difference in cognitive performance between test conditions. However, due to the small sample size, post-hoc analysis was performed and revealed a significantly better cognitive performance during perturbed walking (97%) compared with perturbed standing (92%, p=0.019) and sitting (94%, p=0.05). There were no significant differences in the compensatory strategies. Kinematic step parameters were mostly unaffected by the concurrent cognitive task in all conditions.

Conclusions: Our results seem to support our hypothesis that compensatory balance reactions are reflex-like. during perturbed standing, it seems that the motor task required more cognitive resources than in perturbed walking. During perturbed walking, young subjects seem to have sufficient postural control capabilities which do not require large cognitive resources.

Bayesian approach to sensory integration of shape information in healthy people and anorexia nervosa patients

Risso G. [1,2], Crippa F.[3], Martoni R.M.[4], Bellodi L.[3,4] Baud-Bovy G. [2,3,5]

1. *DIBRIS, Università di Genova,Italy*
2. *Robotics, Brain and Cognitive Sciences Unit, Istituto Italiano di Tecnologia, Italy*
3. *Faculty of Psychology, University Vita-Salute San Raffaele, Italy*
4. *Department of Clinical Neurosciences, San Raffaele Scientific Institute, Italy*
5. *Unit of Experimental Psychology, IRCCS San Raffaele Scientific Institute, Italy*

Information about our environment and bodies is complex and human sensors often provide uncertain and noisy information[1]. Nevertheless, information coming from different senses is usually at least partially redundant and numerous studies have shown that humans' nervous system can integrate information from multiple sources in a statistically optimal fashion[2]. Anorexia Nervosa (AN) patients have a disturbed representation of the body and it has been hypothesized that their ability to process multimodal information might be disrupted[3,4].

The objective of this work was to find out whether AN patients process visual and haptic information about the 2D shape of objects like Healthy Control (HC) volunteers. Adapting a paradigm previously used by Helbig & Ernst's (2007)[5], we presented 2D ellipses of various eccentricities in unimodal haptic, unimodal visual and bimodal visuo-haptic conditions. Participants had to judge whether the ellipse was oriented horizontally or vertically. The analysis of the unimodal conditions yielded several interesting results. First, we found a significant bias in the haptic perception of the stimuli, indicating that haptic ellipses were perceived more horizontally than visual ellipses. Second, we found a tendency of AN patients to overestimate the horizontal axis of the ellipses relative to the HCs in the two modalities. In other words, the AN patients perceived "fattened" ellipses with respect to the HCs, regardless of the sensory modality used to perceive them. Third, the discrimination thresholds for the AN patients in the visual condition were much larger than the same thresholds for the HC group. In other words, the visual modality provided less reliable information about the ellipse shapes to the AN patients. Finally, with respect to the bimodal conditions, we found that the bimodal estimates of the ellipse shape was more reliable in the bimodal conditions for the two groups, in agreement with Bayesian optimal integration principles.

Our results suggest that the processing of visual and haptic shapes in ANs patients is distorted. While the tendency to "fatten" the ellipses was present in the two sensory modalities, we found that the haptic cue provided more reliable information than the visual cue to the AN group. This finding is in line with the idea that patients suffering of AN might discard veridical visual information about their body shape[3,6].

Hypermetria after exposure to visuomotor delay in a virtual game of pong is caused by unaware adaptation of movement planning

Erez Sulimani[1,2], Guy Avraham[1,2], Ferdinando A. Mussa-Ivaldi[3,4], and Ilana Nisky[1,2]

1. *Department of Biomedical Engineering, Ben-Gurion University of the Negev, Israel*
2. *Zlotowsky Center for Neuroscience, Ben-Gurion University of the Negev, Israel*
3. *Shirley Ryan AbilityLab, Chicago, IL*
4. *Department of Biomedical Engineering, Northwestern University, Evanston,* IL

Sensory feedback delays inherently exist in the sensorimotor system due to information transmission and processing, and we must take them into consideration to enable successful interaction with the world. A recent work showed that an experience with a visuomotor delay between the hand and paddle movements during a virtual game of pong leads to hypermetric movements in a subsequent blind reaching task.

Here, we investigated if the effect that was observed during action is also associated with a perceptual bias. Following a delayed pong game, participants were asked to perform blind reaching movements towards a target while imagining an invisible cursor, and a subsequent location assessment task. In the latter, participants were asked to assess the location of the imagined cursor at the end of the reaching movement. We found that participants performed hypermetric reaching movements, but reported that the invisible cursor reached the target. This result suggests that they were unaware of the hypermetria, and therefore, their perception was biased towards the target.

In a second experiment, we examined whether the adaptation to the visuomotor delay affected movement planning or its execution. The experiment was similar to the first experiment except for the blind reaching task; this time, movements were performed without a visible target being presented, but towards a location that was freely chosen by the participant. This enabled us to examine whether the existence of the target, which drives an internal visually-dominated planning process, is important for the hypermetric reaching movements and the perceptual bias. Strikingly, the removal of the target cancelled the hypermetria in the reaching movements. Moreover, participants reported that the invisible cursor was located at the hand position. The combined results suggest that the observed hypermetria is a result of an unaware adaptation of movement planning.

Understanding the way externally-induced delay between the sensory modalities influences our action and perception sheds light on the processes that underlie sensory integration and movement control, and it may help in understanding different pathological conditions that are characterized by delayed information transmission. Moreover, it can be important for designing, developing, and controlling systems that contain inherent delays, such as teleoperation and surgical robotics.

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Human Speech: Encoding by Single Subthalamic Neurons and Coding Deterioration in Parkinson's Disease

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

1. *Functional Neurosurgery Unit, Tel Aviv Sourasky Medical Center, Israel*
2. *Department of Neurology and Neurosurgery, Sackler Faculty of Medicine, Tel Aviv University, Israel*
3. *Sagol School of Neuroscience, Tel Aviv University, Israel*
4. *Department of Neurosurgery, University of California, CA, USA*

Speech production requires complex motor control of multiple speech organs. To understand the neuronal encoding in the speech system, we intraoperatively recorded the activity of single neurons in the subthalamic nucleus (STN) of 18 patients with PD undergoing implantation of deep brain stimulator (DBS) while they articulated five vowel sounds, listened to another individual articulating the vowels, and imagined saying the vowels. We find single units in the STN which represent individual phonemes in all three aspects of speech (production, perception and imagery). We show that these units employ one of two encoding schemes: broad or sharp tuning. Broadly-tuned units respond to all examined phonemes, each with a different firing rate, whereas sharply-tuned ones are specific to 1-2 phonemes. As most Parkinson's disease (PD) patients suffer from speech disorders, mainly dysarthria and hypophonia, we compared patients with and without speech deficits. The spiking activity in patients suffering from speech disorders is significantly lower during speech production, overt or imagined, but not during perception. However, patients with speech disorders harness a larger percentage of neurons for the aforementioned tasks during speech production. Whereas the lower firing rate is mainly in sharply-tuned units, the extra-recruited ones employ a broad tuning encoding scheme. Our findings suggest mechanisms of neuronal degradation due to Parkinsonian speech disorders and their compensation. Because impairment in sharply-tuned units is compensated by broadly-tuned ones, the compensation appears to be suboptimal, lending support to the persistence of speech disorders during the course of the disease.

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Differential contribution of implicit and explicit memory systems to motor learning with age

Noham Wolpe[1,2,3], James N. Ingram[4], Kamen A. Tsvetanov[5], Richard N. Henson[3], Rogier A. Kievit[3], Daniel M. Wolpert[4], Cam-CAN[6], James B. Rowe[2,3]

1. *Wolfson Medical Center, Sackler Faculty of Medicine, Tel Aviv University, Israel*
2. *Department of Clinical Neurosciences, University of Cambridge, Cambridge UK*
3. *Medical Research Council Cognition and Brain Sciences Unit, Cambridge, UK*
4. *Computational and Biological Learning Laboratory, Department of Engineering, University of Cambridge, UK*
5. *Centre for Speech, Language and the Brain, Department of Psychology, University of Cambridge,*
6. *Cambridge Centre for Ageing and Neuroscience (Cam-CAN) University of Cambridge and MRC Cognition and Brain Sciences Unit, UK*

The ability to adapt one's movements to changes in the environment is fundamental in everyday life but can be impaired in healthy ageing. Previous research has linked motor adaptation with both explicit and implicit learning strategies, but how these strategies contribute to reduced motor adaptation with age remains unclear. We studied this question by combining a visuomotor learning paradigm; cognitive tasks that measure explicit and implicit strategies; and structural brain imaging in a large (n=322) population-based cohort from the Cambridge Centre for Ageing and Neuroscience. The degree of movement adaptation to an angular perturbation was significantly reduced with age, with no differences in aftereffects – that is, the tendency to make movement errors in the opposite direction to a previously learned perturbation. Importantly, there was a significant positive interaction between age and explicit memory in relation to the degree of adaptation, such that explicit memory was an important determinant of motor learning, specifically in older adults. An opposite pattern was found for implicit memory. A whole-brain analysis of grey matter volume showed a similar positive interaction effect of bilateral hippocampal and amygdala grey matter with age, wherein grey matter in these regions is positively associated with the degree of adaptation, specifically in older adults. Together, these results converge to reveal a larger role for explicit, but not implicit, memory system in age-related reduction of motor adaptation, and suggest that older adults may shift to an explicit learning strategy that maximises immediate task success.

The unity assumption in haptic size discrimination tasks: when does bimanual integration occur?

Xu Q.[1,2], Risso G.[1,2], Baud-Bovy G.[2,3]

1. *DIBRIS, Università di Genova, Italy*
2. *Robotics, Brain and Cognitive Sciences Unit, Istituto Italiano di Tecnologia, Italy*
3. *Faculty of Psychology, Vita-Salute San Raffaele University & Unit of Experimental Psychology, IRCCS San Raffaele Scientific Institute, Italy*

A key to robust perception is the combination and integration of multiple sources of sensory information[1]. Previous studies have shown that the brain can integrate inputs from different sensory-modalities[2,3] or within the same sense[4,5] in a statistically optimal fashion. However, the mechanisms of how the brain combines haptic information from the two hands are still unclear. While some studies on bimanual haptic integration found that information from the two hands are not integrated[6,7], others found a different result [7]. The objective of this study is therefore to investigate the factors that might explain this discrepancy.

Following-up a preliminary study[7], we hypothesized that integration might be hampered when objects are grounded and force is not transmitted between two hands. To verify this hypothesis, we measured the precision with which participants gauged the size of large objects such as boxes and pliers with one or two hands. In the bimanual conditions, the box could be grounded or lifted above the table. Similarly, the plier experiment included constrained-joint and free manipulation bimanual conditions. The maximum likelihood model (MLE) predicts that redundant information from both hands should yield haptic precision that is superior to unimanual exploration if the information from the two hands is integrated.

In line with our hypothesis, we found that discrimination thresholds were lower when the objects were lifted and/or moved freely in the bimanual conditions. For the box experiment, most of participants showed lower thresholds in the lifting condition than grounded condition. For the plier experiment, the results in the free condition were very similar to those predicted by the MLE hypothesis while the bimanual thresholds in the constrained condition were comparable to unimanual ones.

Our results are best understood by noting that an observer cannot know whether the object held with both hands is the same object when it is grounded. Even though lifting the object does not bring additional information about the object size, it does make it obvious that the two hands are touching the same object. Our results are in line with the “unity assumption”, which posits that multisensory integration depends on the extent to which two sensory inputs refer to a single unitary distal object/event [9–11]. In particular, the results of this study illustrate how this assumption and bimanual integration might depend on patterns of movement and force transmission that signal that the two arms are holding the same object.

Climbing fibers encode the size of the expected reward in monkeys

Merav Yarkoni, Adi Lixenberg, Yehudit Botschko and Mati Joshua

ELSC for Brain Sciences, The Hebrew University of Jerusalem, Israel

Theoretical and experimental studies of cerebellum have indicated that climbing fibers inputs to the cerebellar cortex encode a sensory prediction error signal that drives motor learning. Recently, evidence have accumulated to suggest that information about the reward also drives activity in the cerebellum.

To test whether and how information about reward is encoded in the cerebellum we recorded the manifestation of the climbing fiber activity as complex spikes in the purkinje cells of the cerebellum. Monkeys were engaged in smooth pursuit eye movement task in which the color of the target indicated that size of the upcoming reward. We found that after the target changed color to cue the size of the reward, complex spikes firing rate was larger in trials that the monkey expected a large versus a small reward. By contrast, the complex spike rate was not modulated by the reward size at the end of the eye movement when the reward was delivered. The pattern of complex spike modulation was different from the pattern of licking that did not distinguish between reward sizes at the cue epoch but did strongly discriminate between the sizes of the reward at outcome delivery.

We conclude that the climbing fiber signal is modulated by reward. This signal is akin to the reward prediction error signal that was identified in the dopaminergic neuron in the basal ganglia. We suggest that this signal could instruct learning that was so far hypothesized to be accomplished outside of the cerebellum.

Error origin detection and classification

Boris Yazmir and Miriam Reiner

The Virtual Reality and Neuro-cognition Laboratory*, Faculty of Education in Technology and Science, Technion – Israel Institute of Technology, Israel*

Can we recognize error origins from brain activity? It is well established that an error spotted by a person evokes a brain response known as Error related potential (ErrP). ErrP's is embedded in the ongoing Electroencephalography (EEG) signals. We hypothesize that errors of different types, accord a variety of situations, evoke different ErrP characteristic, determined by the nature of error. Here we examine the feasibility of error origin recognition and classification.

Current Brain Computer Interface (BCI) are prone to miss-classification with an error rate of about 30%. One of the solutions is to use ErrP as feedback signal for the BCI. Implementation of this approach in a step-wise motion task brought about significant decrease in error rate to below 10%. Here we propose to enhance this approach by recognition of error origin, followed by a tailored improved error correction, that will potentially decrease classification system error rate.

With this goal in mind we compared ErrPs evoked by errors of different origin. In order to provide a valid comparison all errors were generated in the same experimental environment, with the same participants. Participants played a virtual 3D tennis-like game, against a computer player. The virtual game world was immersive, ecologically valid and provided a sense of physical forces via a haptic controller. The participant controlled a virtual tennis racket with a force feedback robotic haptic arm. The following error types occurred: (1) Outcome throwing errors - generated when the participant did not score a goal; (2) Outcome repelling internal user errors – generated when the participant missed a ball; (3) Execution external errors with congruent and incongruent visual and proprioceptive feedback – congruent errors generated by shift of the controlling hand, while incongruent are generated by shift of the virtual racket on a screen only; and (4) External target errors – generated by unexpected inclination of the incoming ball.

These errors generated distinctive ErrPs. ErrP of each error type had its' own characteristic signal pattern, spectral response, cortex distribution and source localization. Consequently, it is possible to recognize the origin of error from analysis of its' ErrP. Theoretically, it is possible to build a smart error classifier based on the ErrP. This classifier can provide BCI with error tailored feedback, which in turn can be used for more efficient error correction. In addition, it can be used for diagnostic and rehabilitation purposes as a measure of patient capability to recognize the error origin. This can provide an index for the error management mechanism in the brain of a patient in conditions such as brain injury or stroke conditions.