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Symposia

SPATIAL COGNITION IN ROBOTICS

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Robots have been extensively employed in industrial factories for the last 50 years. Industrial robots are designed to perform repetitive, predictable tasks, but are not able easily adapt or learn new behaviours. In order to execute their programmed tasks, they have to sense only a constrained set of environmental parameters, thus perceptual systems mounted on industrial robots are simple, practical and task-oriented. On the other hand, they are designed to work in environments in which human presence is limited and controlled, if allowed. Thus, while their usefulness is evident, industrial robots area strongly limited. Nowadays, robots have however crossed the security frontier that separated them from people, and extended into a large variety of occupations such as surgical systems, milking robots, fruit picking, vacuum cleaners, lawn mowers, exploration, tour guides, security guards, etc. These service robots constitute an increasingly interesting area, where the robot usually moves in structured environments (hospitals, museums, offices, university campus, neighbourhoods, etc.) and needs to interact with people. In this new scenario, it will be interesting that the robot not only navigates or manipulates objects, but also that it will be able to understand, interpret and represent the environment in an efficient and consistent fashion. Besides, it would have to interact and communicate in human compatible ways. Both problems are made difficult by a multitude of reasons including the broad amount of information, the large number of types of data, the presence of dynamic entities in the environment, etc. Adding to all of these problems are two issues—everything is uncertain and at any time, only partial knowledge of the environment is available. The aim of this symposium is to provide a general overview of how the robotics community is currently addressing the cognition of the environment.

Perceptual organization and artificial attention for visual landmarks detection

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In biological vision systems, attention mechanisms are the responsible of selecting the relevant information from the sensed field of view so that the complete scene can be analyzed using a sequence of rapid eye saccades. In the recent years, efforts have been made to imitate such attention behaviour in artificial vision systems, because it allows optimizing the computational resources as they can be focused on the processing of a set of selected regions only. In the framework of mobile robotics navigation, this work proposes an artificial model where attention is deployed at the level of objects (visual landmarks), and where bottom-up and top-down factors are integrated. Bottom-up attention is implemented through a hierarchical process whose final result is the perceptual grouping of the image content. The hierarchical grouping is applied using a Combinatorial Pyramid that represents each level of the hierarchy by a combinatorial map. Thus, the process takes simultaneously into consideration image regions (faces in the map) and edges (arcs in the map). Feature Integration Theory is then applied, but features are here associated to image regions and edges, and not to isolated pixels. Top-down attention is implemented for searching previously detected landmarks, enabling their re-detection when the robot presumes that it is revisiting a known location. Considering that landmarks are described by a combinatorial submap, this searching is conducted through an error-tolerant submap isomorphism procedure.

The role of mental rotations in primate-inspired robot navigation

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The capacity for performing mental rotations has been observed in multiple species and not solely humans. A question persists regarding just what evolutionary advantage is afforded by this spatial reasoning system, especially for non-human primates, who do not use map reading. In a 3-year project for the Office of Naval Research we are investigating the role of mental rotation in navigation for autonomous robots, not as a replacement for existing methods but rather as a conjunct for certain situations. Using optic flow derived depth maps as quasi-instantaneous snapshots of the environment, a behavioral robotic architecture is enhanced with this semi-reactive navigational capability based on primate models of optic flow and mental rotation. To support this work, a vectorial mathematical framework is developed, spanning the sensorimotor and cognitive spatial aspects of this approach. This presentation provides the motivation, background, theoretical basis, computational models, and implementation results to date in simulation and robots for utilizing primate-inspired mental rotation models as a basis for intelligent robotic navigation.

Learning emergent behaviours for a hierarchical Bayesian framework for active robotic perception

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How should the uncertainty and incompleteness of the environment be represented and modelled so as to increase the autonomy of a robot? Can a robotic system perceive, infer, decide and act more efficiently by using a probabilistic framework? These are two of the challenging questions robotics researchers are currently facing in the design of more autonomous and intelligent artificial robotic systems. In this research work, we contribute with a behaviour learning process for a hierarchical Bayesian framework for multimodal active perception, devised to be emergent, scalable and adaptive. This framework is composed by models built upon a common spatial configuration for encoding perception and action that is naturally fitting for the integration of readings from multiple sensors, using a Bayesian approach devised in previous work. The proposed learning process is shown to reproduce goal-dependent human-like active perception behaviours by learning model parameters (referred to as "attentional sets") for different free-viewing and active search tasks. Learning was performed by presenting several 3D audiovisual virtual scenarios using a head-mounted display, while logging the spatial distribution of fixations of the subject (in 2D, on left and right images, and in 3D space), data which is consequently used as the training set for the framework. As a consequence, the hierarchical Bayesian framework adequately implements high-level behaviour resulting from low-level interaction of simpler building blocks by using the attentional sets learned for each task, and is able to change these attentional sets "on the fly", allowing the implementation of goal-dependent behaviours (i.e. top-down influences).

Spatial and perceptive mapping using semantically self-organizing maps applied to mobile robots

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Mapping is the technique used by robots to build up a map within an unknown environment, or to update a previously built map within a known environment. The problem is related to integrating the information obtained by multiple sensors in a consistent model and describing it by a given representation. The main aspects of mapping are the interpretation of sensor data and the representation of the environment. Metric techniques perform geometrically consistent maps of the environment. On the contrary, topological approaches divide the environment into significant areas, with the aim to capture the connectivity of these areas rather than creating a geometrically accurate map. In the case of several sensors, different algorithms should be used for extracting information from them. Such information can be ordered in a hierarchy of levels in order to obtain semantic meaning of different scene perception. In this context, this paper proposes a method for mapping generic environments (structured or not) based on several semantic maps. In our implementation, each map can be described as a topological map, which is modelled using self-organizing neural networks. The approach was implemented and validated in a set of environments using Pioneer robots, equipped with an omnidirectional camera and a GPS. All the results were obtained using the robot simulator Webots, due to its facility to test extreme conditions. Issues related to high dimensionality, perceptive correspondence and dynamicity have been evaluated. The results obtained in different dynamic and ambiguous environments show the capabilities of the method to reduce data dimensionality and the generalization of the proposal.

The spatial change detection problem in robotics: a probabilistic approach based on mixture of Gaussians

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Understanding and reasoning about the robot surroundings have always been two of the most important needs in several robotics applications. Robot navigation and localization, human-robot interaction or environment modelling are different examples where spatial cognition plays an essential role. In this paper, a probabilistic approach based on Gaussian Mixture Models (GMM) for detecting and segmenting changes in the environment of the robot is described. The aim is to identify significant changes without human supervision (e.g. Furniture or objects that represent a novelty with respect to the known map by the robot) using as input 3D point clouds from Prime Sense RGBD sensor. GMM provides a feature space that enables data compression and effective processing, allowing successfully to segment the set of points acquired by the sensor and thus, to reduce the computational load of the change detection task. This approach is related to the following interesting topics in spatial cognition: (i) what types of change draw attention; (ii) whether changes can be detected in the absence of awareness; and (iii) what mechanisms underlie successful change detection. Experimental results demonstrates the effectiveness of the approach for detecting and segmenting simple changes in indoor environment and contributes to address theoretical questions concerning spatial knowledge and representation. Besides, this work leads to the possibility of adding an attentional mechanism in the proposed change detection task.

Indoor scene perception for object detection and manipulation

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Social robots are designed to interact and share their environments with humans while performing daily activities. They need to build and maintain rich representations of the space and objects around them in order to achieve their goals. In this paper we propose a framework for building model-based representations of the space surrounding the robots and the objects nearby. The approach considers active perception as the phenomena resulting from the controlled interactions between different model-fitting algorithms and a grammar-based generative mechanism called "Grammar for Active Perception" (GAP). The production rules of these grammars describe how world models can be built and modified, and are associated with the behaviours needed by the model-fitting algorithms in order to succeed. Such descriptions can be used to compute the required actions to build consistent models of the environment. The resulting behaviour seizes the a priori knowledge available to the robot, not only to improve the modelling process, but also to guide exploration and visual attention. The models generated using these grammars are attributed graphs that contain geometric and other semantic

properties. In order to provide evidence of the feasibility of the method, we describe the results obtained from the experiments run in a noisy simulated environment with tables, objects and obstacles, in which a robot is asked to perform different perceptive tasks.

On the impact of depth information for visual place classification

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Visual place classification can be addressed as a pattern recognition problem where sequences of images have to be classified depending on semantic areas. These areas usually correspond to room categories like kitchen, bathroom or corridor. Most of the proposals for solving this problem are only based on visual information. These approaches extract visual cues or landmarks from training images and use them to generate a classifier. This process is based on context interpretation instead of pure geometric models. The accuracy of the classifier relies on the presence of discriminative landmarks (such as a micro wave oven), but their detection highly depends on the lighting conditions. In order to cope with changing lighting conditions, new approaches for place classification include distance sensors as an additional source of information. The main advantage of depth information is given by its independence from lighting conditions although distance images are not as intuitive for humans as visual ones. Moreover, landmarks extraction from depth images is a challenging task. This article discusses the impact of depth information for place classification, with a special focus on competitions where place classifiers are evaluated. The most important competition related to place classification is the Robot Vision task, hosted since 2009 in the Cross Language Evaluation Forum (CLEF). The use of depth information (kinect images) has been included in the 2012 edition task.

Topological visual mapping in robotics

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A key problem in robotics is the construction of a map from its environment. This map could be used in different tasks, like localization, recognition, obstacle avoidance, etc. Besides, the Simultaneous Location and Mapping (SLAM) problem has had a lot of interest in the robotics community. This paper presents a new method for visual mapping, using topological instead of metric information. For that purpose, we propose prior image segmentation into regions in order to group the extracted invariant features in a graph so that each graph defines a single region of the image. Although others methods have been proposed for visual SLAM, our method is complete, in the sense that it makes all the process: it presents a new method for image matching; it defines a way to build the topological map; and it also defines a matching criterion for loop-closing. The matching process will take into account visual features and their structure (graph) using the Graph Transformation Matching (GTM) algorithm, which allows us to process the matching and to remove out the outliers. Then, using this image comparison method, we propose an algorithm for constructing topological maps. During the experimentation phase, we will test the robustness of the method and its ability constructing topological maps. We have also introduced new hysteresis behaviour in order to solve some problems found building the graph.

Unified framework for recognition, localization and mapping using wearable cameras

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Monocular approaches to simultaneous localization and mapping (SLAM) are able to build an accurate map of the environment using a single camera. They usually rely on the detection of interest points to estimate the camera position and the map. Low-level features are salient and very numerous. Density of features is a hard problem for reliable data association and map updating. For real-time SLAM applications, just a reduced set of the detected features can be tracked and updated. The feature initialization process consists of the random selection of a spread subset of the detected features. Hence, the resulting map is a meaningless cloud of 3-dimensional points or dense maps with no semantic information. In this work, we will describe how high-level features can be superimposed on the map building to cluster point-based features, providing a more interesting description of the environment. These high-level features will be obtained from an object-based, bottom-up attention mechanism, which extracts from the image a set of proto-objects. These proto-objects could not be always associated to natural objects, but they will typically constitute significant parts of these scene objects. Moreover, they will be affine covariant regions, i.e. they will be invariant to affine transformation, being detected under different viewing conditions (view-point angle, rotation, scale, etc). In this approach, these proto-objects will be used as visual landmarks. The set of point-based features grouped by the proto-object will allow locating the landmark, but the significance of this landmark will come from the proto-object.

FUNCTIONAL SUBDIVISION OF PERCEPTUAL SPACE IN THE VISUAL FIELD

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Early psychophysical and neuropsychological studies indicated some essential inhomogeneities in the visual field such as the different sensitivities measured by light-difference thresholds and the different saccadic programming modes for perifoveal and peripheral stimuli. More recently new evidence has been accumulated, pointing towards a functional subdivision of perceptual space in the visual field. Specifically, the peripheral visual field is significantly different from fovea and perifoveal regions up to 15 degree eccentricities. This symposium will focus on the inhomogeneity of the visual field and bring recent studies on different stimulus eccentricities together. Five speakers from Europe, Asia and the United States will report various evidence using different technologies. In particular, E. Pöppel will talk about visual completion in the perifoveal region of the visual field; Y. Bao will present a functional subdivision of spatial orienting in the visual field; B. Zhou will concentrate on the eccentricity effect of MEG signals to peripheral visual stimuli; H. Li will provide the ERP evidence for different inhibitory mechanisms in the visual field; and Q. Lei will discuss the fMRI correlates of the inhibitory processing in central and peripheral visual field. By summarizing behavioural and imaging studies on the eccentricity effect in the

visual field, this symposium aims to provide a platform for interested researchers from different fields to share their knowledge for a better understanding of the inhomogeneity of the visual field and bring the functional subdivision of perceptual space into future attention of related research.

Spatial orienting in the visual field: a unified perceptual space?

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Visual attention can be oriented towards a spatial location in the visual field exogenously by an abrupt onset of a peripheral cue. In a series of behavioral studies on exogenous orienting of attention with a double-cue paradigm, we demonstrated a functional subdivision of perceptual space in the visual field. Specifically, inhibition of return (IOR) is much stronger at periphery relative to perifoveal visual field up to ca. 15 degree eccentricity, suggesting two dissociable functional areas in the visual field. This eccentricity effect was found to be very robust—independent of cortical magnification and resistant to subjects' practice. An examination of the temporal dynamics of IOR at different eccentricities further revealed that inhibition in the periphery was not only stronger but also lasted longer than that at perifoveal visual field. To further investigate the generality of this functional subdivision of the visual field, we measured IOR effects with another single-cue paradigm and applied a very short cue-target interval which was typically anticipated not to observe any inhibitory effect at all. Consistent with this expectation, no IOR effects at the eccentricities up to 15 degree were observed. However, significant IOR effects beyond 15 degree eccentricities were consistently demonstrated. These results not only revealed an early onset of IOR for more peripheral stimuli, but also confirmed that the perceptual space in the visual field is not homogeneous but underlies a functional subdivision with a border of ca. 15 degree eccentricity.

fMRI correlates of inhibition of return in perifoveal and peripheral visual field

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When a target appears in the same peripheral location as a previous cue, responding is typically delayed if the cue-target interval is relatively long. This phenomenon is termed inhibition of return (IOR) and has been suggested to reflect an attentional bias in favor of novel visual space. It has been demonstrated recently that IOR is much stronger in the far periphery than in the perifoveal (central) visual field and this eccentricity effect is a robust one which is resistant to subjects' practice. The present study applied an event-related fMRI technique to further investigate the neural mechanisms underlying this apparent dissociation of IOR in the visual field. While central stimuli produced stronger activation than peripheral stimuli in specific occipital regions such as lingual gyrus and but not beyond, peripheral versus central stimuli elicited stronger activation in multiple brain regions, particularly those previously implicated in attention and eye movements controls, including frontal eye field, intraparietal sulcus and temporo-parietal junction. Furthermore, the peripheral versus perifoveal IOR contrast showed higher activity in the right dorsolateral prefrontal cortex, and the inverted perifoveal versus peripheral IOR contrast showed higher activity in the bilateral dorsolateral parietal cortex and in the cerebellum and ventromedial temporal cortex. These results suggest that different neural mechanisms are responsible for the dissociable functions between the central and peripheral visual field.

ERP evidence for different inhibitory mechanisms in the visual field

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An abruptly presented spatial cue will inhibit later response to targets appearing several hundred milliseconds following the cue at the same location. This phenomenon is known as "inhibition of return" (IOR) and is generally assumed to reflect a spatial bias against returning attention to previously inspected locations. Recently it has been demonstrated that the magnitude of IOR is much stronger at the periphery relative to the perifoveal regions of the visual field, indicating an inhomogeneity of inhibitory function in the visual field. Here we further investigated the neural correlates of this eccentricity effect with an event-related potential (ERP) study. A typical double-cue IOR paradigm was applied to measure the inhibitory effects for both perifoveal and peripheral stimuli. Event-related potentials were recorded from 128 electrodes and target-elicited ERP were examined. The results showed that IOR effects in different areas of the visual field were related to different ERP component modulations: the IOR in central/perifoveal visual field corresponded to an early difference wave Nde in occipital area, whereas the IOR in far peripheral visual field corresponded to a late decrease of P2 in anterior-central area. These results suggest a functional dissociation of inhibitory neural mechanisms between perifoveal and peripheral regions of the visual field.

The visual field paradox: a theoretical account on the reafference principle providing a common frame for the homogeneity and inhomogeneity of visual representation

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The human visual field has been shown to violate the naïve expectation to be of homogeneous nature. One such inhomogeneity shows up in the processing of stimuli at different eccentricities, the border being observed at approximately 10–15 degrees eccentricity along the horizontal meridian of the visual field. We report here a case of a brain injured patient who has suffered a central injury of the visual pathway in the left hemisphere resulting in a wedge-shaped scotoma in the right visual field. This patient (FS) has participated in many studies on residual vision showing "blindsight" within the scotoma, i.e. lacking any conscious representation of visual stimuli. Contrary to expectation the patient reports conscious vision of moving stimuli that straddle the scotoma. This perceptual completion is observed, however, only within the perifoveal region up to approximately 10/15 degrees eccentricity. Completion is furthermore observed only with vertical stimuli moving in parallel to the vertical meridian, and local features above and below the scotoma have to be identical. Control experiments indicate that this effect is most likely implemented in visual cortex, not being dependent on a secondary pathway bypassing the geniculo-striate projection. This conclusion based in behavioral measurements is supported by observations using fMRI. This case on a unique configuration of a neuronal deficiency stresses again the importance of detailed single-case studies.

Eccentricity effect of MEG signals to peripheral visual stimuli

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It is well known that human visual field exhibits certain inhomogeneity both behaviorally and neurophysiologically. Here we further examined the development of magnetoencephalographic (MEG) signals to a peripheral stimulus at different eccentricities in the visual field. The global field power (GFP) of the MEG signals was calculated to quantify the magnitudes of evoked fields changing after the onset of the stimulus. The results showed larger peak amplitudes of GFP around 150 ms for perifoveal than far peripheral stimuli, consistent with the prediction of cortical magnification. In another study, a peripheral cue preceded the target stimulus at the same or opposite position with an inter-stimulus interval of $\sim$1,000 ms. Participants responded more slowly when the cue and the target were at same than at opposite positions, indicating a significant inhibition of return (IOR). More interestingly, IOR was much larger for targets at far peripheral relative to perifoveal positions, replicating our recent findings. The GFP results further revealed that, at short latencies around 120 ms, there were significant differences between cued and uncued conditions for targets at perifoveal but not at far peripheral positions. However, at longer latencies around 220 ms, the pattern reversed that obvious difference between cued and uncued conditions could be observed for far peripheral rather than perifoveal targets. These results together demonstrate dissociable functions and mechanisms for central and far peripheral visual fields.

MOTOR AND SPATIAL CONGNITION IN MINIMALLY CONSCIOUOS STATES

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Minimally Conscious State (MCS) is a condition of severely altered consciousness, characterized by minimal but definite behavioral evidence of self or environmental awareness. Each of the abstract contributions will focus on different aspects of motor and spatial cognition in MCS, eventually considering comparisons with Vegetative State (VS). Persons with MCS and pervasive motor disabilities tend to be passive and therefore dependent on others in the engagement with their environment. This condition leads to a decrease of environmental stimulation, and consequently of motor and spatial cognition. The possible connection between lack of input stimulation and extinction of goal directed thinking, considering mostly movement and space, will be discussed. One way to help MCS patients to achieve an active role and independent engagement involves the use of assistive technology, namely, microswitches and Speech Generating Devices (SGDs). This assistive technology will be thoroughly described within the symposium. VS and MCS patients can have very different underlying pathomorphological and pathophysiological processes, despite their similar diagnosis. The performances of a large group of these patients in a mental imagery task, comprising both motor and spatial imagery, will be described. Finally, preliminary data from MCS and VS patients, stimulated with transcranial direct current stimulation (TDCS) and repetitive transcranial stimulation (rTMS) in order to increase arousal and promote the recovery of consciousness will be presented, comprising neurophysiological monitoring with EEG and evoked potentials of the patients.

Using brain–computer interfaces to overcome the extinction of goal-directed thinking in minimally conscious state patients

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Minimally Conscious State (MCS) is a condition of severely altered consciousness, in which patients appear to be wakeful and exhibit fluctuating but reproducible signs of awareness. MCS patients do not respond and are therefore dependent on others. In agreement with the embodied cognition assumption that motor actions influence our cognition, the absence of movement and the decrease of consequences for any type of covert or overt response may cause an extinction of goal-directed thinking. Brain–Computer Interfaces (BCIs), which allow a direct output without muscular involvement, may be used to promote goal-directed thinking by allowing the performance of spatial imagery tasks, and could facilitate the interaction of MCS patients with their environment, possibly regaining some degree of communication and autonomy. Kübler and Kotchoubey (2007) proposed a hierarchical BCI-based approach for patients with consciousness disorders, including five steps: recording of the resting state electroencephalography, passive stimulation, stimulation following simple instructions, volitional tasks, and decision making with a BCI. In a study performed by the Tübingen research group, low-level cortical processing was found in all MCS patients, who also exhibited event related potential components, indicating complex information processing in the association cortex. BCIs represent a very promising approach for the detection of cognitive functions in unresponsive patients, and a potential tool for training and rehabilitation.

Motor and spatial imagery in severe disorders of consciousness

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In 2006 the Cambridge Coma Group (UK) described a mental imagery task to be used in patients with severe disorders of consciousness such as vegetative state (VS) and minimally conscious state (MCS). Both motor and spatial imagery is required in this task, aimed at the detection of conscious awareness. Most patients described by the Cambridge Group were of traumatic aetiology. However, it is well known that the morphological and pathophysiological changes underlying VS and MCS, as well as the course of the disease and outcome chances in disorders of consciousness, vary very much as a function of aetiology. In the present talk, data of a large group of VS and MCS patients in both traumatic and non-traumatic (brain anoxia, stroke, and encephalitis) aetiologies are presented. The pattern of findings in the patients is reliably related to their following rehabilitation. Severe axonal injury, in which large areas of the cortical grey matter remain intact but disconnected, is the condition in which positive findings are most often observed in VS and MCS patients. Thus patients can successfully imagine intensive motor activity (i.e., playing tennis and navigating in their apartment) despite the complete immobility and, therefore, inability to control her body and environment. These data make an intriguing case of "disembodiment" in the sense that successful imagination is possible (in adults) when control loops remain within the brain and do not involve the body and the world. The possible role of cortico-cerebellar loops in this putative disembodiment process is discussed.

Technology-based intervention to help persons with minimally conscious state and pervasive motor disabilities perform environmentally-relevant adaptive behavior

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Persons with minimally conscious state and pervasive motor disabilities tend to be passive and depend on others to engage with their environment and obtain stimulation input. One way to help them achieve an active role and independent engagement involves the use of assistive technology, namely, microswitches, Speech Generating Devices (SGDs), and computer-aided systems for stimulus request/choice. Microswitches allow them to control their access to brief periods of preferred stimulation with minimal responses (e.g., partial hand closures and eye blinks). SGDs allow them to make requests of attention or stimulation to their caregivers or other relevant persons. Computer-aided systems are aimed at presenting brief stimulus samples and allowing the participants to choose (access) any of the stimuli for preset time periods. The activation of SGDs and computer-aided systems also occurs through the performance of simple/minimal responses. The studies assessing the aforementioned types of technology with persons with consciousness and motor impairment can be divided into several groups based on whether they employed (a) a single microswitch, (b) a combination of two microswitches, (c) one microswitch and one SGD or two such devices, and (d) a computer-aided system for stimulus request and choice. Research data were generally encouraging indicating that the participants acquired the responses targeted to control basic environmental events/stimuli (i.e., learned to link their responding and the environmental/spatial consequences of it, thus advancing their general cognition and overall performance), could maintain those responses over time, and could also choose between stimuli purposefully.

Transcranial direct current stimulation can promote awareness in patients with alterate state of consciousness: a preliminary study

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Recent studies reported some patients in minimally conscious state (MCS) who responded to brain stimulation. If confirmed, these results would indicate that non invasive cerebral stimulation may promote arousal in MCS. Five patients in stable conditions were enrolled in a

study designed to improve responsiveness in patients with altered state of consciousness. The stimulation protocol consisted of 10 daily sessions of anodal transcranial direct current stimulation (tDCS) (1 mA, 10 min) applied over the left dorso-lateral prefrontal cortex (DLPFC). A sham stimulation was applied for the same period of time as a control condition. Before starting stimulation, patients were assessed by clinical scales specific for identifying covert signs of recovery of consciousness. An electroencephalogram (EEG) was recorded to estimate cortical connectivity before and after tDCS and sham sessions. EEG coherence was calculated for five frequency bands (delta, theta, alpha, beta, and gamma). After real tDCS, we found significant coherence increases between frontal and centro-parietal areas lateralized to the left hemisphere, mainly in gamma (30–50 Hz) and beta (14–30 Hz) frequency bands. Sham tDCS did not induce any significant change in EEG coherence. Clinical assessment of patients revealed a less fluctuating level of consciousness. These results suggest that tDCS may improve interactions between DLPF and posterior areas, facilitating the flow of detailed sensory information about the external world through the posterior parietal cortex. As a result of this, motor system can acquire potential actions that compete for expression in behaviour (embodied cognition theory).

OBJECTS AND ACTION IN THE INDIVIDUAL AND SOCIAL SPACE: AFFORDANCES AND EMBODIED COGNITION

Convenor: *Anna M. Borghi*

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The study of affordances is crucial for an embodied and grounded cognition perspective, because it clearly highlights how deeply action influences cognition. Since the seminal work by Gibson (1979) and the more recent proposals by Ellis and Tucker (2000), in the last years affordances (and micro-affordances) have occupied an important space in the embodied cognition literature. The symposium aims to cover the most recent areas of research on affordances, which will be investigated in their multifaceted dimensions. Among other topics, the symposium will address the following issues: Are affordances automatically activated during object observation? Do different kinds of affordances exist (e.g., stable vs. variable affordances, affordances related to function/use vs. to manipulation), and do they have different neural underpinnings? Are affordances flexibly modulated by the physical context (e.g., closeness to the agent's peripersonal space; presence of multiple affordances evoked by different objects)? And to what extent do the social context and the presence of a shared space influence affordances activation? Which are the possible clinical implications of the study of affordances and space?

Functional anatomical basis for stable and variable affordances

Ferdinand Binkofski

Division for Cognitive Neurology, RWTH Aachen University, Aachen, Germany

Affordances represent what the environment provides or furnishes to acting organisms, but they are not properties of the organisms or of the environment, they rather emerge from the interaction of both. In extension of Gibsonian view, we proposed the distinction between stable and variable affordances. These two sets of affordances are arranged along a continuum and are not dichotomous. Stable affordances emerge from rather stable/invariant features/properties of objects which can be incorporated into an object representation, stored in memory. Variable affordances are processed rather online and allow to establish processes coping with fast changing object features. The existing neuroanatomical evidence suggests that those different kinds of affordances could well be sub-served by different neural pathways. This hypothesis is backed by a meta-analysis of recent functional imaging studies on interaction with objects in which the coordinates of brain regions activated by features related to stable and variable affordances were extracted. ALE based analysis revealed two separate albeit partially overlapping parieto-premotor networks: the one related to stable affordances is localized more ventrally (ventro-dorsal stream) to the network related to variable affordances (dorso-dorsal stream). The results confirm the parallel processing of the different types of affordances in the human brain and maybe stimulating for computational neuroscience.

The physical and social space of affordances

Anna M. Borghi

University of Bologna, ISTC-CNR, Rome, Italy

The majority of studies on affordances have focused on simple actions elicited by objects, such as reaching and grasping, and has taken into account only the physical environment in which the objects and the organisms responding to them are embedded. The focus of the presentation is on how affordances, rather than being automatically activated, imply the capability to flexibly respond to the demands of the physical and the social context. I will briefly overview some studies showing that objects evoke an action conform to their conventional meaning also thanks to the physical context in which they are embedded and to their spatial contiguity with other objects. In addition, I will report evidence showing that the activation of affordances is modulated by the social relationships existing between the organisms responding to them. The way we grasp objects differ depending on the presence of other people and on their distance in space from objects. In addition, affordances vary depending on the kind of actions we intend to perform with others, for example offering or receiving something.

Sharing the reaching space: effects on healthy individuals and psychiatric patients

Elena Daprati

University of Rome Tor Vergata, Rome, Italy

Several lines of evidence suggest that peripersonal space holds a separate functional value compared to 'far' space (i.e. space "beyond arm's reach"), in terms of ecological relevance, form of encoding, and supporting neural networks. Importantly, peripersonal space can be accessed by other individuals, eventually resulting in sharing/competition effects. It is well known that observation of objects located within reaching space activates a representation of related actions in both monkeys and humans. Here, we will describe how memory traces for visually-explored objects are modulated by their relationship to covert actions and how this link can be differentially affected in a joint-space condition in healthy individuals and psychiatric patients.

Objects and agents: affordance in a material and social world

Rob Ellis

School of Psychology, University of Plymouth, UK

Mirror and canonical neural systems, and their respective roles in producing imitation and affordance effects on behaviour, are usually regarded as serving different purposes. In contrast we will argue that they are part of a single, dynamic system in which the actions of other agents and objects in a scene together, and simultaneously, determine the actions afforded to an observer. We will demonstrate that the motor systems of mere observers, irrespective of their goals, are simultaneously affected by multiple sources of possible actions. These sources include the affordances associated with seen objects, the spatial relations among the agents and objects, and the actions of the agents. Thus to reach toward an object in a crowded material and social world is best understood as a dialectical process among this network of influences.

Acquisition of action knowledge through verbal and social learning

Oliver Lindemann[1], Markus Paulus[2]

[1]University of Potsdam, Germany; [2]Ludwig Maximilian University, Munich, Germany

Recent research highlights the importance of motor processes for the development of functional object knowledge and knowledge about sensory action consequences. It is unclear, however, whether the involvement of the motor system goes beyond the processing of information that is gathered through own active experiences. The presented studies examine therefore the acquisition of novel object knowledge and novel action-effect associations in situations in which active motor experiences are lacking and learning is only based on verbal descriptions or action observation. Our data demonstrate a selective effect of motor interference on verbal learning as well as an effect of agency on observational learning. Taken together, these findings suggest that covert motor simulations support the acquisition of action knowledge and provide evidence for a new ideomotor approach to action understanding while verbal and social learning.

The power of action. From personal to interpersonal bodily space

Corrado Sinigaglia

Department of Philosophy, University of Milan

Over the last few years more and more theoretical and empirical papers have been devoted to find out the neural and cognitive processes underpinning basic social phenomena such as sharing and joining actions in development as well as in everyday adult life. However, little research has directly explored whether and to what extent object perception in social contexts, far from being a private business of single perceivers, it could tell us something about the mechanisms underlying the primary ways in which we interact with others. The talk aims to tackle this issue by investigating how a social context might shape the perception of objectual affordances. To get this point, in the first part of the talk I will show that objectual affordance smight depend not only on one's own reaching space but also on the reaching space of another individual. In the second part of the talk I will go into the theoretical implications of these findings, by introducing and discussing the notion of an interpersonal bodily space representation that would allow us to map the surrounding space of other people onto our own action space. Finally, I will conclude by suggesting that such a interpersonal bodily space representation not only helps us refining the notion of affordance but also provides us with a plausible and unitary account of the crucial building blocks for basic social interactions, shedding new light on the processes that ground our primary identification with others and our connectedness to them.

Real and virtual changes to the body affect the perception of affordances

Jeanine Stefanucci, Sarah Creem-Regehr, Michael Geuss, Kyle Gagnon, William Thompson

University of Utah, Utah, USA

Embodied perception theories emphasize the role of bodies, simulation, and action as central to space perception. The notion that action capabilities influence perception is not new, as Gibson (1979) proposed the term *affordances* 30 years ago. We test one aspect of embodiment in space perception—whether the nature of body representation influences the perception of affordances in extrapersonal space. In a series of studies, we show that both physical (real world) and virtual changes to the body influence whether or not people say they can pass through or under an aperture. We use immersive virtual environments (IVEs) as a novel approach to study how action capabilities may influence space perception. In IVEs, multisensory information about the body and sensory-motor coupling can be manipulated in ways not possible in the real world. We first demonstrate that when the body is made wider or taller through physical manipulations in the real world, people's estimates of passing through or under an aperture are altered, as are their judgments of the width or height of the aperture. We then establish that affordance judgments made in real and virtual environments are similar, without implementing changes to the body. Finally, we show that virtual manipulations of body dimensions (some not possible in the real world) affect both decisions about action and actual actions with respect to apertures in IVEs. Overall, our findings suggest that people flexibly incorporate both visual and proprioceptive information about their action capabilities when viewing spaces, suggesting that perception is embodied.

PERCEPTION, MEMORY AND ACTION IN A MULTISENSORY SPACE

Convenors: *Franco Delogu[1], Ineke van Der Ham[2]*

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The accurate representation of our spatial surroundings is crucial for adaptation because it enable us to remember where we left objects

that we need in our daily life, to find our way to our destination and to explore and memorize new spatial layouts. Research on spatial cognition in general and on spatial memory in particular, has been dominated by studies involving vision, which is often considered the main sense for spatial processing. However, it is increasingly evident that also the other senses, both in addition to and in absence of vision, can offer an important contribution to the construction and the use of mental representations of our spatial surroundings. In this symposium, experts in the field of spatial perception and memory will discuss the role of sensory modalities in the encoding, representation and retrieval of spatial information in the spatial tasks of navigation, object localization, and feature to location binding. The goal is to stimulate the discussion on whether the contents of spatial memory are supra-modal and or modality specific. Concerning navigation, the effects of non-visual and multisensory cues in spatial navigation is an important topic, which has rarely been addressed by experimental research. Currently, also owing to the experimental use of virtual reality, it is possible to answer questions about the importance of auditory information and about the integration of auditory and visual information in perceptual and memory processes in navigation. Furthermore, the study of feature to location binding in non visual modalities can help to understand whether the functional and neural relationships between the processing of 'what' and 'where' are dependent or independent from the input modality. Finally, insights about object location memory in audition and in haptics, if contrasted with the abundant corpus of related research in vision, offer a crucial means of intersensory comparison. Such comparison can be helpful to determine whether vision is quantitatively and qualitatively paramount in object location memory or if functionally analogous spatial processing can also be found in non-visual domains.

Cross-modal and intra-modal binding between identity and location in spatial working memory

Riccardo Brunetti[1], Claudia Del Gatto[2]

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Several studies provided evidence for binding between the identity and the location of stimuli in Working Memory (WM). Such associations in encoding between object identity and object location have been found in different sensory modalities. In this study we tested the automaticity of feature-to-location binding in a spatial task, both in unimodal and crossmodal conditions. We digitalized the Corsi Block Tapping task (CBTT) in three different versions: the first one was the original test, which requires reproducing a sequence of taps on the blocks in the correct serial order; the second one included the association of 9 different meaningless images (Chinese ideograms) to each one of the 9 Corsi blocks during the study phase; the third one included the association of 9 different nonverbal sounds (percussive sounds) to each one of the blocks during the study phase. Three different groups of participants (each group $n = 15$) performed a version of the task. Results show no differences between the original and the modified versions of the task. The addition of intramodal or crossmodal information about the identity of the blocks did not affect spatial performance. We concluded that, in a purely spatial task like the CBTT, the information about the identity of the stimuli is not automatically associated to the to-be-recalled spatial information. We discuss our results within the framework of the debate about the automaticity of feature binding in WM.

Object location memory in haptics

Delogu[1], Gravina[2], Bergman Tiest[3], Nijboer[1], Kappers[3], Postma[1]

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Information about the identity and the location of perceptual objects can be automatically integrated in perception and working memory (WM). Moreover, contrasting results in visual and auditory WM studies indicate that the characteristics of feature-to-location binding can vary according to the sensory modality of the input. The present study provides evidence of binding between "what" and "where" information in WM for haptic stimuli. In an old-new recognition task, blindfolded participants were presented with sequences of three haptic stimuli varying in texture and in location. They were then required to judge if a single probestimulus was previously included in the sequence. Recall was measuredboth in a condition in which both texture and location were relevant for the task (experiment 1) and in two condition where only one feature must be recalled (experiment 2). Results showed that when both features were task-relevant, even if the association of location and texture was neither necessary nor required to perform the task, participants showed a recall advantage in conditions in which the location and the texture of the target probe was kept unaltered between encoding and recall. By contrast, when only one feature was task-relevant, the concurrent feature did not influence the recall of the target feature. We conclude that attention to feature binding is not necessary for the emergence of feature integration in haptic WM. For binding to take place, however, it is necessary to encode and maintain in memory both the identity and the location of items.

Does vision rule the senses in spatial cognition?

Fiona N. Newell

Trinity College Dublin, Ireland

We examined the role of visual information on multisensory spatial cognition and found that 'on-line' visual information as well as changes in visual experience during the lifespan can significantly modulate spatial cognition. First, in a series of experiments, we found that spatial updating is not specific to the encoding modality but that observer movement can compensate for changes within and across the visual and haptic domains. Moreover, our results suggest that optic flow information most likely mediates the updating of multisensory spatial representations during observer motion. Indeed, in studies examining developmental effects on spatial cognition, we found that the absence of visual experience during the early stages of life, or reduced visual information in later stages of life, can adversely affect spatial updating across the senses. In a second series of studies we

asked whether ambient visual information, which was unrelated to a haptic spatial task, could affect memory for haptic spatial layout. We found that this task-irrelevant visual information modulated haptic spatial memory such that visuo-spatial, but not visual landmarks, improved haptic performance. The same cross-sensory influences were not observed with ambient auditory information substituted visual information. These results suggest that vision provides the optimal spatial reference frame to which cross-modal scenes are initially encoded. Our findings have implications not only for our understanding of multisensory interactions but also our understanding of spatial cognition in the real world.

Contribution of auditory and visual cues to navigation

Ineke J. M. van der Ham, Anna Zenka, Milan N. A. van der Kuil

Experimental Psychology, Utrecht University

The vast majority of studies on spatial navigation and location memory have focused on the visual modality, whereas other sensory modalities are studied much less frequently. However, when navigating in the real world we are exposed to auditory and other sensory input as well. We present two experiments in which we have compared visual and auditory cues during (1) navigation and (2) location memory in a virtual environment. In experiment 1 participants had to use visual and/or auditory cues to find their way through a virtual maze. These cues consisted of images or sounds of common and easy to recognize objects. In experiment 2 participants had to memorize a location in an otherwise black virtual environments with the help of three visual and/or auditory cues. These cues were either small light sources, or beeps originating from specific locations in the environment. Results indicate that although visual cues lead to the most accurate performance, auditory cues can also be used to navigate and memorize locations. However, a superadditive effect when combining both modalities was not found.

BUILDING SPATIAL KNOWLEDGE FROM LANGUAGE

Convenors: *Michel Denis[1], Marios N. Avraamides[2]*

[1]LIMSI-CNRS; [2]University of Cyprus, Cyprus

Although we typically encode spatial information in our memories directly through our senses, we are nevertheless able to create accurate and vivid spatial representations by means of language. By reading texts or listening to verbal descriptions of spatial environments, we can build mental representations for immediate, remote, or even fictitious environments. However, in contrast to representations derived from perception, those acquired from language are considered unique due to characteristics of the linguistic medium. Linguistic descriptions are inherently serial, they impose a spatial reference frame on the recipient, and are often imprecise. Therefore, spatial representations constructed from language may differ in important ways from those derived from perception, and vision in particular, in the way they can support spatial action. This symposium includes 5 presentations that will discuss new research findings on how people encode and maintain spatial information in memory from language and how they use it to carry out various spatial tasks such as route planning and navigation.

Active and passive navigation: effects on spatial models and route descriptions

Marie-Paule Daniel, Michel Denis

LIMSI-CNRS, Orsay, France

Walking along a route or mentally navigating along it is likely to produce differences on the mental representation induced. In a first study, two different routes were contrasted according to their richness in landmarks. The participants were asked to describe the one they had just travelled. The results showed that without any explicit constraint of conciseness, the participants mentioned all the information they can remember. Even though both routes presented approximately the same length and number of turns, the route with the greatest number of landmarks resulted in significantly longer descriptions (almost twice as long). But the recognition tests showed similar results regarding the memorization of the route. The number of pictures correctly identified as well as the number of pairs correctly ordered was similar. A second experiment was intended to examine the effects of a passive condition on the memorization of a route. New participants were presented with a movie of one route, then submitted to the same recognition tests. Interestingly, the results showed that navigating on a route as well as viewing a movie of it produced very similar memorization scores on the recognition tests. But the movie condition led to highly increased response times. Our data show that the passive condition required more cognitive effort than the active one, especially with older participants. It will be interesting to consider the results of the next step: Will a virtual environment succeed also to guarantee good memorization without increasing as much the cognitive load?

Coordinating in spatial perspective-taking: how speakers' description strategies affect their partners' memory representations

Alexia Galati, Marios N. Avraamides

University of Cyprus, Cyprus

How do speakers' spatial descriptions affect their conversational partners' resulting spatial memories? We examined whether advance knowledge about the partner's perspective affects the perspectives of speakers' descriptions and the representations their partners construct from these descriptions. In 18 pairs, Directors described to a Matcher, misaligned by 90°, 135°, or 180°, arrays learned while either knowing the Matcher's perspective in advance or not. Knowing the Matcher's perspective in advance did not, on its own, determine the perspective of descriptions; instead, descriptions reflected strategic choices that depended on the cognitive demands of perspective-taking. Directors used more Matcher-centered expressions when perspective-taking was easy (when Matchers were offset by 90°) and egocentric ones when it was more difficult (when offset by the oblique 135°). Partners

often explicitly agreed on these perspectives, especially when knowing in advance that perspective-taking would be difficult for Directors. Memory tests following descriptions suggested that Matchers had represented both partners' perspectives in memory: they were faster to orient to imagined perspectives aligned with their Directors and faster to respond from perspectives aligned with their own. Critically, the Directors' earlier descriptions predicted the facilitation of these perspectives. The more Directors had used Matcher-centered expressions, the more facilitation Matchers showed for their own perspective; conversely, the more Directors had used egocentric expressions, the more facilitation Matchers showed for the Directors' perspective. Thus, in spatial tasks partners behave contingently to maximize coordination: they consult their partner's perspective to adapt their description strategies, and construct spatial memories on the basis of their partner's descriptions.

Visual and verbal information in spatial models: modes of intake and types of output

Valérie Gyselinck[1], Marie-Paule Daniel[2], Doriane Gras[1], Maya Hickman[3], Pascale Piolino[1]

[1]Université Paris Descartes, France; [2]LIMSI-CNRS, Orsay, France; [3]Université de Paris VIII, France

This presentation will focus on results of experiments from a larger project dedicated to the study of how humans construct and use mental models of spatial information relevant to itineraries in large-scale wayfinding situations. The construction of spatial models from a visual input (a virtual environment) or a verbal input (spatial description) was compared. Once acquired, spatial information can be reproduced by the learner in different types of responses, which may affect representations. Only few available studies have however examined the impact of intake/output modes on human spatial representations. Results from a first series of experiments in young adults suggest that the difference of spatial performance observed when comparing a visual and a verbal presentation of itineraries depends on the nature of the task (verbal tasks such as description of the itineray, or verification of statements about landmarks and their spatial relationships versus more visuo-spatial tasks such as visual recognition of landmarks, location of landmarks on a map, recognition of roads) and whether route or survey knowledge is assessed. In addition, results from experiments using a dual-task paradigm indicate that the verbal working memory is involved even when the learning material and the tests used to assess performance are only visual. This suggests that a verbal recoding of some information occurs during learning, which contributes to characterizing spatial models.

Spatial representations derived from route and survey descriptions: similarities and differences

Francesca Pazzaglia, Chiara Meneghetti

University of Padua, Padua, Italy

A number of studies showed that individual differences in wayfinding ability and spatial representation have a relevant influence on environmental learning. In these studies, visual inputs (such as navigation, map learning) were frequently used. We extended the analysis to learning of spatial descriptions from different perspectives, i.e. survey (from bird's eye view) and route (from a person's point of view). In several studies, we explored the impact that visuo-spatial abilities and cognitive styles in spatial representation have in the comprehension and memorization of survey and route descriptions. Results showed that spatial abilities, such as spatial visualization and mental rotation, predicted the recall of survey more than that of route descriptions. Further, groups with higher spatial abilities had a better performance—with respect to their lower counterparts—in the verification of inferential sentences and map drawing subsequent to learning of spatial texts. Overall, our results suggest that: (i) spatial cognitive abilities and spatial preferences differently sustain mental representations derived from survey and route descriptions and (ii) spatial preferences have a central role in determining the characteristics of that representation.

Would you follow your own route description?

Jan M. Wiener[1], Thora Tenbrink[2], Christoph Hölscher[3]

[1]Bournemouth University, UK; [2]University of Bremen, Germany; [3]University of Freiburg, Germany

We disentangle cognitive and communicative factors influencing planning strategies in the everyday task of choosing a route to a familiar location. Describing the way for a stranger in town calls for fundamentally different cognitive processes and strategies than actually walking to a destination. In a series of experiments, we address route choices, planning processes, and description strategies in a familiar urban environment when asked to walk to a goal location, to describe a route for oneself, or to describe a route for an addressee. Results show systematic differences in the chosen routes with respect to efficiency, number of turns and streets, and street size. The analysis of verbal data provides consistent further insights concerning the nature of the underlying cognitive processes. Actual route navigation is predominantly direction-based and characterized by incremental perception-based optimization processes. In contrast, in-advance route descriptions draw on memory resources to a higher degree and accordingly rely more on salient graph-based structures, and they are affected by concerns of communicability. The results are consistent with the assumption that strategy choice follows a principle of cognitive economy that is highly adaptive to the degree of perceptual information available for the task.

SPACE AND EMBODIED COGNITION OF NUMBER AND QUANTITY

Convenor: *Martin H. Fischer*

Potsdam, Germany

Intuitive numerical cognition deviates from formal mathematical practice. Several biases were established decades ago with chronometric methods, such as distance, size, and semantic congruity effects. Together, these observations were used to infer a mental number line with specific cognitive features. More recently cognitive scientists have begun to utilize spatial behavior as an additional source of information about number representations and processing, leading to

the discovery of Spatial-Numerical Associations (SNARC effect) and the Operational Momentum effect. What do these and other spatial biases in numerical cognition tell us about the cognitive representation of number concepts and about cognition more generally? In this symposium an international group of leading experts will review recent aspects of this debate, ranging from empirical studies of spatial-numerical learning, finger-counting, and cortical activation in numerical tasks, to theoretical arguments about the possible implications of grounding, embodiment and Situatedness of spatial-numerical cognition for our understanding of human knowledge more generally.

Neuroscience of embodied numerical cognition

Michael Andres

Ghent University, Belgium

We will argue that the way we express physically numerical concepts, by using grip aperture to describe a magnitude or by raising fingers while counting, reflects "embodied" representations of numbers in the adult brain. To illustrate this, we will focus on number and finger interactions in the context of simple arithmetic operations. In order to specify the influence of finger representation on mental arithmetic both at the cognitive and neural level, we conducted behavioral, electrophysiological and brain imaging studies. In dual-task experiments ($N = 16$), we found that finger movements interfered with subtraction and addition, but not multiplication, and that such a selective interference was specific to finger movements. Next, transcranial magnetic stimulation was used to probe corticospinal excitability (CSE) in the left and right hands during the same arithmetic operations. Results ($N = 10$) showed that addition and subtraction led to significant CSE changes when compared to multiplication and that these changes were primarily determined by the size of the arithmetic answer. Finally, functional magnetic resonance imaging ($N = 18$) was used to reveal the brain regions showing overlapping activity during mental arithmetic and finger judgments that required participants to discriminate between flexed and extended fingers without looking at the imposed hand posture. Critical regions were identified in the parietal cortex and voxelwise correlations were measured across tasks in order to explore patterns of similarity between finger discrimination and each arithmetic operation. We will discuss our results with respect to ontogenetic and phylogenetic views of number and finger interactions.

From number lines to time lines: how "numerical" is the mental number line?

Peter Brugger[1], Michèle Frey[1], Maya Fehr[1], Tobias Loetscher[2]

[1]Neurology Department, Neuropsychology Unit, University Hospital Zurich, Switzerland; [2]School of Psychology, Flinders University, Adelaide, South Australia

Approaching its 20th birthday, the SNARC (spatial-numerical association of response codes) effect is younger than ever: a bewildering number of explanations have been proposed over the past few years for an effect initially thought to be specific to numerical processing. Already at the turn of the millennium it became clear that more than mere number magnitude is involved: the left-hand reaction time (RT) advantage for small numbers also spreads to non-numerical material and, importantly, is easily turned into one for large numbers, if only the stimulus numbers are conceived of times on a clockface—it seems to be our (contextual or situational) associations to "left" and "right" that determine RT advantages to small or large numbers, not number magnitude per se. We briefly present some of SNARC's siblings, the SMARC, SPARC and STEARC effects, where M, P and TE stand for "musical", "political" and "temporal", respectively (left-hand RT advantage for low relative to high tones, left-wing relative to right-wing parties and past relative to future events). We then introduce a series of experiments on differential RT advantages to items presented earlier or later in auditorily presented lists of words. Forced-choice recognition showed faster left-hand RTs to items of the first half of the list and vice versa, faster right-hand RTs for items of the second half. These findings permit a novel angle under which to look at the classical primacy-recency dichotomy in word list learning; human subjects seem to automatically "spatialize" verbal information acquired in a fix temporal sequence.

How do spatial representations enhance cognitive numerical processing?

Helen De Cruz

Somerville College, University of Oxford and Institute of Philosophy, University of Leuven

Several philosophical theories seek to explain how the use of the external world can enhance cognitive processing: internalism, active externalism, and cognitive integration. According to internalism, the external world is recruited to help cognitive processes but it is not genuinely part of cognition. According to active externalism, cognition is a coupled process, where internal cognitive operations interact with the environment. The externalized processes are only cognitive if they are structurally similar to the internal process (this is the parity principle). Cognitive integration holds that cognition can be fruitfully conceptualized as an integration of internal and external processes. This involves a causal, dynamic interaction between both types of processes, where the practices of manipulating external objects can lead to structural changes in the way internal cognitive processes take place. The aim of this paper is to examine whether the use of external tools in number processing (e.g., abacuses, counting rods, finger counting) can shed light on this philosophical debate. Relying on philosophical analysis and on a review of empirical work in developmental psychology and the cognitive neuroscience of number, I will show that the case of number cognition is most compatible with cognitive integration. Put differently: to explain the empirical data on the relationship between number and external tools, cognitive integration does a better explanatory job than the other positions, as the cognitive processes are not reducible to intracranial occurrences (as internalism holds), and there is typically no parity between internally and externally performed numerical computations (as externalism holds).

A hierarchical view of grounded, embodied, and situated numerical cognition

Martin H. Fischer

University of Potsdam, Germany

There is much recent interest in the idea that we represent our knowledge together with the sensory and motor features that were

activated during its acquisition. This talk will review the evidence for such embodiment in the domain of numerical cognition, a traditional prototype of abstract symbol manipulation. The focus will be on spatial-numerical associations, such as the SNARC effect (small numbers are associated with left space, larger numbers with right space) and its recently discovered modulation by reading habits and finger counting habits. Using empirical evidence from behavioural research, I will first describe sensory and motor biases induced by SNARC, thus identifying numbers as embodied concepts. Next, I will propose that a hierarchical relationship between grounded, embodied, and situated aspects of number knowledge helps to understand the variety of SNARC-related findings obtained so far, and also yields testable predictions about numerical cognition. I will report several such recent tests, ranging from cross-cultural comparisons of horizontal and vertical SNARC effects (Shaki and Fischer 2012, JEP-HPP) to motor cortical activation studies in participants with left- and right-hand counting preferences (Tschentscher et al. 2012, NeuroImage). These results will help me to evaluate the usefulness of the proposed conceptual hierarchy.

Learning and development of embodied numerosity

Korbinian Moeller[1], Ursula Fischer[2], Tanja Link[3], Wasner, Stefan Huber[2], Ulrike Cress[2], Hans-Christoph Nuerk[1]

[1]Eberhard Karls University of Tübingen, IWM-KMRC Tübingen, Tübingen, Germany; [2]IWM-KMRC Tübingen, Tübingen, Germany; [3]University of Tübingen, Tübingen, Germany

The presentation will focus on two recent theoretical developments: (i) The predictive value of children's early spatial-numerical competencies for their future arithmetic abilities has received growing interest (*Mental number line representation*). (ii) Seemingly abstract numerical cognitions are routed in our sensory and bodily experiences, which continue to influence our mind and behavior (*Embodied numerosity*). However, while correlative relationships are well established for both theoretical developments, the causal links are rather weak. Will the use of bodily-sensory experiences during basic spatial-numerical training improve numerical capabilities? To address this question we have run a cascading research program. In 3 different studies, we conducted number line trainings in which children learned to place a number on the correct spatial position on a line and investigated learning progress in number line accuracy and numerical transfer tasks. We employed different age groups (kindergarten, elementary school children), different media techniques (digital dance mat, Smartboard, Kinect), several number ranges (0–10, 0–100) and different control conditions (same task, but different media e.g., dance-mat vs. tablet-PC; same media, but different task, e.g. number line task vs. colored number pointing task). We have consistently observed greater training success with employment of new media allowing for embodied learning of numerosity in both number line evaluation and transfer tasks. The results of this research program will be presented and the implications for arithmetic learning will be discussed as an example how cognitive-neuropsychological theories can help to develop training settings that can ultimately improve and promote arithmetic learning in education.

SPATIAL STRATEGIES IN PRIMATES: DECISION MAKING IN LARGE-SCALE AND SMALL-SCALE SPACE

Convenors: *Paul A. Garber[1], Francine L. Dolins[2]*

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Primate species face significant challenges in locating resources that vary significantly in time, space, and quantity. In some species resources are clumped and individuals exploit home ranges of less than 1 hectare (ha). In other species, resources are widely scattered and individuals exploit home ranges of over 20 km^2. Moreover, our understanding of primate spatial memory has been limited by the fact that studies of spatial memory in wild primates have tended to focus on navigation in large space, whereas studies of primates in captive and laboratory settings have principally focused on the ability of individuals to orient to and remember the location of objects in small-scale spaces. In this symposium, we examine the ability of monkeys and apes to internally represent spatial information across a range of spatial scales and compare species differences in the types of information used and integrated in forming a cognitive spatial map.

Spatial working memory for clustered and linear configurations of sites in a virtual reality foraging task

Carlo De Lillo, Frances C. James

University of Leicester, UK

We present the results of two experiments on the role played by search strategies and the geometric configuration of the environment in the ability of human participants to temporarily remember locations in a simulated foraging task. The experiments were carried out in a realistic immersive Virtual Reality (VR) environment. This set-up allowed us to assess the effects of variables related to the search pattern and the configuration of the search space that would have been difficult to manipulate with human participants in real large scale environments. Critically, one of the tasks required participants to recall specific search patterns that they were induced to follow in an encoding phase. Such patterns could conform to specific organizational constraints or systematically violate them. For example, in a "patchy" foraging environment organized in spatial clusters participants could be required to search locations within the cluster in consecutive moves, or forced to migrate between clusters in consecutive moves. The results showed that people benefit from the use of organized search patterns when attempting to monitor their travel though both a "patchy" foraging space and more diffuse configuration of locations such as a square matrix. The data from the experiments will be discussed in relation to results previously obtained with children, monkeys (*Cebus apella and* Papio papio) and rats (*Rattus norvegicus*) performing search tasks requiring navigating large scale environments and recall tasks requiring serial responses in small scale arrays. Such comparative analyses provide useful

information concerning the plausibility of animal models of human working memory.

Comparing captive chimpanzees' navigational strategies and spatial memory in virtual small- and large-scale space

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Primate foraging entails challenges of localizing resources across an ecologically complex landscape. The same species may exploit feeding sites distributed both in large- and small-scale space, adapting their ranging based on nutrient balancing, seasonal availability, competition, and group size. Deciphering the most efficient routes between resource sites is therefore essential in reducing energy costs and is directly related to the generation of mental representations of space. It is predicted that cognitive strategies generated to navigate in large-scale and small-scale space will differ in relation to the amount and type of spatial/landmark information encoded by the forager. Testing and comparing search strategies of captive and free-ranging primates in large- and small-scale space presents significant methodological challenges. These include making clear comparisons between environments that differ in amount of spatial/ecological information available and attended to, the types of variables potentially available as landmarks, and distance-as-effort in larger versus smaller environments. In order to circumvent these problems, we presented four captive chimpanzees with computer-generated virtual environments displaying parallel landmark information but differing in scale. Their task was to navigate to multiple goal locations (reflecting multiple food items per patch) that were either clumped or scattered. Our results indicate that all four chimpanzees applied a topological cognitive strategy when resources were presented in small-scale space and employed a metric representation to locate resources in large-scale space. Thus, the chimpanzees demonstrated shifts in spatial strategies in relation to the scale, spatial information, and goal distribution of resources.

Introduction to the symposium: spatial cognition in non-human primates: the scope of the problems facing free-ranging and captive primates orienting to and navigating in small- and large-scale space

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Primate species face significant challenges in locating resources that vary significantly in time, space, and quantity. In some species resources are clumped and individuals exploit home ranges of less than 1 hectare. In other species, resources are widely scattered and individuals exploit home ranges of over 20 km^2. The availability, renewal rate, and temporal predictability associated with acquiring these resources may vary over the course of hours in the same day, across days, across weeks, and across seasons of the year. Thus, foraging rules that may be efficient for one species, may result in limited feeding success for another species. Moreover, our understanding of primate spatial memory has been limited by the fact that studies of wild primates have tended to focus on navigation in large-scale space, whereas studies of primates in captive and laboratory settings have principally focused on the ability of individuals to orient to and remember the location of objects in small-scale space. In this presentation, we examine our current understanding of the ability of monkeys and apes to internally represent spatial information across a range of spatial scales, and present a comparative framework for studying species differences according to the types of information used and integrated in forming an internal spatial map.

Using multiple maps: temporal changes in route-based travel in wild Bolivian saddleback tamarins (*Saguinus fuscicollis weddelli*)

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In this study we examined spatial memory in wild saddleback tamarins (*Saguinus fuscicollis weddelli*). We collected data on diet, travel, and range use in the same tamarin social group during 2009 and 2011. During the 2011 field season, we also set up 3 feeding platforms located 124–191 m apart in the group's range. In total, we collected data on the group's travel routes and on the sequential use of feeding sites during 40 complete and 12 partial observation days. We considered plant species that formed $\geq$1 % of the diet to be major food sources and we mapped the location of the individual trees of these species. We also recorded the location of the study group at 10 min intervals using a GPS unit, and used GIS software to analyze these data. In total the monkeys used 96 major feeding sites from 18 species, but only 2 of these species and 7 feeding sites were used in both years. Our results indicate that the tamarins used a limited set of nodes to reorient travel (N = 9 in 2009, n = 6 in 2011) and a larger set of route segments (N = 29 in 2009, n = 26 in 2011) to move between feeding sites. In addition, there was little overlap in the routes and nodes used between years. Overall, our results indicate that the tamarins employed a route-based mental map to navigate between feeding sites, and this map changed over time in response to changes in the distribution and availability of food resources.

Great apes' strategies for locating hidden objects in small-scale space

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When animals encode the location of a food source they use different cues such as the spatial layout of the surrounding space, or features about the objects present. Here we present several studies that investigated (1) which cues, featural or spatial, apes preferentially encode to remember the location of a hidden food, (2) whether apes encode a hiding location in terms of spatial relations such as "in the middle" or "left of" and (3) whether apes can use information about the location of a hidden food in one array to find a hidden food in a different but identical array. One set of studies showed that apes can use both spatial and featural cues to remember the location of hidden

food items, but which cue will be the most dominant depends on the task demands (e.g. the number of hiding locations). Another set of studies showed that apes do not spontaneously encode a hiding place in its relation to other hiding places in the array (e.g. left of the other cups) nor in its relation to a configuration of landmarks (e.g. in the middle of two landmarks). Finally, the third set of studies showed that apes display some ability to transfer their knowledge about the location of a hidden food reward in one array of containers to find a hidden food reward in a different but identical array.

Do Tai chimpanzees use botanical knowledge in their search for fruit in large scale space

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The synchronous appearance of fruit is known to trigger primates to inspect trees of the same species. We used observations of this search behaviour to investigate the use of botanical knowledge in daily ranging decisions of chimpanzees (*Pan troglodytes*) in the Taï National Park, Côte d'Ivoire. We followed five adult females for 27–29 days each and marked the geographical location of their daily travel route, the trees they fed in and those that were "inspected". The subsequent days we determined the fruiting state and size of the marked trees. In addition, we recorded the location and size of 15,740 productive fruit trees in the females' territory. We found that inspected trees were significantly larger than other productive trees of the same species, suggesting the possibility that chimpanzee have knowledge of the productive potential of forest trees. To investigate this suggestion, we tested whether crown size influenced the probability of inspection and goal directed towards inspected trees, controlling for fruiting state, feeding activities and tree density. To investigate whether knowledge on fruit production could encompass year-long memories, we used observations on one female that was followed for three subsequent years within the same fruiting seasons, for 28–35 consecutive days. We tested whether her experiences in previous years, such as feeding durations and fruit quantities influenced the probability of inspection in subsequent years and thus her ranging decisions in large scale space.

Foraging decisions in large- and small-scale space in wild white-faced capuchin monkeys (Cebus capucinus)

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This research explores spatial memory in Costa Rican white-faced capuchins. Data were collected during an 8-month natural field study and a 3-month experimental field study. We examined whether capuchins' ranging patterns were more consistent with a route-based or a coordinate-based spatial representation. We calculated the Circuitry Index (CI) that measures the degree to which foragers use direct routes to reach feeding sites. CI is a measure of the actual distance travelled divided by the straight-line distance. In the natural field study, when moving between sites (mean distance: 111 ± 81 m), capuchins had a circuity index of 1.42, so they travelled 42 % further than the most direct route. Capuchins were found to consistently re-use a set of route segments and redirect travel at nodes. We also found that as the capuchins approached a target (mean distance: 55 ± 5 m), movements appeared to be more goal directed and they travelled 14 % further than the straight-line distance, and deviated only 6 % when in the immediate vicinity of this target (30 m). In one of the field experiments, we tested the capuchins' ability to travel directly between four feeding platforms (120×120 m/169 m apart). When travelling to the platforms, they travelled 24 % further than the straight-line distance. At the vicinity of the goal (30 m), monkeys' path deviated only 3 %. Considering the calculation of CIs, the results support the contention that in large-scale space, capuchins rely on a route-based spatial representation, while in small-scale space they navigate using a coordinate-based spatial representation or near-to-target landmarks.

PERIPERSONAL SPACE: THE BOUNDARY BETWEEN BODY, OBJECTS AND EVENTS

Convenor: *Tina Iachini*

Second University of Naples, Department of Psychology, Italy

Peripersonal space is the portion of space close to our body and within the reach of our limbs. This space has been defined as action space to underline its relevance for action capabilities or linked to the concept of flight initiation distance to underline its relevance for personal safety. Indeed, it may serve actions directed towards objects or defensive reactions in response to harmful events. Therefore, the coding of this space has a special value for the survival of all moving species. This special adaptive value can be traced at multiple levels. All senses contribute to its representation, with special reference to the haptic modality. Besides this multisensory nature, motor components should have a special relevance. The guidance of the body to act with or avoid objects requires an integrated representation of the body schema and the space closely around. Therefore, peripersonal space is plastic and flexible as it gets adapted to the development of the body and is modulated by tool use. Neural and behavioural evidence coherently suggests that the concept of peripersonal space is necessary to understand the link between action possibilities, body safety, emotional aspects and interaction with our conspecifics. As such, the study of peripersonal space offers an opportunity to see how the embodied cognition approach may model the complexity of the behavior. The purpose of this symposium is to discuss some basic aspects of peripersonal space: its multisensory representation and its role in action, the link with the body schema and the safety functions.

Embodied perception of reachable space: how do we manage threatening objects?

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Being able to accurately perceive our peripersonal space is critical since peripersonal space contains the objects that we can immediately

reach and manipulate but also the obstacles representing a potential threat to the body. In the past, several studies have shown that the perception of peripersonal space is quite accurate, although reachability estimates were proved to be widely influenced by the environmental context, the emotional state, the postural constraints, or even the presence of mental and neurological illness. Though involving primarily egocentric distance information, specifying whether or not an object is reachable or not necessitates a motor-based perceptual system combining sensory variables with motor-related information. According to this view, anticipating the consequences of potential motor actions through motor simulation is thought to represent the mechanism enabling the perceptual distinction between reachable and non-reachable objects. In this context, we will present recent psychophysical and neurobiological data obtained in our labs showing that: (1) modifying the spatial consequences of acting or apparent objects' dangerousness affects the perception of peripersonal space, (2) the neural network subtending reachability judgments overlaps with the neural network involved in the production of intentional actions, (3) spatial language depends in some aspects on the representation of peripersonal space. Considered together, these data provide new evidence for a perception of peripersonal space based on a motor-dependent perceptual system and will be discussed in reference to the embodied theories of perception and cognition.

The ownership of a virtual body induced by visuo-tactile stimulation indicates the alteration of self-boundaries

Martin Dobricki, Betty J. Mohler, Heinrich H. Bülthoff

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Watching a virtual body (avatar) being stroked while one's own body is being synchronously stroked has been shown to elicit the experience of bodily ownership over the avatar in the viewer. Previously this has been interpreted such that individuals take exclusively ownership over the avatar. However, it should be considered that due to the sensory integration of visual and tactile percepts avatar ownership could be the result of a decrease of differentiation between (visual) non-self and (tactile) self-percepts. Hence, in this case individuals would incorporate an avatar, because the boundaries of what they experience as "themselves" get altered. We have used a head-mounted display based setup in which participants viewed an avatar from behind within a virtual city. We stroked the participants' body while they watched the avatar getting synchronously stroked. Subsequently, we assessed their avatar and their spatial presence experience with a questionnaire, and then repeated the initial treatment. Finally, we rotated the participants' perspective around their vertical axis for 1 min. During rotation the avatar was in the same location in front of the viewer. Participants were asked to indicate when they started to experience self-motion. They reported higher identification with the avatar and showed a later onset of visually induced self-motion perception after visuo-tactile stimulation. Overall, our results indicate that there was a decrease of differentiation between non-self and self-percepts. Hence, we propose that avatar ownership should not be understood as a "body swapping", but as an integration of the avatar within an individual's multimodal self-boundaries.

Hand a(s) tool to go beyond the body

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Along the evolutionary history, humans have reached a high level of sophistication in the way they interact with the environment. One important step in this process besides manual dexterity has been the introduction of tools, enabling humans to go beyond the boundaries of their physical possibilities. We will focus some "low-level" aspects of cognition that highlight how tool-use plays a causal role in modifying both spatial and bodily representations. The updating of representations of the body and its action-space seems essential for efficient motor control during development and skilful tool-use in the adult life. The almost one-century-old hypothesis that tool-use induces plastic changes resulting in the tool being incorporated in the body representation is widely accepted, and intuitive enough to become a popular notion. Here, we will critically review the evidence supporting this hypothesis, on the basis of the effects of hand-use and tool-use on the multisensory coding of peripersonal space in the normal and pathological brain. Recent findings and on-going work from our laboratory, taking advantage of different behavioural methods, will be discussed as evidence supporting the incorporation of a tool in the body representation. In a series of experiments we will document the effects of tool-use both on the kinematics of hand movements and the localisation of somatosensory stimuli on the body surface, as well as the conditions that are necessary for these effects to be manifest. These findings speak in favour of genuine, tool-use-dependent plasticity of the body representation for the control of action.

Interpersonal space in autism spectrum disorders

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People automatically and reliably regulate the distance maintained between themselves and others during social interaction (Hall et al. 1966). Personal space, defined as the area individuals maintain around themselves into which intrusion by others causes discomfort, is one mechanism by which this automatic regulation of interpersonal distance is achieved. One's sense of personal space is dependent on the amygdala (Kennedy et al. 2009), a structure involved in social approach and avoidance. Here, we have investigated personal space in a population with impairments in social approach such as autism. Personals space was measure in children with autism spectrum disorder (ASD) and in children with typical development (TD). Participants were asked to stand with their feet on a line marked on

the floor. In half of the trials the experimenter walked toward them, while in the other half participants walked toward the experimenter. Subjects were asked to indicate the position at which they felt most comfortable. Chin-to-chin distance was recorded using a digital laser measurer. This procedure was repeated in two conditions: before and after the experimenter read a story to the subjects. The results showed that TD children felt comfortable at a closer distance compared to ASD children. Moreover, TD children' preferred distance decreased after the interaction with the experimenter. By contrast in ASD children this distance was not different before and after the interaction. These data suggest that autism influences the regulation of social distances between individuals.

Ready to act and react: hands in peripersonal space

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The idea that the encoding of peripersonal space reflects a simulated motor action towards a location has gained much consensus in the recent literature. Several studies have shown a close link between object characteristics, range of space and action programs. Therefore, peripersonal space may well be defined as action space. Peripersonal space also has an important adaptive value as safety space. It is important to consider both of these facets as constitutive of the neural/cognitive existence of peripersonal space. However, it is still unclear the relation between object affordances and the processing of space (peripersonal or extrapersonal) in which the object is positioned. We hypothesized that if the encoding of space involves motor simulation, motor interference should damage spatial localization. We present a research carried out in immersive virtual reality where participants had to judge the position of manipulable or not manipulable stimuli with respect to their body, while keeping their dominant hand free or blocked. The results showed an effect of motor interference on peripersonal space and, secondarily, on manipulable objects. In particular, spatial judgements were faster in peri- than extra-personal space when participants' hands were free. This suggests that motor processing and alerting function must cooperate to allow fast reactions when stimuli are close to our body. We will discuss this evidence in light of the embodied theory and we will try to reconcile the view of peripersonal space as action and safety space.

Body schema in Anorexia Nervosa

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Central to Anorexia Nervosa (AN) is a disturbance in how body weight and shape are experienced, i.e. a body representation disturbance. Extensive research on the visual component of body representation shows that AN patients overestimate their body size in visual tasks. Recently we showed in a series of studies that AN patients' somatosensory processing is altered compared to controls. Body representation disturbances thus extend from the visual domain to the tactile domain. However, to date research has only focused on body representation disturbances in AN on a perceptual level (i.e. *body image* disturbances). In the current study we investigated whether action related disturbances in body representation, i.e. *body schema* disturbances, could be identified in AN as well. Specifically we compared AN patients and healthy controls on an aperture task. Participants were asked to walk through apertures varying in width. For each participant we calculated the Shoulder to Aperture Ratio (A/S). We expected AN patients to show a higher A/S which would indicate that AN patients rotate their body relatively sooner that healthy controls. Which in turn would imply that AN patient have an unconscious representation of their body, which is used action, that does not match their actual body dimensions. We believe it is important to also focus on unconscious body representation disturbances in AN (i.e. body schema) as treatment of body representation disturbances in AN is extremely complicated and often unsuccessful. If a body schema disturbance is present in AN, this might add to treatment of body representation disturbances.

Do eyes have it? The relationship between the eye movement system and spatial memory

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Despite considerable advances in our theoretical understanding of visuo-spatial working memory (VSWM) there remains little consensus in the literature on how spatial stimuli are encoded and maintained within working memory. One proposal is that the eye-movement system plays a key role during encoding, storage, and retrieval processes operating in VSWM (Baddeley 1986). Spatial locations in peripersonal space may be encoded through the planning of potential eye-movements. These locations can be maintained and retrieved in working memory using saccade plans that map and guide an individual to the correct locations (Pearson 2007; Pearson and Sahraie 2003). However, an alternative approach is that maintenance in VSWM is mediated by covert attention shifts that co-occur with eye-movements, rather than eye-movements themselves (Awh et al. 1999). This paper will present the results of experiments that have explored the involvement of the eye-movement system during the encoding, maintenance, and retrieval of spatial locations in VSWM. Data will be presented that demonstrate that saccades executed during a maintenance interval can selectively interference with performance of a Corsi Blocks-procedure to a significantly greater extent that equivalent covert attention shifts that do not require eye movements. Further data will be presented using an abducted-eye paradigm in which attention and oculomotor processes are decoupled by abducting the eye by 40 degrees into the temporal hemifield. It will be argued from these results that the eye-movement system plays a key role during the rehearsal of location-specific representations in working memory.

Talking about what you feel: space, language and touch in blind and sighted individuals

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When communicating about the spatial positions of objects in the outside world it is critically important to use the same reference frame. Blind individuals are thought to depend to a great extent on spatial language processing. It is not clear yet which reference frames they prefer under which conditions. In this presentation we will show work on matching spatial descriptions to haptic object configurations. In a recent experiment a large group of sighted, blind and visually impaired participants (>200) gave ratings on the acceptability of a number of verbal statements (e.g. the ball is above the shoe) in relation to object relations which were haptically explored. Interestingly, the blind more often choose an object centered reference frame (i.e. the shoe) than the sighted and visually impaired, who were as likely to pick a relative reference frame (own body). We argue that this reflects a stronger reliance in the blind on the functional relationship between haptically explored objects. Employing a more complex haptic object display in a separate study (Postma et al. 2007), we observed blind to more often give object centered descriptions of the display, whereas sighted more frequently used board oriented descriptions. We will discuss these findings in terms of how blindness affects reference frame processing in language and perception.

BODILY AWARENESS AND EMBODIED MENTAL TRANSFORMATIONS OF EGOCENTRIC SPACE

Convenor: *Klaus Kessler*

University of Glasgow, UK

This symposium aims at elucidating the involvement of bodily representations and processes of motor simulation during mental transformations of egocentric space. The overall topic is important because it spans a variety of essential human features and abilities such as bodily self-awareness in space as well as the unique human ability to manipulate these representations when required. That is, embodied manipulations can be recruited, for instance, to subserve high-level cognitive processes such as perspective taking and may impact on effective motor learning by imitation (e.g. learning to dance, fight, or play an instrument). The presentations in this symposium will cover a large variety of research questions related to the general topic. For instance: How does conflicting multisensory input modulate egocentric space and spatial awareness? How do we 'disembody' ourselves, i.e. which bodily representations are suppressed in order to minimise interference with an ongoing transformation and/or which representations break down during uncontrolled disembodiment? What is the nature of the bodily representations and processes that contribute towards—or are part of—transformations of egocentric space? How are embodied egocentric transformations modulated by sensory manipulations (e.g. vestibular stimulation) and context variables (e.g. animacy)? It is equally important to point out which egocentric spatial transformations might not depend on whole-body representations, in other words, to point out the limits of embodied processing.

Multisensory conflicts modulate spatial aspects of bodily self-consciousness

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Here we present a series of studies showing that both spatial aspects of bodily self-consciousness and tactile processing are modulated by visuo-tactile conflicts and that this visuo-tactile integration can itself be disrupted by modifying proprioceptive signals from the lower limbs. In these experiments we used the full body illusion (FBI) setup in which subjects viewed their own ('virtual') body being stroked with a stick (via a camera and head mounted display) either synchronously or asynchronously with respect to tactile stroking delivered to their backs. In the illusion (synchronous) condition: (1) subjects self-identify with their virtual body and (2) there is a bias in self-location towards the position of the seen virtual body when compared with the control asynchronous condition. By measuring the crossmodal congruency effect (CCE) during the FBI we showed that there is a change in the spatial representation of tactile stimuli so that touch is perceived 'outside of the body' when subjects' self-location is biased towards the position of the virtual body. A second study—using somatosensory evoked potentials—showed that these changes in bodily self-consciousness modulate activity in primary and higher-tier somatosensory cortex at two distinct processing steps. In a third study, we disturbed bilateral leg or arm proprioceptive signals. Only leg muscle stimulation altered the magnitude of self-identification and mislocalization of touch in a synchrony-dependent fashion. These findings highlight the differential effects of various multisensory combinations on self-consciousness and tactile processing and further our understanding of the multisensory bases of the bodily self.

Exploring embodiment and perspective-taking in reports of out-of-body experiences in the non-clinical population

Jason J Braithwaite, Emma L Broglia

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Recent evidence suggests that the complex neurocognitive processes underlying stable self-awareness can breakdown and lead to striking distortions in body-image and body-based hallucinations. One such hallucination is the out-of-body experience (OBE) which can be defined as *"an experience where the observer perceives the world from a vantage point outside of the physical self"*. These experiences are typified by a shift in the perspective of the perceiving 'self'. Such experiences have been associated with elevated scores on measures of temporal-lobe dysfunction, impairments in own-body transformation tasks, and increased signs of cortical hyper-excitability (Braithwaite et al. 2011, in press). A number of studies have argued that the brain processes involved in the mental transformation of one's own body may be the same as those implicated in the computation of the exocentric perspective reported in the OBE. Employing a variety of body-transformation tasks and perspective-taking tasks, we explored performance from those who report OBEs compared to control samples. In addition, we also explored performance from a group of observers who report related hallucinatory "sensed-presence experiences". These hallucinations are also common in the non-clinical population—though they do not involve a shift in perspective. We present evidence that hallucinators produce distinct performance on tasks that may require perspective-taking and transformations of one's own body (relative to controls). We conclude that investigating such striking experiences can provide novel insights on stable embodied 'in-the-body' experiences and contribute to current theoretical frameworks in the field of perspective-taking, embodiment and 'the self'.

The influence of spatial cues on instructed and spontaneous spatial perspective taking

Sarah H. Creem-Regehr, Kyle T. Gagnon, Margaret R. Tarampi, Jeanine K. Stefanucci

University of Utah, Utah, USA

Humans have a remarkable ability to perform imagined egocentric transformations of their own perspective, a process that is critical for many tasks including planning of actions, navigation, and spatial communication with others. The nature of spatial perspective taking, judging what a scene looks like from a new viewpoint, is related to the notion of embodied spatial cognition, as it involves body-based decisions but notably, from a disembodied location. The ease of spatial perspective taking has been shown with instructed tasks, in which viewers are explicitly told to update the egocentric spatial location of objects with respect to an imagined viewing position and heading, as well as with spontaneous tasks, in which location judgments or actions required in the presence of another agent are automatically made from the agent's perspective. Our studies varied the cues indicating imagined viewing perspective to test whether spontaneous perspective taking would influence an instructed perspective taking task. Using a desktop-display, viewers determined the egocentric location of a named object with respect to their imagined egocentric position around a table (left, right, top, or bottom). A spotlight, avatar, or cylinder was used as the cue to the instructed imagined perspective. Our results show that while speed and accuracy of perspective taking is overall influenced by the saliency of the cue provided, in some circumstances, spontaneous perspective taking could not be inhibited, creating a conflict with the instructed perspective. We discuss these findings with respect to the information and mechanisms supporting egocentric imagined spatial transformations.

Bodies in space: mental transformation and vestibular information processing

Luzia Grabherr, Caroline Falconer, Fred W. Mast

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Numerous studies in the visual and auditory domain showed that perception and mental imagery share common mechanisms. The vestibular system is involved in the perception of body rotation and translation. A few studies have investigated the role of vestibular information during imagined spatial transformations. We have tested participants with bilateral and unilateral vestibular loss and compared their performance in tasks requiring mental transformations of bodies and body-parts with healthy controls. Participants with complete (bilateral) vestibular loss showed impaired ability in mental transformation compared to participants with partial (unilateral) vestibular loss and healthy controls. Similar results were found in healthy participants tested under microgravity conditions; they showed impaired performance in the mental transformation of bodies and body-parts compared to normal gravity condition. Interestingly, mental own-body transformation was found to improve under caloric vestibular stimulation compared to sham stimulation. We conclude that the processing of vestibular information is involved in imagined spatial transformations of bodily stimuli.

Differently embodied transformations in visuo-spatial perspective taking

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Visuo-spatial perspective taking (VPT) is an essential human capacity for establishing shared views of the world. While other species seem capable of following gaze and of inferring what is hidden from another's view, human aptitude for mentally adopting other points of view seems to be unique. Such a separation into simple and sophisticated forms of perspective taking is reflected in Michelon and Zacks' (2006) distinction between two cognitive mechanisms and in Flavell et al's (1981) definition of two developmental levels (VPT-1 and VPT-2). Put simply, VPT-1 allows inferring visibility and seems to employ a line-of-sight mechanism (LoS), while VPT-2 allows the observer to mentally adopt someone else's viewpoint, supposedly by means of a mental rotation of the self. Our recent behavioural studies have revealed that these two forms of VPT can be further distinguished in terms of the bodily representations they involve. The SR mechanism during VPT-2 was significantly modulated by changes of the whole-body posture implying that large parts of the body schema were recruited. This is in agreement with findings by others that mental transformations of egocentric space are strongly related to multisensory representations of the body. LoS during VPT-1, however, was not influenced by posture, yet, it is likely that gaze-perception and -control were involved. We will present behavioural

results and preliminary analyses of MEG data where we directly compared VPT-1 and VPT-2 within the same participants.

The neural and cognitive time course of resolving conflict between perspectives

A. D. R. Surtees[1], J. P. McCleery[2], S. C. Utz[2], I. A. Apperly[2]

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Multiple brain regions have been implicated in neuroimaging and neuropsychological studies of Theory of Mind (ToM). In two recent studies, we have used Event Related Potentials to investigate the cognitive and neural time course of ToM using a visual perspective-taking task (Samson et al. 2010). In this task, participants make judgements of what can be seen from their own position and that of a cartoon avatar located in a different spatial position. These perspectives can be either consistent or inconsistent. An earlier posterior component indexed self and other perspectives and a right frontal component appeared to resolve conflict between perspectives. That a late frontal component resolved conflicting perspectives suggests a role for executive function in selecting between perspectives that have been calculated. In a follow up study, we investigated whether conflicts between perspectives may have occurred earlier. By systematically manipulating whether a given perspective matched a probe, we found evidence of N400-like components for all our conditions (thought to be evidence of semantic integration). These components differed between self and other perspective-taking, and between consistent and inconsistent trials. Meaningful sensitivity to visual perspectives from our own egocentric position and the position of another are processed relatively early in perspective-taking. Contradictions between self and other perspectives seem to require semantic resolution at an early stage of processing as well as resolution through executive control before making an appropriate decision/response.

The role of the brain's frontal eye fields in constructing frame of reference

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Establishing contextual reference during discourse is a vital part of language function. We use personal pronouns (e.g. he/she/it) to refer to previously experienced objects, utterances and events. These, however, are often no longer present in the environment and have to be maintained and manipulated in working memory (WM). One aspect of this manipulation is the construction of a spatial frame of reference (e.g. "He was in front of it" where "he" is established as figure and "it" is the ground). The WM processes underlying this function may be different from those involved in establishing a non-spatial relation (e.g. "He was older than her"). The brain's frontal eye fields (FEF), responsible for eye movement control, are known to be involved in processing spatial WM. This talk reviews both functional magnetic resonance imaging (fMRI) experiments and a subsequent behavioral interference study demonstrating a specific role for the FEFs and the brain's eye movement control system in manipulation of WM content for establishing object-centered spatial reference frames during verbally cued recall of recent visual and linguistic experiences.

Separating mental transformations and spatial compatibility effects in the own body transformation task

Mark May, Mike Wendt

Helmut-Schmidt-University Hamburg, Germany

We will report about experiments that aimed at disentangling mental transformation and spatial compatibility in the own body task (e.g., Zacks et al. 1999). Left-right judgments from the viewpoint of an upright schematic human figure take longer in case of a mismatch with the participant's facing direction (i.e., front facing stimuli). Accounts of mental perspective transformation have been challenged on the grounds of a confound with spatial S-R compatibility. To deconfound facing direction correspondence and spatial compatibility, we presented human figures in various orientations in the picture plane, thereby intermixing conditions which were neutral regarding spatial S-R compatibility, as confirmed by the absence of an interaction of figure facing direction and response side. Replicating results from previous studies, upside-down presentation impaired performance on back facing figures but did not affect performance on front facing figures, thereby yielding a facing direction mismatch cost for upright figures but facilitation for upside-down figures. This pattern of results suggests that mental rotation (in the picture plane) and spatial compatibility work in the same direction for back facing stimuli and counteract each other for front facing stimuli. Crucially, a facing direction mismatch cost was also obtained for the neutral stimuli, precluding a full-fledged account in terms of spatial compatibility. The precise mechanisms of spatial transformation in these conditions have yet to be specified.

Off with his head! The role of embodied transformations in perspective taking

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We examined the role of stimulus animacy in two types of imagined spatial transformations. Perspective transformations are transformations of the egocentric reference frame and are used to adopt novel perspectives. Object-based transformations are transformations of the intrinsic reference frame of objects, as exemplified by rotations of objects in the typical mental rotation task. In these studies we manipulated animacy by varying the degree to which the stimulus resembled a human body while preserving the gross structure. Less-animate figures were produced by placing a teapot or human head atop a set of white cubes approximating the pose of a human figure. Participants either judged whether figures were marked on their left or right sides, which predominantly elicits perspective transformations, or whether two rotated figures were the same or mirrored versions of each other, which predominantly elicits object-based transformations. We assessed the effect of animacy cues on two components of response time: a rotation-independent component hypothesized to reflect stimulus encoding and responding, and a rotation-dependent component hypothesized to reflect the spatial transformation. Animacy influenced both components of perspective transformations, but influenced only the non-rotational components of object-based

transformations. These results suggest that embodied spatial transformations require access to different aspects of the body schema, depending on the requirements of the task. The presence of a human head may be a particularly salient cue for a figure's spatial orientation, and thus facilitates perspective taking.

PERIPERSONAL SPACE REPRESENTATION IN THE PRIMATE BRAIN

Convenor: *Elisabetta Ladavas*

Univerty of Bologne, Italy

The space immediately surrounding the body, i.e. Perispersonal Space (PPS) mediates every interaction between the individual and the external world. PPS is coded in a plastic, continuously updated representation, which involves multisensory integration of visual, tactile, proprioceptive, auditory inputs, as well as motor signals concerning preparation of body actions. This topic is of central interest for many branches of cognitive psychology and cognitive neuroscience, and for research on spatial cognition, in particular. The aim of this symposium is to create a platform for sharing and integrating different approaches to study PPS as an intermodal, coherent construct.

Accordingly, we will review multisensory mechanisms underlying PPS representation in the monkey (Duhamel) and human (Ehrsson) brain. We will show how such representation dynamically changes as a function of experience (Serino) and actions (Bassolino/Pozzo). We will propose that PPS also constitutes an interface for social interactions between the self and others, as suggested by recent evidence in monkeys (Fogassi) and humans (di Pellegrino).

The role of action in space and body representations

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To efficiently interact with the external world, our brain relies on multisensory representations of the body in space, related both to the position and the dimension of the body parts (the body schema, BS) and to the location of the external objects in the space surrounding the body (the peripersonal space, PPS). It has been shown that both PPS and BS are dynamically shaped by action: interacting with far objects by using a tool extends the boundaries of the PPS and affects the perceived dimension of the arm representation in the BS. Conversely, possible effects induced by the absence of motion on these representations remain elusive. To address this issue, we study the PPS and the BS before and after 10 h of right arm immobilization in healthy subjects. Modifications of the PPS are tested by means of an audio-tactile integration task, while changes of the BS are evaluated through a tactile distance perception judgment. Since the effect previously reported on the PPS and the BS after tool-use, here we expect a contraction of the PPS boundaries closer to the body and a shrinkage of the arm representation in the BS following immobilization. Further, the same measurements are performed on the left "unrestricted" arm in order to test if the compensatory overuse of the free limb during non-use can modify space and body representations, probably in the opposite direction of immobilization. Our results are discussed in terms of plasticity and mechanisms underlying PPS and BS representations.

Multisensory space representation within the non-human primate intraparietal sulcus (IPS)

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The parietal cortex is highly multimodal and plays a key role in the processing of objects and actions in space, both in human and non-human primates. Here, I will focus on the intraparietal sulcus (IPS) and in particular, on the ventral intraparietal area VIP. This area is proposed to code multisensory peripersonal space and stimuli movement with respect to the subject. I will first present single cell recordings addressing visuo-tactile integration in this cortical region. In particular, I will show that the majority of VIP neurons, including unimodal neurons, perform multisensory integration. I will also discuss whether and how these neuronal processes account for enhanced behavioral performance at detecting bimodal as compared to unimodal stimuli. Next, I will present non-human primate fMRI data probing the involvement of the IPS, and specifically VIP, in the processing of visual, tactile and auditory moving stimuli around and towards the face. This approach nicely complements single cell recordings, providing a ground of comparison and extrapolation of monkey data to human studies. I will use this methodology to address the contribution of the IPS to three different functions in relation with space coding: multisensory convergence, multisensory integration and near space coding as opposed to far space coding. I will conclude by questioning the specific contribution of VIP in relation to the larger functional network it belongs to.

Neural bases of peripersonal space in humans revealed by fMRI-adaptation

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The majority of our interactions with the external world occur in the space surrounding our hands. Behavioral studies in humans and electrophysiological recordings in non-human primates have suggested the existence of a specific representation of the space immediately surrounding the body. In macaques, neurons whose visual receptive fields are selective for a region of space closely surrounding a body-part have been found in premotor and parietal areas. Here we will present novel findings revealing the neural bases of a selective peri-hand space representation in humans. Specifically, using an fMRI-adaptation paradigm we found evidence for areas in the anterior part of the intraparietal sulcus, as well as the dorsal and ventral portions of the premotor cortex, that exhibit selective BOLD-adaptation to a real 3-dimensional object presented near the hand. Crucially, these areas did not show any adaptation if the stimulus was presented in far space (1 meter), or when the hand was retracted from the object. Moreover, we found that the selectivity of

the visual response in parietal and premotor regions was anchored to the hand, being remapped across different positions of the hand in space. Lastly, we demonstrated a relationship between the central representation of peri-hand space and perception of a hand as one's own. In sum, our findings significantly advance our current understanding of the cortical mechanisms underlying the coding of peripersonal space in healthy humans, and fill a gap in our knowledge on this topic based on neurophysiological studies in non-human primates and neuropsychological observations in neglect patients.

Social modulation of multisensory processing in peripersonal space

Chiara Teneggi[1], Elisa Canzoneri[2], Andrea Serino[2], Giuseppe di Pellegrino[2]

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Converging evidence from animal and human studies suggests that the representation of the space near the body, termed the peripersonal space, involves the integration of information from different sensory modalities, such as audition and touch. Peripersonal space is where we physically interact with external objects and other individuals. Yet, multisensory processing in peripersonal space has been rarely investigated in social context. Here, we used an audio-tactile interaction task to determine whether peripersonal space representation is affected by human presence, and modulated by the social relations between individuals. Participants responded to tactile stimuli delivered on their face while concurrent task-irrelevant sounds approached or receded from the participant's face. In Experiment 1, we show that the boundaries of peripersonal space, as indexed by audio-tactile interactions in near and far space, changes when subjects observe another individual versus a non-human body, such as a robot. In Experiment 2, we demonstrate that social interactions during an economic game affect the boundaries of peripersonal space between the self and the other, depending on whether the other behaved fairly or unfairly during the game. These results reveal that low-level multisensory processing used to construct spatial representations is prone to social modulation and strongly shaped by valuation of other people's social behaviour.

Plasticity in peripersonal space representation: effects of body extension and body incorporation

Andrea Serino, Elisa Canzoneri

University of Bologna

Multisensory representations of the body and of the space around it (i.e. Peri-personal space, PPS) depend on the physical structure of the body, in that they are constructed from incoming sensory signals from different body parts. Here we present experimental data showing how changes in the structure or in the function of the physical body modify mental representations of the body in space.

Following a sudden change in the physical body, such as upper limb amputation, mental representations of the stump and of the space around it modify. Such representations are further shaped if prostheses are used to replace the lost body part. On the other hand, tool use in healthy subjects can be conceived as a functional extension of the physical body; as a consequence, tool-use extends the perceived dimensions of the body and PPS representation. Our data show that different physical or functional modifications in the structure of the physical body induce coherent plastic effects in mental body and PPS representations. Such high degree of plasticity suggests that our sense of body in space is not given at once, but it is constantly constructed and adapted through experience.

PERCEPTION AND REPRESENTATION OF VERTICAL SPACE

Convenor: *Daniele Nardi*

Sapienza University of Rome, Italy

Navigation and spatial orientation in human and non-human animals has been relatively well studied in the two-dimensional, horizontal plane, but little is known about vertically-extended environments. Theoretical considerations and empirical evidence suggests that this dimension has a very distinctive characteristic compared to the horizontal ones, because it is parallel to the force of gravity. The increased energetic cost associated with movements along the vertical dimension in terrestrial environments is linked to the fact that terrain slopes are more salient than other horizontal cues used for orientation (pigeons; Nardi et al. 2011). Furthermore, studies on rats have shown that, in relation to the greater effort of vertical movements, there is a bias for horizontal movements in 3-D spaces; this is also substantiated by the neurological finding that vertical information is encoded in a coarser and less precise fashion than horizontal information (Hayman et al. 2011). The vertical dimension is very important also in aquatic environments: the hydrostatic pressure information, in fact, overrides other sources of spatial information for navigation in a water column (fish; Holbrook and Burt de Perera 2009). The study of vertical spaces is ecologically relevant for human navigation too; the lay of the land often includes a rich vertical topography, and research has shown that terrain slopes can be used to improve navigation performance. However, recent evidence suggests that this facilitation applies only to good navigators—people that know how to use and attend the slope cues to inform their navigational representation (Weisberg and Newcombe 2011). Finally, vertically-extended surfaces present distinct properties also in relation to perception: in particular, there is a well reported bias in the estimation of geographical slants. Recent studies have shown that these effects can be caused by perceptual scaling of visual, vertically-extended surfaces—a mechanism for improving coding efficiency for normal pedestrian slant inclinations (Hajnal et al. 2011). The symposium will cover recent neurological, perceptual, and behavioral findings on the perception and representation of vertical spaces, obtained with human and non-human animal models, using real and virtual environment procedures. The goal is to bridge the different but related lines of research, in order to provide a synthetic view on this topic, and to establish future goals of common interest.

The vertical component of fishes' representation of space

Theresa Burt de Perera

University of Oxford

To date, research has focused on how animals encode the horizontal component of space. However, most animals travel vertically within their environments, particularly those that fly or swim.Pelagic fish move with six degrees of freedom and must use and integrate these components to navigate accurately.Using an assay based on associative learning of the vertical and horizontal components of space within a rotating Y-maze, we found that fish (*Astyanaxfasciatus*) learned and remembered information from both horizontal and vertical axes when they were presented either separately or as an integrated three-dimensional unit. When information from the two components conflicted the fish used the previously learned vertical information in preference to the horizontal, suggesting that the vertical axis contains particularly salient spatial cues—presumably including hydrostatic pressure. To explore this possibility we developed a physical theoretical model that shows how fish could determine their absolute depth using pressure. Empirical studies will reveal whether hydrostatic pressure can be used as a navigational cue. In the next step we considered full volumetric spatial cognition. *Astyanax* were trained to swim towards a reward in a rotating Y-maze before removing the arms during probe trials. The fishwere tracked in three-dimensions as they swam freely through the surrounding cubic tank. We showed that fish were able to accurately encode metric information in a volume, and that the error accrued in the horizontal and vertical axes of space whilst swimming was equal. Together, our results reveal the importance to fishes of encoding the vertical component of space.

Angular scale expansion and the perception of action space

Frank H. Durgin, Zhi Li

Swarthmore College

Coding strategies employed by biological information processing systems must be representationally efficient because of limited channel capacity. Perceptual distortions of space may embody efficient coding strategies rather than energetics of action. Angular variables are systematically distorted in human visual experience, in a manner consistent with the principles of efficient coding: The main (central) range of angles relevant to locomotor control is densely represented (expanded) and the outer range is sparsely represented (compressed). When looking down at a ground plane, people feel they are looking further down (nearer) than they are. This overestimation of gaze declination is quantitatively (geometrically) consistent with the observed underestimation of egocentric distances in the literature, and with the perceptual exaggeration of height and slant. Using an angular gain of 1.5 measured in 6 prior experiments using a variety of methods (verbal estimation, non-verbal matching, horizontal/vertical bisection), we have found that an otherwise parameter-free geometric model based on angular scale expansion perfectly predicts participant (mis)matching of vertical extents to egocentric distances. Under full-cue conditions, the world around us is distorted in perception primarily as a result of angular coding biases that likely serve a functional role in maintaining higher coding precision for the range of angles most often experienced. These distortions are valuable for planning, controlling and calibrating actions because they retain more precise information concerning the range of angles most relevant for locomotion. Moreover, these distortions are multimodal, affecting even the perception of slant by the hands and feet and thus predict accurate action, as found.

Is the cognitive map flat? Studies of the neural representation of three-dimensional space

Kate Jeffery

University College London, UK

Studies of the representation of large-scale, navigable space at the single neuron level can shed light on the cognitive processes underlying spatial cognition. In ordinary, horizontal environments, place cells in the rodent hippocampus encode location while grid cells, in the neighbouring entorhinal cortex, encode an integrated signal of distance and direction. In order to gain insights into how space is represented in three dimensions, we have studied how place and grid cells respond to travel in the vertical dimension. Rats were required to forage for food reward on either a helical track or a vertical climbing wall (the "pegboard") while place cells or grid cells were recorded. We found that while grid cells were highly insensitive to vertical distances, place cells did show some responsiveness, though at a coarser scale than for horizontal distances. The findings suggest that the representation of vertical space, or perhaps space in the dimension normal to the body plane of the animal, is represented differently, and maybe non-metrically. Preliminary behavioural studies support this notion, showing that rodents prioritize horizontal over vertical movements, both on the pegboard and in a lattice maze. Thus, the so-called "cognitive map" of space may perhaps not be uniform in all dimensions, despite our subjective experience to the contrary. This talk will explore why a planar cognitive map may be adaptive.

Does terrain slope really dominate goal searching?

Daniele Nardi

Sapienza University of Rome, Italy

Recent research on non-human animals, both in terrestrial and aquatic settings, has revealed that the vertical component of the environment provides a very salient spatial reference frame. In particular, it has been shown that homing pigeons locate a goal by using the slope of the terrain even if other cues, with higher predictive value, are available. This result, in apparent contrast with associative models of spatial learning, suggests that the vertical information of the environment is qualitatively different from horizontal cues, because of the link with the force of gravity. In order to further examine this issue, we tested pigeons in a goal location task with slope and another theoretically salient cue: a beacon feature. In this condition, searching behavior was controlled almost equally by the two cues. This result is the first, in a series of studies, to show that slope fails to dominate the goal-searching process. It suggests that slope, although very salient, is a stimulus that obeys principles of associative learning. As an interesting additional finding, the reliance on slope and on the feature was affected by the goal location during training (uphill vs. downhill): pigeons trained to an uphill goal used slope more than pigeons with a downhill goal. This suggests that the increased effort and energetic cost associated with

upward movements in terrestrial environments may affect the cue-weighting mechanism of goal searching.

The other side of the mountain: slope as a cue in navigation

Steven Weisberg, Edward Brakoniecki, Nora Newcombe

Temple University, Philadelphia, PA, USA

Navigation depends upon accurately positioning objects in large-scale space with respect to each other and around oneself. Terrain slope has been shown to be a useful cue in learning environments (*Restat*, Steck et al. 2004), presumably because it provides directional information (i.e., the school is uphill from the post office). However, research has demonstrated individual differences in the ability to rely on slope cues (Nardi et al. 2011), suggesting that the usefulness of slope may depend upon an individual's navigation ability. We tested the hypothesis that a sloped terrain would facilitate a more accurate representation only for those participants able to take advantage of the information (i.e., good navigators). Participants learned a set of buildings in one of two desktop virtual environments that differed only in whether the terrain was sloped or flat. A map construction task and a judgment of relative direction (JRD) task assessed participants' knowledge of the environment. The Santa Barbara Sense of Direction Scale (Hegarty et al. 2001) measured navigation ability. As predicted, a significant interaction obtained for the map construction task between self-reported navigation ability and environment, suggesting that good navigators are able to use the slope information effectively while bad navigators are impaired in the slope condition. Results followed the same pattern for the JRD, but the interaction did not reach significance. In a follow-up study, we are investigating the relationship between participants' strategy choice and their performance on the navigation tasks to rule out a possible mediating influence.

MULTISENSORY AND EMOTIONAL SPACE IN ART AND SCIENCE

Convenor: *Isabella Pasqualini*

Ecole Polytechnique Fédérale de Lausanne/Institute of Architecture and the City/ALICE

How can the artistic interpretation of space convey a message to the observer or evoke a sensation, a mood? The investigation of multisensory perception of space as deployed in different scientific and artistic fields requires the involvement of an interdisciplinary frame ranging from the arts to cognitive neuroscience. Recent data in cognitive neuroscience revealed the fundamental role of multisensory integration of visual, tactile, vestibular, proprioceptive and motoric stimuli involved in the subjective experience of the bodily self in space. This suggests multisensory mechanisms of integration supporting the spatial experience of the bodily self are important for the artistic expression and conceptualization. In this symposium we intend to address how examples from the arts illustrate the investigation of multisensory integration and how artistic cues and spaces are represented and linked to self-consciousness to form in the observer a unified perspective so characteristic of the bodily self in space.

Doubles everywhere: belletristic contributions to the science of the bodily self

Sebastian Dieguez

Laboratory for Cognitive and Neurological Sciences, Unité de Neurologie, Département de Médecine, Université de Fribourg, Switzerland

The topic of the double is a hallmark of romantic, gothic and fantastic literature. In the guise of the second self, the alter ego or the doppelgänger, fictional doubles have long fascinated critics, clinicians and scientists. Although psychoanalysis has been at the forefront of interpretations of the literary double, we argue that recent advances in the cognitive sciences allow for a more robust theoretical framework. In particular, data from studies on self-perception, self-localization and spatial representation provide a neurocognitive grounding for the emergence of literary doubles. In turn selected neuropsychiatric case reports such as heautoscopy, the feeling of a presence and out-of-body experiences strikingly mimic the varieties of literary doubles. Taken together, this vast array of observations allows for a systematic typology of doubles involving substitution, alternation and duplication as key mechanisms. Examples include works from Maupassant, Hoffman, Poe, Stevenson and others. We discuss the possible neural networks underlying the fragmented and mislocalized self from the perspective of multisensory integration. These mechanisms notably rely on parietal, frontal and subcortical systems. We suggest that writers have been able to tap into these unconscious processes, and exploit for creative and symbolic purposes the unusual representations of the self that they permit. The framework further suggests that the very same mechanisms allowing imagining and describing varieties of the double, are, when disrupted, the ones involved in pathologies of the self.

The artist in the studio: immersion into the body of the avatar

Nicole Ottiger

ZHdK (Zurich University of the Arts), EPFL (École Polytechnique Fédérale de Lausanne)

Why do artists make self-portraits and what makes them so particular from other artistic representations? In a self-portrait the artist renders the intimate representation of the own personal self and it may be regarded as a method of investigation on one-self, both physically and emotionally. While rendering his self-perception the artist must extend the represented self beyond the perceived self. Self-portraits usually include autobiographic aspects that challenge the artist's awareness of the objective representation of self. For example, in the past it has been claimed that in the painted self-portrait the painter is represented twice, as the painting painter, by choice of technique and mode of expression, and, as the depicted subject. I argue that in virtual surroundings (digital media) the user generates a virtual self. In art representation the virtual self was always observed, yet recently it has gained a figurative element. These topics are examined within my artistic research carried out during an artist residence at the Laboratory of Cognitive Neuroscience/EPFL. I present data from studies in virtual reality where subjects were immersed into the body of an avatar while psychological responses and brain activity were monitored. By disrupting fundamental aspects of bodily self-consciousness, such as self-location and self-identification, subjects reported a shift in their sense of where and what they perceived themselves to be. By example of personal artworks I will discuss that self-depiction is based on the constant attempt to localize the self.

The architectonic self: own body perception and feelings in architectonic space

Isabella Pasqualini[1], Olaf Blanke[2]

[1]Ecole Polytechnique Fédérale de Lausanne/Institute of Architecture and the City/ALICE; [2]Ecole Polytechnique Fédérale de Lausanne/ Brain and Mind Institute/LNCO

Past theories speculated about the impact of architecture on body and bodily feelings through the interference of haptic, visual, and multisensory mechanisms, and how these contribute to the human feeling of existing in a place. How far then does the architectonic form and interior contribute in conveying and altering bodily states of the observer through architectonic features? Recent works in cognitive neuroscience revealed detailed visuo-tactile mechanisms of the bodily self, such as body ownership and self-location and how the bodily self impacts fake and virtual bodies in peripersonal space. Accordingly, we ask whether and how architectonic space affects the bodily self. How does architectonic form impact the ownership and self-location of the beholder as manipulated through multisensory stimulation? These points are targeted theoretically by linking architectonic embodiment to cognitive science, architectonically by linking spatial cognition and aesthetics to the architectonic design process, and, experimentally by testing basic architectonic features in established behavioural set-ups. We will present scientific experiments based on the investigation of bodily feelings in a specific architectonic framework. Our results point to how specific environmental features may impact bodily self-consciousness or, inversely, how altered states of bodily self-consciousness affect the perception of environmental features. We discuss bodily self-consciousness and specify those bodily feelings, which we believe to be fundamental in the architectonic experience.

Emotion, multisensory integration and space perception: when space is felt too small or too big

Isabelle Viaud-Delmon

CNRS UMR 9912, IRCAM

Complaints related to spatial disorientation have seldom been considered as a possible manifestation of a distorted multisensory integrative ability. Several kinds of mismatches among simultaneous sensory information are encountered in everyday life but despite this, the central nervous system usually manages to update the internal representation of the body in the surrounding space. In some cases, a sensory mismatch may elicit an erroneous perception of the body in space, resulting in emotional problems like anxiety. Different attempts have been made to understand the conditions that lead to these problems, which seem to always involve multisensory and vestibular integration. We will first present several human and animal studies suggesting that emotional dysregulation, and anxiety in particular, are related to the contribution of the vestibular system to perception and orientation in space. We will then propose that an innovative approach to the study of the link between space perception and emotion is to focus on the auditory sensory modality. Most often, auditory perception is not considered as a main contributor to human space perception. However, it is the only sensory modality that provides information about the whole space surrounding the body, as well as about the interaction between the body and the space. Building on this, we will provide examples of the link between art, body movements, auditory information and space perception.

Art and architecture as experience. An alternative approach to bridging art history and the neurosciences

Nina Zschocke

Institute for the History and Theory of Architecture, ETH Zurich, Switzerland

In 1972 Michael Baxandal notes that the processes responsible for the cultural relativism of art perception "do not work serially" and are "indescribably complex and still obscure in [their] physiological detail". While art history still shows considerable interest in the brain sciences 40 years later, most cross-disciplinary studies today are referring to the neurosciences in an attempt to seek scientific legitimization of variations of a generalized and largely deterministic model of perception, reducing interaction between a work of art and its observers to a set of biological automatisms. I will challenge such an approach and take upart theory's interest in the historico-cultural and situational dimensions of art experience. Looking at architecture and installative works of art by James Turrell, Robert Smithson and others, I will explore instable perceptions of depth and changing experiences of space that indicate complex interactions between perceptual and higher cognitive processes. The argument will be based on an ongoing study that draws on recent theories describing neuronal processes underlying multistable phenomena, eye-movement, visual attention and decision making. As I will show, a large number of neuroscientific studies provide theoretical models that help us analyse not anthropological constants but the influence of cultural, individual and situational variables on aesthetic experience.

EMBODIED AESTHETICS: VISUAL AND SENSORIMOTOR COMPONENTS OF SENSORIMOTOR COMPONENTS OF AESTHETIC EXPERIENCE

Convenors: *Luca F. Ticini[1], Cosimo Urgesi[2]*

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Echoing the phenomenological tradition in philosophy, recent hypotheses have proposed that the aesthetic experience is grounded on the embodied simulation of the actions, emotions, and corporeal sensations represented in an artwork (Freedberg and Gallese 2007). We refer to these simulative processes as embodied aesthetics. While insofar numerous studies have focused on static representation of art, nowadays a new line of research is investigating the brain responses to those art forms, such as dance, characterized by a dynamic dimension and that require a translation of the body in space in order to become manifest. Crucially, recent neuroimaging investigations have demonstrated that the ability of an observer to reproduce (or not) the actions embedded in a work of art (such as the brush strokes in a painting, the movements of the dancers in a ballet performance or the hand actions in a piece of piano music) may indeed play a major role in aesthetic experience (e.g., Freedberg and

Gallese 2007; Calvo-Merino et al. 2008; Cross and Ticini 2011). These results advocate a role for the brain's action-observation network (AON) in aesthetic evaluation. The AON comprises brain structures associated with the motoric representation of others' actions, including premotor and parietal areas, as well as occipito-temporal regions involved in the visual representation of body form and motion (Calvo-Merino et al. 2010; Cross et al. 2011). In the present symposium, we bring together the leading experts in sensorimotor aesthetics to present an up-to-date overview of the field, highlighted by their most recent investigations on the role of visual and sensorimotor processes in aesthetic experience. The speakers will address a number of topics related to aesthetic perception, ranging from studies investigating perception of human body forms (e.g., thinness or obesity) and body actions (e.g., dance), to the aesthetic outcomes of body movements in the spatial dimension (e.g., music) and the role one's own physical experience plays in shaping the aesthetic response. Moreover, the work to be presented has used a combination of methods including behavioral, neuroimaging and neurostimulation. Importantly, that all speakers have previously collaborated in embodied aesthetic research will ensure an integrate approach to the topic.

The influence of experience on aesthetic processing: insight from ballet dancers watching dance postures

Beatriz Calvo-Merino[1], Alexander Jones[2], Helge Gillmeister[3], Maria Tziraki[2], Bettina Forster[2]

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The motor knowledge of a dancer influences how he sees movements and sensorimotor information in general. Here we investigate how his experience modulates the associated embodiment process that has been described during aesthetic perception. We specifically investigate the embodiment neurophysiological correlates (such as somatosensory event-related potentials) during the aesthetic process. EEG was recorded for two groups of participants (18 expert dancers, 18 control non-dancers) during the observation of pairs of body postures while they performed two tasks: (a) an aesthetic preference task, (b) a perceptual task in which the same pairs of body postures were judged for changes in luminance. Moreover, in order to understand if embodiment follows a somatotopic structure, we selected body posture pairs that differed in either upper or lower limb positions. Somatosensory event-related potentials were evoked by tactually stimulating hands and feet using small solenoids while participants performed both aesthetic and perceptual tasks. Embodiment was measured as the congruency between the body part touched (hands, feet) and the observed body posture limb change (upper, lower limbs). The results showed task differences starting at very early stage of processing (P45, N80), likely in primary somatosensory cortex. Moreover, the expert group showed earlier indicators of embodiment in the aesthetic task than the non-expert group. These results show that different attitudes for seeing (e.g., aesthetic) and acquired sensorimotor expertise modulates sensory responses at a very early stages. Finally, these findings may explain why liking is related to physical sensations and embodiment of an observed piece of art.

The embodied aesthetics of watching dance

Emily S. Cross

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Formal inquiry into the neuroaesthetics of watching dance has only just begun. While still less studied than the neuroaesthetics of visual art, dance neuroaesthetics is a particularly rich subfield to explore, as it is informed not only by research on the neurobiology of aesthetics, but also by an extensive literature on how a perceiver's prior physical experience shapes his or her perception of a particular action. Recently, we addressed how observers' aesthetic evaluation of dance is related to their physical ability to reproduce observed movements. We hypothesized that sensorimotor brain regions would respond strongest to movements participants most enjoyed watching. Twenty-two dance-naïve participants underwent functional magnetic resonance imaging whilst evaluating how much they liked watching and how well they thought they could physically reproduce a series of dance movements. Stimuli were 64 3-s clips of ballet and modern dance sequences, performed by a professional male or female dancer. Our findings showed that participants most enjoyed movements they rated as most difficult to reproduce. Moreover, this interaction between aesthetic enjoyment and perceived physical ability was associated with activation of occipitotemporal and parietal brain regions, providing evidence for a sensorimotor sensitivity not only for aesthetically-pleasing stimuli, but for those that are beyond the observers' physical abilities as well. Together, the findings begin to illuminate how the embodied simulation account of aesthetic experience might apply to watching dance, and raise a number of questions related to interactions between physical experience and aesthetic experience that are the subject of ongoing investigation in our laboratory.

Learning to like it: aesthetic perception of choreographic patterns

Guido Orgs, Patrick Haggard

Institute of Cognitive Neuroscience, University College London

Grammar is an important cognitive key for language and music perception. In a series of experiments, we link grammatical structures to aesthetic perception of body movements. We createdsymmetrical (ABCDCBA) and asymmetrical (ABCDBCA) sequencesof apparent movement. Apparent movement sequences consisted of seven individual dance postures, extracted from previously recorded movement videos and rendered as grey-scale photographs. Additionally,"Good continuation" of apparent movements was manipulated by changing the number of movement path reversals within a sequence. In a first experiment, we presented these sequences in an artificial grammar learning paradigm: In an initial exposure phase, one group of participants ($N = 20$) saw only symmetrical sequences, while another group ($N = 20$) saw only asymmetrical sequences. In a subsequent test phase, both groups rated all sequences and all static postures on an aesthetic evaluation scale. Both groups preferred "good" continuation sequences over sequences with many path reversals. Static postures that maximized static symmetry were preferred to postures

with less symmetrical limbs. Importantly, participants who had been initially familiarized with asymmetrical sequences additionally showed increased liking for asymmetrical sequences, suggesting a *structural mere exposure* effect. Aesthetic preferences thus depend on spatial features of the static postures, local apparent movement continuation and global grammatical structure. We propose a hierarchical model of aesthetic perception of human movement with distinct processing levels for postures, movements and composition.

Embodied aesthetics: audiomotor representation of music in experts and laypersons

Luca F. Ticini[1], Giacomo Novembre[1], Florian Waszak[2], Simone Schuetz-Bosbach[1], Peter Keller[1]

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Our brain can recognize the actions of others by representing their sounds as a motor event. Previous studies have demonstrated the activation of the listener's motor cortex during passive perception of over-familiar motor acts, such as the sound of a trained piano performance. Less is known about the embodiment of the sounds of unfamiliar actions. We used music as a model to investigate how the motor system is engaged by passive listening to a piano performance that was unfamiliar and untrained. Transcranial magnetic stimulation (TMS) was employed to measure the correspondence between auditory and motor codes in a group of music experts and a group of laypersons. We compared the corticomotor excitability in response to the presentation of 60 performances of the same melody that differed only in expressive timing (i.e., the subtle temporal nuances introduced by a performer to an otherwise perfectly timed interpretation). Each performance was followed by a question referring to preceding audio (how much participants liked the performance just heard). The findings revealed strongest activation of the motor system to unrehearsed melodies that were rated as esthetically more pleasing. This activation is common to music experts and laypersons. As such, these findings argue that the human motor system is sensitive to a broader range of features beyond those that are familiar and deepen our understanding on the embodied simulation account of esthetic experience.

TMS investigations of the influence of body form and body action representations on body aesthetic perception

Cosimo Urgesi, Sonia Mele, Valentina Cazzato

Department of Human Sciences, University of Udine, Italy

Aesthetic perception of the human body is strongly driven by the interaction between body movement (e.g., gait or dance moves) and body form (e.g., fatness) cues. The Body motion and Body form exert a strong influence on aesthetic body judgments. Observing body actions engages a large fronto-temporo-parietal system which includes not only visual areas, such as the superior temporal sulcus, but also motor areas. On the other hand, the visual processing of body forms engages a lateral occipito-temporal area, referred to as extrastriate body area (EBA) and a medial fusiform region, known as fusiform body area (FBA). In a series of studies we explored the role of extrastriate and premotor areas on the aesthetic judgements of human bodies. We asked healthy participants to judge how much they liked virtual adult female and male bodies whose width was varied to apparently increase or diminish their body size. Furthermore, the implied movement of each body was manipulated by rendering static or dynamic poses. The aesthetic judgements were requested after repetitive transcranial magnetic stimulation of EBA, ventral premotor cortex and the vertex. In different groups of subjects areas in both the left and in the right hemispheres were targeted. We found a substantial role of EBA (in particular in the left hemisphere) in altering the aesthetic perception of body fatness, while stimulation of left and right premotor cortex affected body motion aesthetic perception. The results suggest that visual and motor body representations interact in determining aesthetic evaluation.

BODY PERCEPTION, PERIPERSONAL SPACE AND PAIN: CLINICAL FINDINGS AND CONCEPTUAL ASPECTS

Convenor: *Jörg Trojan*

Department of Cognitive and Clinical Neuroscience, Central Institute of Mental Health, Mannheim

The experience of acute and chronic pain is closely related to the way we perceive our body. Most of this evidence stems from clinical observations. For instance, pain patients perceive hurting body sites as being spatially distorted. Recent experimental studies have started to shed light on how pain is connected to body image and peripersonal space. This symposium will cover three main topics: We will (1) give an introduction to the field and discuss conceptual aspects of body perception and pain; (2) demonstrate the effects of the visibility of the hurting body area, alterations in body image, and limb position on pain perception; and (3) discuss underlying mechanisms as well as perspectives on diagnostics and treatment of chronic pain.

See your pain: site-specific visual feedback reduces pain perception

Martin Diers[1], Walter Zieglgänsberger[2], Jörg Trojan[1], Herta Flor[1]

[1]Department of Cognitive and Clinical Neuroscience, Central Institute of Mental Health; [2]Department of Clinical Neuropharmacology, Max-Planck-Institute for Psychiatry

Background and aims: The body image which is often taken for granted is disrupted in patients with chronic back pain. The back is normally a rather unknown area of the body. Until now nothing is known about the influence of seeing one's own back during painful stimulation. Methods: We tested 17 patients with chronic back pain and 17 healthy controls by implementing online video feedback of the back compared to feedback of the dorsum of the hand as well as magnified and minified video feedback of the back during pressure pain and subcutaneous electrical stimulation on the musculus trapezius. Pain threshold and pain tolerance were assessed. Pressure pain stimulation intensity was set to 50 % above pain threshold. Subcutaneous stimulation intensity was set to 70 % above pain threshold. Subjects had to rate pain intensity and unpleasantness after each stimulation block on an 11-point numerical rating scale. Results:

Patients with chronic back pain reported significantly higher pain ratings compared to healthy controls. Visual feedback of the back reduced perceived pain intensity compared to feedback of the hand. Conclusion: It is possible that seeing the painful region makes the aversive stimulus less threatening. This finding raises the possibility that training of the body image or visual feedback of the pain region may help patients with chronic pain.

If you cross your arms, it hurts less: neural correlates of the 'crossed hands' analgesia

D. M. Torta

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Pain perception goes beyond the mere conscious detection of nociceptive stimuli. Recent evidences indicate that the experience of pain emerges from a complex interplay between body and space representation, both in experimental and clinical contexts. For example, as suggested by previous studies (Gallace et al. 2011), crossing the hands over the midline reduces the perceived intensity of painful stimuli delivered to the hands. This effect is thought to occur as a consequence of the mismatch between the two frames of reference our brain uses to localize external stimuli: anatomical and space-based (Sambo, Torta et al., under review). Normally, these two systems of reference provide a coherent information, however, when the hands are crossed over the midline, the information coming from the two systems is no longer easily integrated. Neurophysiologic findings have suggested that this effect occurs at late stages of the elaboration of the stimulus (Gallace et al. 2011).Such a hypothesis is now confirmed by a recent fMRI investigation of the crossed-hands analgesia whose results indicate that the posterior parietal cortex is less active when stimuli are delivered to the crossed hands.(Torta et al. under review). In contrast, brain regions related to attention, homeostasis and body representation (e.g. the frontal and cingulate cortices and the insula) are more active when hands are crossed. Together the results of these studies uphold the hypothesis that an impeded integration of information coming from different frames of reference underpins the analgesic effect of crossing the hands.

The role of body image and peripersonal space in pain

Jörg Trojan, Herta Flor

Central Institute of Mental Health, Mannheim

The experience of acute and chronic pain is closely related to the way we perceive our body. Most of this evidence stems from clinical observations: Amputees often suffer from pain in their amputated limb and the amount of pain seems to be related to distorted spatial perception of the limb ('telescoping'). Patients with Complex Regional Pain Syndrome (CRPS) suffer from intense pain in their hand and often perceive them as being larger than they actually are. Back pain patients have problems in delineating the outline of their backs and their body image is distorted in the painful area. The common involvement of changes in body perception points to a common neurophysiological mechanism. While the idea of specific neurophysiological structures for relaying nociceptive information—at least partially—holds on the peripheral level, it becomes increasingly clear that the quest for a single "pain centre" in the brain is misled. Rather, pain is rooted in integrated, multi-modal representations of our body. This resonates with recent psychological perspectives viewing pain as an embodied sensation, which can only be understood within a broader framework including other sensory and affective aspects of body perception. This talk will give an introduction to the field, give an overview of the clinical evidence on the relationship between body perception and pain, and discuss conceptual and methodological aspects.

Pain and disturbances in body awareness

Camila Valenzuela-Moguillansky

Laboratoire Psychologie de la Perception CNRS UMR 8158, Université Paris Descartes, Paris, France and Centre de Recherche en Épistémologie Appliquée CNRS UMR 7656, École Polytechnique, Paris, France

Evidence shows a relationship between pain and disruptions in body awareness. Pain-related alterations in body awareness have been previously reported in chronic pain syndromes such as complex regional pain syndrome (CRPS), phantom limb pain and chronic lower back pain. These alterations have been reported at the subjective, behavioural and neural level. Conversely, modifications in body awareness induced by the use of different devices such as the mirror box, prisms and more recently virtual reality have been shown to modulate pain perception. In this presentation I will present two studies that assess this bidirectional relationship. In the first study I show that a modification of one aspect of body awareness, the so-called "sense of body-ownership", by the used of a visuo-tactile illusion called the "rubber hand illusion" (RHI), modulates pain perception induced by thermal stimulation. The second study is a qualitative study that aims to assess the impact of chronic and global pain on the bodily experience of fibromyalgia patients. Through an interview technique inspired by phenomenological approaches, I gathered patients' descriptions of their pain crises. The analysis of the interviews shows that throughout a pain crisis, a basic structure repeats itself in a recursive manner. The main components of this structure are the bodily sensations, their recognition, and the physical and mental attitudes associated with this recognition. These attitudes seem to have a modulating role, reinforcing or appeasing the crisis. Detailed descriptions of the alteration of the patients' body and inner space perception were also obtained.

THINKING WITH, IN, AND ABOUT SPACE

Convenors: *Barbara Tversky*[1], *Susan Levine*[2]

Stanford University, Stanford, USA; [2]*University of Chicago, Chicago, USA*

This symposium explores ways that spatial thinking and action support thought and learning in other domains. The talks will examine the roles of spatial metaphors and spatial gestures in promoting learning and understanding, and show how these can support understanding scientific and other abstract concepts by providing a basis for

spatial abstractions. Overall, our symposium will bring out important connections among space, action, and abstraction.

Spatial alignment and spatial language contribute to learning about engineering

Dedre Gentner[1], Susan Levine[2], Micah Goldwater[1], Raedy Ping[2]

[1]Northwestern University, USA; [2]University of Chicago, Chicago, USA

We present two studies investigating how brief training sessions utilizing analogical comparison and spatial language can help teach children a key principle of stable construction—that diagonal braces stabilize structures. Study 1 was conducted at the Chicago Children's Museum, at an interactive activity in which families construct model skyscrapers. Children compared two juxtaposed model skyscrapers, one stable (with a diagonal brace) and one unstable (without a diagonal brace). Comparing the two buildings allows children to align their common structure, and highlights the crucial difference (the diagonal brace) that causes the difference in stability. Prior analogical research suggests that overall similarity supports the ability to align two structures. To test this, we ran three groups: High-similarity between the stable and unstable skyscrapers; Low-similarity between them; and No training. Afterward, families built their own skyscraper. Then children were given the Repair Task: they were given an unstable building and one piece to repair it. Performance was higher in the two Comparison groups than in the No-training group and higher in the high-similarity comparison group than in the low-similarity group. Further, parental use of spatial language during the building session was predictive of successful repairs. A follow-up study in the lab manipulated the use of spatial language as well as the similarity of the model buildings during comparison training. We also examined children's ability to transfer the knowledge of diagonal braces to novel buildings. As in Study 1, both the use of spatial language and receiving high similarity comparison fostered learning of the diagonal bracing principle.

Gesture predicts readiness-to-learn in adults learning a complex spatial task

Susan Goldin-Meadow[1], Raedy Ping[1], Mary-Anne Decatur, Sam Larson, Elena Zinchenko

[1]University of Chicago, Chicago, USA

When children explain their answers to tasks that they have yet to master, some produce gestures that include additional information not found in their speech. These children are likely to benefit from instruction in the task. Here we investigate the possibility that different types of gesture-speech relationships might index readiness to learn for adult novice learners as they grapple with a sophisticated spatial domain. Adults, naïve to organic chemistry, were asked to create stereoisomers of molecules, a task that requires mentally transforming and drawing an alternative spatial arrangement of the parts of the molecule. Adults whose gestures added correct information to the information conveyed in speech at pretest improved on the task after instruction—adults whose gestures did not add information or added only incorrect information did not improve. These findings suggest that, even for adult learners and complex tasks, gesture reveals implicit knowledge about the task at hand and can be used to identify who is ready to learn.

Spatial metaphors: aspects of concrete spatial meaning are retained in abstract contexts

Anja Jamrozik, Dedre Gentner

Northwestern University

Spatial prepositions are often extended to abstract contexts. Do these uses simply reflect a multiplicity of different word senses, or are they generative extensions of spatial meanings to abstract contexts? A case in point are the spatial prepositions *in* and *on*, which have a wide range of abstract meanings (e.g., *in* love, *in* a hurry, *on* time, *on* a mission). These uses are often assumed to be completely idiomatic and unrelated to these prepositions' spatial meanings. However, we instead propose that these abstract uses preserve an aspect of the basic spatial meaning, namely, *locus of control*—the degree to which the figure versus the ground controls the figure-ground relationship. When used to describe spatial relationships, *on* is more likely to be used if the figure has more control of the relationship—e.g., if the figure is animate, as in "the firefly is on the plate" (Feist and Gentner 1998, 2003). If the ground has more control of the relationship, as in "the coin is in her hand," *in* is more likely to be used (Coventry et al. 1994; Feist and Gentner 2003). Our findings suggest that *locus of control* can likewise distinguish abstract uses of *in* and *on*. Specifically, we find that *on* conveys high control of the situation by the figure (relative to *in*), in frequent abstract contexts (e.g., *in* love/*on* a roll) and even in novel abstract contexts. We conclude that aspects of spatial meaning are retained when spatial prepositions are used in abstract, seemingly idiomatic ways.

The role of embodiment in children's understanding of units of measure

Susan Levine[1], Eliza Kongdon, Mee-kyoung Kwon, Raedy Ping[1]

[1]University of Chicago, Chicago, USA

We explore whether gestures might be as helpful or even more helpful than discrete unit chips in improving children's performance on a ruler measurement task. In this study with first and second grade children, there are four training conditions: (1) using unit chips placed on a ruler to measure objects that are aligned at the "0" point of a ruler, (2) using unit chips to measure objects shifted away from the "0" point, (3) using a gesture (thumb and forefinger) on a ruler to measure aligned objects (4) using a gesture to measure objects shifted away from the "0" point. The embodiment literature (e.g., Fisher et al. 2011) suggests that gesture may help children flexibly embody the idea of a unit as a measure of space. Preliminary results suggest that for children who count hash marks rather than spatial units as their initial incorrect measurement strategy, gesture improves performance in both the shifted and non-shifted conditions whereas unit chips only improve performance in the shifted condition. Moreover, the use of unit chips versus gestures results in similar levels of improvement at immediate post-test, but by follow up testing one-week later, children in the shifted gesture condition outperform those in the shifted unit chip

condition. This is because children who benefit from a gesture-based training strategy continued to improve over the one-week period following training. In line with embodiment theories, our findings indicate benefits of gestured units over concrete object units in enhancing children's understanding of ruler measurement both at immediate test and over time.

Some ways gestures guide thought

Barbara Tversky[1], Azadeh Jamalian, Seokmin Kang

[1]Stanford University, Stanford, USA

Explanations are often accompanied by gestures that abstract and convey core ideas. In several experiments, participants viewed identically worded explanations accompanied by alternative forms of gestures with alternative consequences for knowledge acquisition, notably of action and of time. Participants who watched an explanation of a mechanical system that was accompanied by gestures conveying action included more action in their own visual and verbal explanations than participants who watched identical explanations accompanied by gestures conveying structure. Participants who heard descriptions of cyclical processes accompanied by circular gestures drew more circular diagrams than those who saw linear gestures; they also were more likely to go back to the first step when asked, what happens next? Appropriate gestures also affected choice of perspective on time and comprehension of simultaneity. Because they are actions, gestures seem to be especially effective at conveying change and actions in time.

LEARNING WITH AND ABOUT SPATIAL VISUALIZATION

Convenor: *David Uttal*

Spatial Intelligence and Learning Center, Department of Psychology, Northwestern University, Evanston, IL

Spatial visualizations, such as maps, models, drawings, charts, and computer animations, are pervasive in education and communication. In some cases, the excitement about the use of visualizations stems specifically from their spatial qualities; by making information visual, the hope is that we also make it tractable, and easy to understand. But the use of visualizations undergoes important developments, and visualizations only facilitate learning and thinking when the user understands both *what* the visualization is intended to represent and *how* the information in the visualization can be used. This symposium will explore the learning and development of the use of spatial visualizations in a variety of contexts and ages. Two talks will explore the development in young children of the ability to acquire spatial information from maps. The next two talks explore the influences of using spatial visualizations in learning to think about complex problem solving (e.g. in geoscience in high school and college students). The final talk explores the use of CogSketch (a sketching program for capturing people's spatial representations) in teaching.

Training spatial visualization with interactive animation and virtual models

Cheryl Ann Cohen, David Uttal

Spatial Intelligence and Learning Center, Department of Psychology, Northwestern University, Evanston, IL, USA

A growing body of evidence suggests that spatial abilities contribute to performance in science, technology, engineering, and mathematics (STEM) fields. One important spatial thinking skill that contributes to performance in many domains of mathematics and science is the ability to mentally represent the two-dimensional cross section of a three-dimensional object. We investigated the efficacy of a training protocol that uses interactive animation and virtual objects to train cross-sectioning skill. Our sample population consists of undergraduates who demonstrate low spatial thinking ability. In the training intervention, participants interact with an animation to discover the cross-sectional shape that is produced when a cutting plane intersects a geometric solid at an orthogonal or oblique cutting plane. Previous work suggests that this process leads to improved cross-sectioning skills. Here we compare post-intervention performance across three conditions: animation training without verbal instruction; animation training augmented by verbal instruction, and a control condition in which participants see static images of correct-cross sectional shapes, but do not interact with an animation. We also report on retention of cross-sectioning skill 1 week after training, and compare participants' performance on a multiple choice versus production (drawing) measure of the post-test instrument. We discuss the possible cognitive mechanisms involved in cross-sectioning, and suggest possible applications for this training intervention.

Sketching for learning: computer-based coaching of student-created visual representations

Kenneth D. Forbus, Maria Chang, Jon Wetzel

Northwestern University

Sketching is a natural way for people to communicate ideas and to think through situations. Thus it provides a natural modality for education. CogSketch, which is being created by the Spatial Intelligence and Learning Center, uses cognitive models of visual, spatial, analogical, and conceptual processing to facilitate building new kinds of sketch-based educational software. This talk will outline CogSketch, and describe two kinds of software we are building on top of it: *Sketch Worksheets* compare a student's work to an expert's solution, computing differences that are used to provide advice and evaluate grading rubrics. The second, *Design Coach*, is aimed at helping engineering students learn to communicate about their designs. Students describe their designs in terms of comic strips and a language-like interface. It uses qualitative reasoning to work through the consequences of a student's design, and provides feedback about any inconsistencies it finds.

Young children's learning and spatial relations: comparing maps and spatial language

Nina Simms, Dedre Gentner, David Uttal

Northwestern University; Spatial Intelligence and Learning Center (SILC)

Reasoning about spatial relations can be challenging for young children; therefore, finding ways to communicate spatial relational information to children is vital. Here, we explore two kinds of symbols that might help children understand spatial relations: *labels* and *maps*. Relational language can help children reason about spatial relations (Loewenstein and Gentner 2005). Maps also help children represent spatial relations (Uttal et al. 2006), but differ from labels in important ways (Davies and Uttal 2007). In particular, labels must convey multiple spatial relations *sequentially*, often encode only *qualitative* information, and are *arbitrary*, whereas maps convey multiple spatial relations *simultaneously*, encode *qualitative* and *quantitative* information, and are *iconic*. In the current study, we asked whether labels and maps, separately and in combination, could help preschoolers reason about a particularly challenging spatial relation: the *midpoint*. *Midpoint* is complex in that it encodes location relative to more than one entity, a characteristic that may make maps particularly well-suited to communicate about the *midpoint*. In this study, 2- and 3-year-olds played a challenging hiding-and-finding game: a hidden object was always located at the midpoint between two landmarks, but the positions of the landmarks changed on each trial. Consistent with prior findings, hearing a label during the task improved children's accuracy. Surprisingly, however, children's performance did not benefit from seeing a map. These results invite further exploration into the conditions under which maps are helpful to young children, and reinforce the role of language as a powerful tool for conveying spatial relational information.

Expanding spatial thinking via geospatial technologies within project-based curricula

Erin A. Wilkerson[1], Nathaniel G. Meadow[1], Robert A. Kolvoord[2], Annie Senior[1], Eleanor S. Tushman[1], David H. Uttal[1]

[1]Northwestern University; [2]James Madison University

Spatial thinking is of critical importance in the learning and practice of science.Spatial skills are strongly predictive of achievement, persistence, and attainment in STEM fields. In some fields, spatial ability contributes more unique variance than SAT scores to the prediction of STEM skills and achievement. This work aims to discover how geospatial technologies (e.g. GIS, GPS, remote sensing) function as a key component in secondary education, STEM and other learning. A vital objective is to assess the development of critical thinking skills that transfer to projects beyond the traditional classroom context. Using a mixed-methods approach we examine the evolution of students' spatial thinking skills via interviews with the students discussing their work on an unconventional semester-long class project. To test secondary students' improvement in spatial thinking we asked two analogous hypothetical questions. Both questions were spatial in nature and rich in potentially relevant data. In pre-test/post-test fashion; we asked one hypothetical question during the opening interview and the other during the closing interview. In response to the hypothetical questions, students' ability to provide spatially rich solutions, as measured by distinct relevant datasets discussed, increased two-fold from beginning to end of the class project. Furthermore, analysis of students' language in other interviews throughout the semester indicates a significant rise in the use of spatial terms over the course of the project. Future work is aimed at investigating the role of gesture in the development of these students' spatial skills.

The effect of analogy and relational language on preschooler's map learning

Lei Yuan, David Uttal, Dedre Gentner, Kelly Sheehan

Northwestern University

Map-reading ability is not only important in its own right, but also in relation to many other crucial cognitive capacities. Previous research have identified several important cognitive components involve in the process of map-reading (such as representational insight and relational correspondence). However it is not clear how these abilities unfold developmentally, and how they relate to each other. In the present study, we adopted a Structural-Mapping account on children's acquisition of map reading. In study 1, we tested the combining effect of analogy and relational language. Children in the experiment group received a training session based on analogy and relational language before testing, while control group did not. We presented children with two tasks (identical-item task and cross-mapping task) in which they needed to use a map to search for a hidden object in a scale model. Results indicated that children in the experiment group performed significantly better than children in the control condition on cross-mapping tasks, but not on identical-item tasks. In study 2, we gave children training based on either analogy or relational language. Results showed that children with the training of analogy outperformed their counterparts in the other group. In conclusion, our study found that analogy and relational language are effective in promoting map learning. Our data also suggests that analogy might be the primary driving factor in this process.

A PROBABILISTIC PERSPECTIVE ON UNERSTANDING SPATIAL INFORMATION PROCESSING IN THE MAMMALIAN BRAIN

Convenor: *Thomas Wolbers*

University of Edinburgh, Centre for Cognitive and Neural Systems

In virtually all everyday situations, we can compute spatial information from multiple sensory cues. For example, speed or direction of self-motion can be derived from external cues such as visual, haptic and auditory flow, in addition to body based cues provided by vestibular and proprioceptive feedback and by motor efference copies. However, such cues often vary in their reliability and can even provide disparate information. As a consequence, computing a

unified spatial signal from noisy and conflicting sensory inputs is a key computational problem that the mammalian brain needs to solve when dealing with spatial information. In this symposium, we will discuss recent empirical and theoretical findings that have begun to unravel the computational principles underlying multisensory integration of spatial cues. The symposium will adopt an interdisciplinary approach to address this complex issue, with the speakers bridging the gap between animal electrophysiology (Angelaki), theoretical neuroscience (Beck), developmental psychology (Nardini) and functional neuroimaging (Wolbers). We will demonstrate how taking a probabilistic perspective has made it possible to understand more precisely how neuronal circuits represent different types of spatial information and how these are integrated to guide spatial decisions. These findings will be of broad interest to the diverse audience of this conference, with implications for understanding navigation, multisensory processing, embodied cognition and rehabilitation.

From neurons to behavior in self-motion perception: merging theoretical and empirical approaches in a multisensory paradigm

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All animals that navigate through their environment need to estimate their direction of self-motion, or heading. Like much of spatial cognition, heading perception is an inherently multisensory task, involving a variety of visual (e.g., optic flow) and nonvisual (e.g., vestibular) cues. We trained rhesus monkeys to perform a heading discrimination task from visual and vestibular cues delivered by a virtual-reality apparatus. Consistent with the standard model of statistically optimal (i.e., Bayesian or maximum-likelihood) cue integration, we found that monkeys combine these cues nearly optimally, weighting them in proportion to their reliability and improving their discrimination performance—the first such demonstration in nonhumans. During the task, we recorded from neurons in cortical area MSTd, an area known to receive visual and vestibular signals relevant for self-motion. Single-neuron analyses and population decoding methods revealed robust neural correlates of cue integration behaviour, including increased sensitivity under cue combination and a manifestation of trial-by-trial cue reweighting with changes in reliability. We also found that the mathematical combination rule employed by MSTd neurons, previously thought to be at odds with theoretical predictions, is in fact broadly consistent with optimal probabilistic computation when accounting for the observed tuning properties. In parallel, we developed a general model of multisensory integration that predicts the near-optimal MSTd combination rule, as well as many classic findings in the multisensory literature, by exploiting a canonical neural computation known as divisive normalization. Taken together, these studies provide unprecedented leverage for unifying modern theoretical findings with the traditional empirical principles of multisensory integration.

Probabilistic neural theories of multisensory integration

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Behavioral and psychophysical experiments consistently show that humans and animals perform near-optimal Bayesian inference in a wide variety of domains, ranging from low level perceptual/motor tasks to high level cognitive tasks. This implies that (1) neural activity must represent probability distribution functions over task relevant stimuli rather than just values of stimuli and (2) neural circuits must (at least approximately) implement the operations of probabilistic inference. The linear probabilistic population coding framework provides a single coherent scheme by which this can be accomplished. Previous applications of this approach have largely focused on simple situations for which probabilistic inference is tractable. To address this short coming, I will consider the problem faced by the nervous system in its most general form: namely the identification of latent causes of complex patterns of sensory input (sensory spikes) from multiple modalities. First, I will show that this problem can be mapped onto the problem of document classification via Latent Dirichlet Allocation. I will then demonstrate that a particular approximate probabilistic inference algorithm (variational Bayesian inference) applied to this problem can be naturally mapped onto the operations of a single layer of recurrently connected neurons which represent the approximate posterior distribution over latent causes using a linear probabilistic population code. Additionally, I will show that (1) this neural implementation requires a specific nonlinearity known as divisive normalization which is found in all neural circuits and (2) that the probabilistic learning of model parameters can be done via a simple variation of Hebb's rule.

Bayesian integration of spatial information in development

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Developing sensory systems must learn correspondences between different sources of spatial information (e.g. those from vision and those from the vestibular system), and rules for combining these for adaptive behaviour. Bayesian cue integration via weighted averaging is a combination rule that minimises the variability of estimates and is consistent with humans' behaviour in many sensory-motor tasks. The present studies investigated whether humans find Bayesian solutions to spatial tasks, and how these abilities emerge in childhood. In a navigation study, 4- to 8-year-olds and adults had use of visual and vestibular information to navigate back to a location after a short interval. In a pointing study, 4- to 12-year-olds and adults had use of vision and proprioception to localise their hand on a table-top. Further studies investigated computation of gains in a rewarded task in which participants needed to combine information about their own visuomotor uncertainty with information about reward structure. Human adults did find Bayesian solutions to these kinds of spatial problems, but children did not do so until age 8 years or later. Younger children used single (rather than combined) estimates, or combined estimates

using sub-optimal weights. These results suggest that multisensory perception, action and decision networks underlying spatial behaviour are not optimised for variance reduction until late in childhood. These networks may need significant time and experience to learn optimal combination rules. It is also possible that developing sensory systems are optimised for goals other than variance reduction.

Heading computations in the human brain—insights from psychophysics and functional neuroimaging

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Locomotion, obstacle avoidance and goal-directed navigation critically depend on our ability to monitor the direction in which we are moving. In non-human primates, areas MST and VIP are known to compute the direction of self-motion from a variety of cues, including optic flow and vestibular cues. Critically, neuronal populations take the reliabilities of different cue types into account, which is suggestive of Bayes optimal neural computations. In the present set of experiments, we investigated how humans integrate visual and auditory cues to determine the direction of self-motion. Using naturalistic sounds and optic flow arising from a ground plane presented in 3D, we show that human observers take the reliabilities of both cues into account when multiple cues are available, thereby reducing the variance of their directional estimates. In a subsequent fMRI experiment, we then demonstrate the multisensory properties of several cortical areas implicated in self-motion processing, and we use effective connectivity analyses to identify changes in connectivity strengths that accompany a dynamic reweighting of visual and auditory cues. Finally, multivariate pattern classification reveals how different areas implicated in self-motion processing contribute to behavioural performance. Taken together, these experiments begin to elucidate how the human brain deals with multiple sensory cues to compute a key spatial primitive necessary for a variety of spatial behaviours. Our results fit well with a number of recent studies that have demonstrated Bayes optimal computations in various neuronal circuits, which suggest that Bayesian integration maybe a canonical operation of the mammalian nervous system.