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Oral presentations

Nodding in (dis-) agreement: a tale of two cultures

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Head movement is commonly used in communication to express a positive vs. negative response. However, whereas in US culture vertical head movement is associated with positivity (nodding to say "yes") and horizontal head movement is associated with negativity (shaking heads to say "no"), in Bulgaria the traditional response pattern is reversed, i.e., horizontal head movement means "yes" and vertical head movement means "no." Thus agreement is "embodied" spatially via different movement directions across these two cultures. We examined the effect of such cultural differences on cognitive processing that has no communicative value by comparing ratings of color likeability, brightness, and positive feeling associated with different color dots moving across a screen in a 2 (direction: vertical vs. horizontal) by 2 (speed: fast vs. slow) design. Participants followed the movement of the dots with their heads going up and down or left and right. We found a three-way country by speed by direction of movement interaction in ratings for how good colors made participants feel. Bulgarian participants rated as better mood inducers colors perceived in combination with slower head movements irrespective of direction of movement. US participants, on the other hand, rated as better mood enhancing color dots observed in combination with fast vertical head movement than otherwise. There was also a two-way interaction between country and movement speed for ratings of likeability but none for ratings of color brightness. Findings will be discussed in terms of variability in gestural meaning and culture-specific embodiment patterns.

Eye-movements and bisection behavior in spatial neglect syndrome. Representational biases induced by the segment length and spatial dislocation of the stimulus

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Systematic spatial biases in the visually guided actions were observed for patients with right hemisphere damage. Neglect patients generally show an inability to take into account information coming from the left side of space. Typical symptoms of neglect are rightward errors in line bisection and left-side deficits in visual search task. The present study explored behavioral and eye-movement measures in spatial unilateral neglect in response to an online bisection task. Bisection stimuli were horizontal gaps represented by two red spheres, one to either side of the midline, that were presented, after a fixation point, on a white background. The experimental subjects (patients N = 10; control N = 10) could give their response pointing the perceived midpoint starting from stimuli onset. Eye-movement (total number of fixations, fixation length and direction of the first fixation) and bisection responses were considered. Consistent spatial biases were found for patients in comparison with controls (mixed repeated measure ANOVA) for both bisection position and fixations as a function of segment length (from shorter to longer) and segment spatial dislocation (from right to left spatial dislocation). The eccentric left-position induced a greater rightward bias in patients, with increasing more rightside bisection and visual right-directed fixation. Contrarily, segment length produced significant differences between-groups only for eye movement behavior, with increased fixation count and duration rightward oriented in response to longer segment. Nevertheless, the left-to-right and longer-to-shorter "continuous-gradient effect" was not totally supported by our results, whereas an "extreme left-gradient effect" was suggested and discussed.

Urban growth morphology analysis in response to the sonic character

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This paper explores the sonic characteristics of urban spaces, with the application of apprehending space and form theory. The theory defines auditory spaces as acoustical arenas, which are spaces defined and delineated by sonic events. Behavioral response to sounds within public spaces and its simulation is a relatively untapped research within urban design. It will be beneficial to the field to observe the evolution of urban morphology in response to soundmarks. Historically, cities were built around a soundmark, for example, the resonance of a church bell or propagation of a calling for prayer, or a factory horn. Anyone living beyond the horizon of this soundmark, was not considered citizens of that town. Furthermore, the volume of urban sonic arenas depends on natural parameters; such as the geomorphology and the macro climate of the area. Geological formations can act as sound barriers or sound conduits, steep terrain would cast large sound shadows, while valleys propagate a target sound across large distances. Digital simulation is necessary to visualize the ephemeral and temporal nature of sound, within a dynamic immersive environment like urban spaces. This paper digitally analyses the different morphologies of old cities and forms of growth in relation to the sound propagation and ecological effects. An experiment is conducted with the aid of an ancient north African city model, exposed to a point cloud agent system. By analyzing how the sound propagates

from the known soundmark through the urban fabric, with the wind trajectory interference; the paper compares the theoretical concept of soundmarks and the known perimeter of the ancient city.

Bayesian optimal cue integration is preserved in old age

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During navigation, humans integrate information from different sensory modalities in a statistically optimal fashion. Specifically, the influence of a given cue on navigational behaviour depends on its perceived reliability, a Bayesian optimisation that minimises response variance. During healthy aging, navigation based on single cues (such as visual) becomes less accurate; however, it is unknown whether there is also a decline in cross-modal integration of cues. To address this important issue, 26 young and 20 old participants completed a simple homing task in a darkened environment, illuminated by LED landmarks. Participants visited 3 locations (outbound) before returning to the first (rebound) as accurately as possible. Four conditions were completed, two single cued (landmarks only available, self-motion only available), one where both cues were available (to verify participants benefited from having multiple cues available) and a conflict condition, in which landmarks were covertly rotated by 15° after the outbound but before rebound to assess integration behaviour. In support of previous findings, old participants performed significantly worse overall, across all conditions. Most importantly, however, in the conflict condition, both groups weighted landmarks and self-motion cues according to their reliabilities, with a slightly higher weighting on landmarks (old: 0.58, young: 0.60). As these results closely matched the predictions of a Bayesian optimal integration model, we conclude that (i) age-related decline in navigation is predominantly caused by an overall decline in computing and storing spatial information from navigational cues, but (ii) that cross-modal cue integration continues to follow statistically optimal principles in old age.

4 year olds localize tactile stimuli using an external frame of reference

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Adults show a deficit in their ability to localize tactile stimuli to their hands when their arms are in the less familiar, crossed posture. It is thought that this "crossed-hands effect" arises due to conflict (when the hands are crossed) between the anatomical and external frames of reference within which touches can be perceived. Previous research has studied this effect, with a temporal order judgement (TOJ) task, in young children and observed that the crossed-hands effect first emerges after 5.5-years. In the TOJ task, children are asked to judge the temporal order of stimuli presented across their hands in quick succession. Here, we present the findings of a simpler task in which 4-6-year-olds were asked to localize a single vibrotactile stimulus presented to either hand. We also compared the effect of posture under conditions in which children either did, or did not, have visual information about current hand posture. With this method, the older children (5-year-olds and 6-year-olds) performed close to ceiling in both posture conditions. However, we observed a crossed-hands effect in the youngest age-group testable; 4-year-olds. We conclude that young children localize tactile stimuli with respect to an external frame of reference from early in childhood or before. Additionally, when visual information about posture was made available, 4-year-olds' tactile localization accuracy in the uncrossed-hands posture deteriorated and the crossed-hands effect disappeared. We discuss these findings with respect to visual-tactile-proprioceptive integration abilities of young children and examine potential sources of the discrepancies between our findings and those using the TOJ task.

Visual Attention in spatial language comprehension

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It is well established that the understanding of spatial descriptions involves attentional mechanisms, but how precisely people deploy *visual* attention during spatial language processing is unclear. Situated language comprehension accounts assume that when people hear *A is above B* while inspecting a matching picture, they first fixate A as it is mentioned, and then begin to fixate B upon hearing 'above'. Models of spatial language apprehension, by contrast, posit a reverse shift of attention from B to A is necessary to understand the spatial relationship. In three eye-tracking experiments (each $N = 32$) we monitored participants' visual attention to objects during comprehension of German descriptions such as *Die Uhr ist über dem Rahmen* ('The clock is above the frame'). To also assess robustness of any effects across tasks, we asked participants to verify (post-sentence in experiment 1 and speeded in experiment 2) whether the sentence matched (vs. didn't match) the picture, or to passively listen to the sentence during scene inspection (experiment 3). Participants fixated the frame (vs. the clock) more often shortly after hearing 'above' in all three studies, corroborating predictions of situated language processing accounts. After inspecting the frame, however, people next inspected the clock in all three studies, thus corroborating models of spatial language apprehension. The results highlight the invariance of at least some gaze pattern across different verification and passive listening tasks. Accommodating them requires further mechanisms from both accounts, as well as refined linking hypotheses between sub-processes of comprehension (e.g., computing spatial relationships) and eye gaze measures.

Hyperbole, abstract motion and spatial knowledge: sequential vs. simultaneous scanning

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Hyperbole represents an interesting trope in the light of Lausberg's definition (1969), based on spatial categories, its link to imagery, its co-occurrence with non-literal expressions (Gibbs 1992, Nemesi 2004, Norrick 2004, Cano Mora 2009). Within the framework of cognitive rhetoric (Sperber 1975), we analyze hyperbole in terms of "abstract motion" (Langacker 1990). We show some results of a reading-comprehension experiment focused on hyperboles expressed through verbs of movement (Italian corpora data are shown, see Claridge 2011). Parameters are: idiomatic/non-idiomatic hyperbole (e.g. salire alle stelle 'to skyrocket'/crollare 'to collapse'); image-schemas (Johnson

1987). We hypothesize that hyperboles based on SOURCE-PATH-GOAL schemas are processed through a simultaneous scanning, while hyperboles based on PATH schemas are processed through a sequential scanning. Results can lead to applications aimed to verify the existence of neural correlates of different configurations of spatial knowledge (Holmqvist & Płuciennik 2004). Presently, neurolinguistic analysis show results on: the semantic-pragmatic processing of literal vs. figurative expressions (Rapp 2011, Bambini 2011); the correlation semantic difficulty/neural activity (Sharp 2010) and neural activation/content-specific processes (Ferstl 2005); the supra-modal nature of spatial imagery in abstract mental representation (Struiksma 2009, Simmons 2008); the cognitive advantage of constructions (Goldberg 2012); the fact that bilateral activation of the angular gyrus and language areas appear specific to the mental scanning of topographic representation built from texts (Mellet 2002). On the ground of such data, we outline a neurolinguistic experimental design. Parameters can be used in fMRI testing to verify whether different patterns of activations are correlated to the processing of different hyperboles.

Categorical and coordinate spatial relations of object processing in deaf signing adults

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This work investigates how manual or vocal language modalities and hearing status affect the specialization of development of hemisphere preferences for spatial relation representations of object processing. In normal hearing adults, the brain computes at least two kinds of spatial relation representations (Kosslyn, 1987). The categorical spatial relation representation is used to assign a spatial relation to a category (e.g., an equivalence class such as above, below) whereas the coordinate representation is used to represent the precise distance and location in a metric coordinate system (e.g., metric spatial properties). It is suggested that the left hemisphere (LH) makes more effective use of categorical representation and the right hemisphere (RH) makes more effective use of coordinate. In this study, 17 native signing deaf adults and control group of 19 non-signing hearing individuals were tested using a same/different matching task on categorical and coordinate representations of object processing using stimuli adapted from Laeng and Peters (1995). In addition, a spatial short-term memory task and a non-verbal reasoning task were administered to all participants (Corsi test and Raven's Standard Progressive Matrices) to control for the ability of the two groups. Whilst the hearing participants displayed the typical suggested pattern; the deaf participants evidenced a LH preference for the categorical representations but no preference for the coordinate spatial relation representation. Discussion will follow on the role of experience of early onset of deafness and sign language use in visual cognition.

The nature of the beneficial role of spontaneous gesture in spatial problem solving

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Spontaneous gestures play an important role in spatial problem solving. We investigated the functional role and underlying mechanism of spontaneous gestures in spatial problem solving. In Experiment 1, 132 participants were required to solve a mental rotation task (see Figure 1) without speaking. Participants gestured more frequently in difficult trials than in easy trials. In Experiment 2, 66 new participants were given two identical sets of mental rotation tasks problems, as the one used in Experiment 1. Participants who were encouraged to gesture in the first set of mental rotation task problemssolved more problems correctly than those who were allowed to gesture or those who were prohibited from gesturing both in the first set and in the second set in which all participants were prohibited from gesturing. The gestures produced by the gesture-encouraged group and the gesture-allowed group were not qualitatively different. In Experiment 3, 32 new participants were first given a set of mental rotation problems and then a second set of non-gesturing paper folding problems. The gesture-encouraged group solved more problems correctly in the first set of mental rotation problems and the second set of non-gesturing paper folding problems. We concluded that gesture improves spatial problem solving. Furthermore, gesture has a lasting beneficial effect even when gesture is not available and the beneficial effect is problem-general.We suggested that gesture enhances spatial problem solving by provide a rich sensori-motor representation of the physical world and pick up information that is less readily available to visuo-spatial processes.

Modal preferences in creative problem solving

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Embodied cognitive science appeals to the idea that cognition depends on the body as well as the brain. This study looks at whether we are more likely to engage just the brain or enlist the body for complex cognitive functioning such as creative problem solving. Participants were presented with a puzzle based on De Bono's lateral thinking puzzles. The puzzle consisted of rotating and joining two-dimensional shapes to make a three dimensional one. In one condition participants were given the choice of either solving the puzzle mentally or through manipulation of the images on a computer screen. In another condition the subjects had to solve the puzzle first mentally and then report which mode they would have preferred to solve the puzzle. In all conditions an overwhelming majority of participants chose to solve the puzzle by manipulation, even though there was not a significant increase on performance. It appeared that participants were making a conscious choice for the body to play a feedback-driven role in creative cognitive processing. This strong preference for manual manipulation over mental representation, regardless of the impact on performance, would seem to suggest that it is our natural tendency to involve the body in complex cognitive functioning. This would support the theory that cognition may be more than just a neural process, that it is a dynamic interplay between body, brain and world. The experiential feedback of the body moving through space and time may be an inherently important factor in creative cognition.

Affordance effects in the absence of the intention to act on seen objects

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There now exists an impressive experimental literature that suggests that when viewing objects, the actions that may be performed with them are

potentiated in the observer. More recent work has used Event Related Potentials (ERPs) to study the timing of the neural events underpinning these effects and variously found action effects from 75-250 ms after stimulus onset. However, the overwhelming majority of these data have been collected from tasks in which the participant is preparing a response to every stimulus. The present research takes a novel approach to the question of object affordances by asking whether this preparation of a response is a necessary prerequisite to the generation of an affordance effect. ERPs were recorded during a go, no-go task using stimuli with left and right facing handles that are known to elicit lateralised affordance responses. Instead of a lateralised manual response, participants made a vocal (i.e. non-lateralised) response when they saw a kitchen utensil (50 % of trials) and made no response to tool items (50 % of trials). Equivalent responses were observed for go and no-go trials, with early significant effects of object affordance from 125-175 ms ($F(1,33) = 4.130$, $p = 0.05$) and150-200 ms ($F(1,33) = 7.600$, $p = 0.009$). These results are analogous with those from previous research that involved response preparation to every stimulus, refuting the idea that the preparation of a motor response is necessary to elicit a motor affordance effect, suggesting that affordance processes represent an automatic link between processing in visual and motor areas.

Spatial memory exclusivity: investigating the effect of semantics and distinctiveness on location memory integration

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Memory for spatial information is often fragmented or error prone. For instance, recent work shows that under certain conditions multiple spatial memories for a given target object do not benefit the accuracy of a subject's location memory. It is argued that this 'exclusivity effect' is the result of an inability to combine or integrate independent spatial memories. The current research sought to overcome such exclusivity by 1) manipulating the semantic connection between spatial memories and 2) increasing the distinctiveness across pairs of spatial memories. Additionally, it explored whether subjects' memory of a target's location was a function of their memory for its content. The dependent variable was location accuracy. The independent variables were *number of anchor points* (single vs. paired), which offered a test of exclusivity; *semantic connection between memories* (manipulated by using familiar vs. non-familiar pairs of anchor points); and *memory distinctiveness* (achieved by having matching vs. non-matching semantic content of target/anchor sets). Results revealed the continued presence of exclusivity under both manipulations. Additional analyses showed a trade-off between recalling the content of a target and the location of a target, particularly under circumstances of heavy cognitive load. Together these results suggest the previously evidenced exclusivity effect arose not from any stimuli-specific characteristic, but from structural characteristics of the human spatial memory system itself.

The exploration of relational models within urban morphogenesis

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With the urbanisation of cities, we have witnessed the separation of distinct areas as singular classifications through zoning with a similar logic applied to building volumes. Infrastructure systems are further used to divide and separate these zones. This model of city organisation has been frequently criticized as a failure for a variety of reasons that include poor planning and brutal and oppressive mode of urbanisation. As a result, the human perception of space has altered tremendously, from anamorphic state (between building and street) that varied according to local (climatic and societal) factors, to the repetition of monotonous buildings along today's ubiquitous urban grid. The grid acts as the dominant pattern for most modern cities. This has removed the intimate spatial experience that existed between a society and the city. While digital tools allow the embodiment of space and its cognitive experience (i.e. depicting how one experiences space through animation and renderings), they have not been able to reinstate the amorphic quality that existed in cities of the past. The paper explores how the introduction of relational models and systematic methodologies (i.e. mathematical models) during the design phase can begin to reinstate amorphic qualities through local morphologies (variation of buildings on a local level). As a result, generated city morphologies seek to enhance ourspatial cognition (our ability to recognize information and data, based on our perception and experience within a specific spatial environment).

The language of landmarks: the role of background knowledge in indoor wayfinding

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Most empirical studies about human indoor navigation have concentrated on immovable structures (e.g., the geometrical structure of the building, influence of lighting). In order to effectively navigate through unknown environments, humans do rely on strategies based onthese immovable structures, but they can also infer information about their position and the relative position of their target by interpreting movable structures(object-like landmarks like furniture) relying on background knowledge gained from former navigation experience in similar environments. Results of our first empirical study, a questionnaire ($N = 25$), indicate that participants have background knowledge of the relative position of the target locations tested (auditorium, broom closet, main entrance/exit, restroom, server room), and that specific landmarks are considered as indicative for their position within the environment. In this context, objects like a notice board or artwork are interpreted semantically, with respect to their possible function in the building and their likely spatial relation to specific types of target locations. For the different targets, landmarks differed significantly with respect to their function as markers (i.e., objects with a high indicator function), and neutrals, (objects with no unique identification). We tested these findings in a forced choice navigation task ($N = 62$) in a virtual environment. This procedure revealed an interaction between the spatial landmark classification and strategies based on geometrical layout. This indicates that background knowledge plays a major role for efficient wayfinding, and modifies strategies well known from previous work in the field.

Effects of manual experience on 4- to 11-month-olds' mental object rotation

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In this study, effects of manual experience on infants' ability to mentally rotate objects were investigated using the violation-of-

expectation paradigm. Four- to 11-month-olds watched an asymmetric object being moved straight down behind an occluder. When the occluder was lowered, it revealed the original object (possible event) or its mirror image (impossible event) in one of five orientations. It was varied between infants what kind of information they were allowed to gather about the object prior to this mental rotation task. In Experiment 1, 6-month-olds were either allowed to touch the asymmetric object while an experimenter moved it in front of them (manual exploration condition), or they were only allowed to observe the same object movement (observation condition). Results showed that 6-month-olds looked significantly longer at the mirror image in the 'manual exploration' condition, suggesting that they were able to mentally rotate the object. In contrast, 6-month-olds in the 'observation' condition did not discriminate between the images. Experiment 2 showed that without prior manual exploration of the object, it was not until 10 to 11 months of age that infants looked longer at the mirror image. Experiment 3 showed that even after manual exploration of the object, 4-month-olds were not able to discriminate between the images. Results demonstrate that manual exploration facilitates infants' mental rotation abilities, allowing them to discriminate the rotated images about 4 months earlier than without prior manual experience with the object. Our findings highlight the importance of motor experience for cognitive performance.

Empathy in aesthetic experience: from *Einfühlung* to simulation in perception of still works of visual art

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The present literature review reflects an attempt to collect interdisciplinary references and apply the idea of embodied cognition to visual perception and in particular to perception of still visual artworks. This approach stems from the possibilty to revive the original concept of Einfühlung in light of the research development of the recent years. It focuses mainly on two distinct areas: psychological and aesthetic, both philosophical and empirical. In particular, the first includes research on empathy, imitation and embodied simulation. The latter refers to various theories of empathetic response to a work of art. The concept of Einfühlung is discussed in context of motor theories of empathy and perception that create the foundation for "feeling into" the content and form related properties of a painting. The reviewed literature provides a frame of reference to study the aesthetic experience not only as a purely cognitive perceptual event, but as a complex psychophysiological reaction.

Influence of numerical magnitudes on the free choice of an object position

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In the last years the link between numerical magnitude and mechanisms of spatial orienting has been underlined in an increasing number of studies. Similarly, the relationship between numerical magnitude and grasping actions started to be investigated. The present study focused on the influence of numerical magnitude processing in the free choice of the position of an object. Participants were presented with a digit (ranging between 1 to 9) on a computer screen and were required to decide whether it was smaller or larger than 5. Then they were to grasp a small cube and change its position before vocally responding "higher" or "lower". Results showed that in the initial phase of the grasp movement the grip aperture (i.e., the distance between the thumb and the index finger) was modulated by the numerical magnitude, as a larger grip aperture was observed during the larger digits condition compared to the smaller digits one. Moreover, participants systematically shifted the position of the cube more leftward with smaller digits compared to larger ones. A tendency was observed for the vertical axis as well: participants tended to shift the object closer to themselves with smaller digits compared to larger ones. These results extend previous findings indicating that the processing of magnitude is tightly related to the mechanisms of spatial orienting that subserve action execution.

Bottom-up effect of prism adaptation on hemineglect in virtual spatial domain

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Unilateral neglect is a disabling syndrome due to right hemisphere brain damage. Prism adaptation (PA) has been used to improve several aspects of unilateral neglect. Parameters ranging from the classical neuropsychological tests to mental imagery or to others sensory modalities have been successfully ameliorated following a brief period of adaptation to wedge prisms shifting the visual field to the right. The aim of the study was to assess whether the beneficial 'bottom-up' effects of PA may generalize to a virtual spatial domain. Four right brain-damaged patients with a left chronic neglect were included. After-effect of PA was assessed by measure of straight-ahead pointing movements in darkness. Cognitive effects were assessed by neuropsychological tests and by a virtual reality task: the patient had to explore a virtual supermarket (VAP-S) and to catch eight objects located on the right or left sides. For this task, two parameters were measured: a lateralization index (LI) of the objects taking, and the drawing from memory of the supermarket plan. For each patient, experimental procedure included 2 pre-tests, ten PA sessions during 2 weeks, and 4 post-tests immediately, 3, 7 and 30 days after PA. The results show a significant after-effect directed toward the left side associated to significant improvement of neglect and significant modification of LI for objects in the virtual reality task

after PA. Moreover, a significant improvement of the drawing from memory of virtual supermarket plan is observed, suggesting an enhancement of the visuo-graphic, topographic and semantic aspects of spatial representation after PA.

The effect of aging on route memorization

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When we follow a route in an unknown city, we build a mental representation of the environment, which is stored in long-term memory and could be used later in different kind of tasks like recognizing the place, redoing the route, or drawing a map. In this experiment, we focus on the cognitive resources that are used to build and then manipulate that mental representation, and the effect of aging on the spatial representation. Previous research has demonstrated age-related decline in the use of spatial representation, but the spatial representation is complex and requires the integration of many components that may show differential susceptibility to aging. Different tasks were used to assess the effect of aging on different components of the spatial representation. The video of an unfamiliar route in a city near Paris was projected to the young and older participants twice. After the presentation, four tasks were used to assess the mental representation of the participants (visual recognition task, direction decision task, order decision task, and statement verification). Different tests were used to identify the factors that explain individual differences in the performance. The results show that older adults have poorer performance than younger adults in the 4 tasks. Analyses of mediation show that the effect of aging on visual recognition task would be explained by the impairment of episodic memory. Moreover, the effect of aging on the direction task would be explained by the impairment of working memory.

Relationship between numerical abilities and spatial cognition in preschool children

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A large body of evidence indicates the association between the representations of space and numerical abilities in healthy and brain-damaged adults. Most of the results derived from those studies, investigating the representation of mental number line (the numbers are initially represented on a continuous left-to-right-oriented line). But only few developmental studies investigated how numerosity is extracted from a visual-spatial display in early ages. The aim of present study was to investigate the development of spatial-numeric associations before children begin school. We examined the directional biases in how children (3-, 4- and 5-year olds) used numeric information on a spatial task before formal reading practice and schooling. Using manual non-directional bisection paradigm children were asked to indicate the midpoint of a horizontally displayed line flanked by two dot arrays differing in numerosity. The visuo-spatial properties of the flanker varied across the four conditions (equal total surface, different total surface, well-defined contour, structured arrays of the dots). The results showed that children in each age group displayed bias in their line bisection, choosing a midpoint that is closer to the larger numerosity. However, children tend to show bias toward the larger numerosity in those conditions where the total surface of the flanker was unequal. The results indicate that spatial-numeric associations emerge long before children begin reading. This ability might be modulated by embodied visuo-motor activity such as counting routine with fingers.

Older people exhibit a specific deficit in navigational strategy switching

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Navigation abilities are among those most severely affected by dementia and ageing. While impairments in individual component processes supported by the medial temporal lobe (e.g. cognitive mapping) account for some of the effects of ageing on navigation, the ability to switch between different navigational strategies may also contribute. Strategy switching is mediated by the medial prefrontal cortex and the locus coeruleus noradrenaline (LCNA) system, which has been shown to degrade in ageing. We investigated navigational strategy switching in younger (18-30) and older (60-80) people using a virtual plus maze (VPM). This task involves finding a reward based on either an allocentric place strategy or an egocentric response strategy. Periodically, the required strategy changes (switch), or the rewarded place or response changes (reversal). Animal work has demonstrated that LCNA dysfunction impairs switch but not reversal learning. Similarly, we found that while all participants were able to learn reversals, many older participants (but only one younger participant) were unable to learn switches. Furthermore, of those who were able to learn switches, older participants took significantly longer to do so than younger participants, despite learning reversals as quickly. We also computed a switch-reversal difference score for each participant, which was significantly higher for the older group. Our findings indicate that a specific strategy switching deficit does contribute to age-related navigation impairments, and this implicates degeneration of the LCNA system. We are currently further exploring the LCNA system's involvement by measuring physiological correlates of LCNA activity during strategy switching in young and old people.

Behavioral, EEG and fMRI investigations of number-space interactions: when numbers act as attentional cues

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Behavioral studies indicate that there is a relation between numbers and space (DeHevia et al., 2008). To date, however, no studies investigated

whether the facilitation observed in target detection tasks using number cues (Fischer et al., 2003) is followed by inhibition of return (IOR) at longer intervals, as could be expected with visuo-spatial attention shifts. Moreover there are currently no fMRI studies on the neuronal correlates of attentional shifts induced by irrelevant numbers. To address these issues we designed a behavioral study to assess attentional facilitation/inhibition by using six cue-target intervals (100-1250 ms). We show that digits not only produce facilitation effects at shorter intervals, but also induce inhibitory effects at longer intervals. We also implemented a slow event-related fMRI paradigm and an EEG study to investigate the neuronal correlates of visuo-spatial attention cueing induced by Arabic numerals. In both studies participants performed a lateral color discrimination task (red/green) that was preceded by a brief irrelevant and centrally presented digit (i.e. 1, 2, 8, 9). Our results indicate a number magnitude-target side congruency effect in occipital regions of interest (ROIs) and a magnitude effect in parietal ROIs. The EEG study reveals early visual (P1 target-locked amplitude modulations over occipito-parietal electrodes) and parieto-frontal (ADAN and EDAN cue-locked amplitude modulations) attention effects. We propose and discuss the view that automatic encoding of semantic representations related to number symbols in parietal cortex lead to shifts in visuo-spatial attention and enhanced visual processing in the occipital cortex according to number-space congruency rules.

Processing motion implied in language: eye-movement differences during aspect comprehension

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A powerful property of language is being able to talk about objects, motion, and action without those referents directly in the visual field. Differences in abstract linguistic properties may have detectable effects on sensorimotor processes that are intimately tied to narrative comprehension. One such property is linguistic aspect, which provides information about how events unfold in time. This study found distributional differences and differences in average fixation duration in two aspectual conditions. The imperfective aspect condition (focus on the ongoing nature of events) included sentences such as, "John *was opening* boxes." The perfective aspect condition (focus on completion or endpoint of events) included sentences like "John *opened* boxes." Results indicated that imperfective sentences elicited short, fleeting fixations in a wider spatial distribution throughout the visual field, as though the linguistic emphasis on ongoing action activated sensorimotor processes associated with actually perceiving ongoing action. Average fixation durations for imperfective sentences were 170 ms shorter than those for perfective sentences ($p < .01$). The patterns of eye movements were also found to be more widely dispersed over the screen in the imperfective condition. The same pattern emerged when analyzing only a fixed duration two-second silence period between sentences, indicating this is not an artifact of the slightly longer duration of imperfective sentences. We suggest that when aspect places emphasis on the continuous unfolding of an event versus the completedness of an event, efferent motor signals carry this information as revealed in the distribution and timing of eye movements.

Gestures for spatial reasoning

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Can our own gestures help us reason, and if so, how? Gesturing helps word-finding, but reasoning is more than finding words and not necessarily verbal. Here we investigate spontaneous use of gestures in spatial reasoning. Because gestures are actions in space, they have the potential to represent mental actions in space, actions that create spatial structures. Previous research has shown that performing purely spatial tasks, notably mental rotation, is often accompanied by analogous actions of the hand. Will people spontaneously use a coordinated set of gestures to represent spatial structures as well as spatial actions? Will those gestures map the spatial structure isomorphically? Will the perspective of the description affect the kinds of gestures participants use? Will participants use gestures both to comprehend spatial descriptions and to answer questions about them? Will gesture use depend on spatial ability? Will gesture use be associated with better performance? Forty-eight participants alone in a room studied descriptions of four environments from route or survey perspectives. Mental rotation ability was assessed. Participants were later tested on their direct and inferred knowledge of the environments. The majority of participants gestured while reading the descriptions and many gestured while answering questions, using simple gestures, primarily points and tracings, to lay out the spatial structure described by the text. The nature of the gestures and the relationship of the gestures to spatial ability and to performance will be discussed in detail. The implications of the findings for embodied thought will be analyzed.

Hands that think, eyes that feel, minds that see: integrating visual art and academic learning for disadvantaged students

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Visuo-spatial thinking forms the basis for learning across academic subject areas. Rich visual arts instruction can be shown to cultivate thinking strategies which enhance student academic achievement. *Framing Student Success: Connecting Rigorous Visual Arts, Math and Literacy, is* a project conceived by Studio in a School and funded by the U.S. Department of Education. Following the same students from third through fifth grade, the *FSS* study investigates the impact of targeted high quality visual arts instruction for students' math and literacy skills in underachieving urban schools. To make transfer happen, it is vital to have the connections be both deep and explicit, a key feature of this project. For example, in one unit students used paper to construct three dimensional solids for abstract sculptures inspired by modernists such as Anthony Caro and David Smith. Children learned to relate two and three dimensional forms, and the characteristics of basic Euclidean solids, while at the same time

grasping the multiple meanings of abstract art. Through imbuing their sculptures with metaphorical and expressive significance, the underlying mathematics seems to have been much more thoroughly internalized. Standardized test results have confirmed that integration of visual arts with elementary core curriculum has, indeed, had an impact on their students' academic success. In a randomized, control study, students in treatment schools have scored higher on standardized math and literacy tests than students in control schools.

When up-words meet down-sentences: evidence for word- or sentence-based compatibility effects?

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Processing words (targets) referring to entities with a typical location up or down in the visual field (e.g., 'roof' vs. 'root') and a subsequent key-response up or down show compatibility effects between targets and response (Lachmair, Dudschig, de Filippis, de la Vega, & Kaup, 2011). A plausible explanation is that interacting with the world leaves multimodal experiential traces in the brain. When later people process words, the corresponding traces are re-activated. This provides the possibility for an interaction between task-relevant subsystems. What happens when these targets are embedded in sentences? Does the same compatibility effect occur, and if so is it possible to cancel this effect with sentences that reverse the location information induced by the targets? In Experiment 1 we used sentences with supportive context (e.g. 'The soldier looks at the waving flag.', target: 'flag'; target location: up) and replicated the compatibility effect between target and response. In Experiment 2 we tried to cancel this effect with sentences that reversed the location information induced by the targets (e.g. 'The sad soldier presents the widow with the flag.', target location: up; sentence-based location: down). Nevertheless, a compatibility effect between target and response was observed. We did not find a compatibility effect between sentence-location and response. To exclude timing aspects we conducted Experiment 3 with an extension at the end of the sentences (e.g. 'The sad soldier presents the widow with the flag in the evening.'). Again we did not find a compatibility effect between sentence-based location and response.

Formally grounding spatio-temporal thinking

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To navigate through daily life, humans use their ability to conceptualize spatio-temporal information, which ultimately leads to a system of categories. Likewise, the disciplines of the spatial sciences rely heavily on conceptualization and categorization as means to create knowledge when they process spatio-temporal data. In the spatial sciences and in related branches of artificial intelligence, an approach has been developed for processing spatio-temporal data on the level of coarse categories for spatial and temporal relations and notions of similarity between these relations: qualitative spatio-temporal representation and reasoning (QSTR). Calculi developed in QSTR (e.g., topology) allow for the meaningful processing of and reasoning with spatio-temporal information because they focus on categorical (discrete) changes or salient discontinuities in dynamic spatial environments thought to be relevant to an information processing system both human and artificial. While qualitative calculi are naturally appealing and are, on a general level, widely acknowledged in the cognitive sciences, there is comparatively little behavioral assessment of whether or not these calculi are indeed cognitively adequate. This is an astonishing conundrum given that these calculi are ubiquitous and are often intended to improve processes at the human–machine interface and are on several occasions claimed to be cognitively adequate. We have systematically evaluated several approaches to formally characterize spatial relations from a cognitive-behavioral perspective for both, static as well as dynamically changing spatial relations. This contribution will detail our results addressing the question how formal characterization of space can help us understand how people think with, in, and about space.

Respiration as an indicator of embodied music cognition in collaborative vocal performance

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In collaborative music practice respiration may function not only as a biological mechanism supporting effective vocal technique, but also as an anticipatory signal that allows for perceptual matching and effective decision making between performers. Embodied music cognition provides the theoretical framework necessary to understand signification practices and behavioural resonances that occur in non-linguistic musical communication. Within the context of collaborative music making in vocal performance, respiration is a form of synchronization and embodied attuning in the space between participants. Respiration allows not only for coordination, but also for engagement of higher-level intentional processes, such as expressive affect and feeling. Therefore, an alteration of the timing of respiration was expected according to the phrase initiation of the singer. Singer-pianist pairs were asked to perform four pieces—first in an individual and then collaborative condition. 12 subjects (6 pianists, 6 singers) participated in the study. The pairs were based on musicians who had previously collaborated together and were balanced according to experience, specifically 3 pairs of musicians with more then 10 years experience and 3 pairs of musicians currently training. Respiration was monitored via *Plux* respiration sensors, consisting of a monolithic silicon pressure sensor encapsulated in an air membrane. The timing of respiration between pianists and singers was analyzed between groups to identify individual strategies. Experience and familiarity with the piece were important factors that impacted the effectiveness of communication between performers. Respiration functioned as a tool for mutual co-articulation and coordination of somatic information. At the beginning of each phrase, the timing of inhalations changed reflecting the signifying collaborative intention between individual and collaborative conditions. The effects of expressivity, experience and musical familiarity were also examined. Case-by-case

analysis of phrase initiation showed the influence of collaborative performance on the respiratory patterns of performers. This analysis should contribute to a more comprehensive understanding of the communicative strategies that contribute to efficient performance practices between performers.

Physical physics: embodiment of vector quantities in the classroom

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This work is guided by our laboratory and fMRI investigations and by theories of embodied cognition, a central tenet of which is that offline cognition (i.e., cognition that occurs in the absence of relevant environmental input) is grounded in sensorimotor processes. Embodied representations are often associated with high degrees of knowledge or skill; here, we attempt to leverage specific sensorimotor experience as a tool for learning. We are using an embodied cognition framework to elucidate how specific lab experiences impact student learning of physics concepts that have inherent spatial properties, and to uncover the underlying mechanism. We have developed a unit for teaching angular momentum in introductory physics courses during which students experience the sensorimotor consequences of torque, and subsequently use this experience as a basis for understanding changes in angular momentum. In addition, we investigate the contribution of individual differences in spatial ability and kinesthetic sense. Knowledge about the efficacy of training embodied representations is imperative for providing guidance to educators, and gives us further insight into the mechanism driving embodied learning.

The role of attention in affordance effects: can we afford to ignore it?

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It has been demonstrated that the task irrelevant orientation of an object's graspable handle produces a stimulus–response compatibility effect, resulting in faster reaction times when the location of the response corresponds to that of the object's handle. There is ongoing debate whether to attribute this affordance effect to embodied motor resonance or to attentional components. In an attempt to reconcile these two viewpoints we conducted an experiment to investigate whether the manipulation of attention in the auditory modality produces changes in the effects of visual affordance. Subjects were presented images of everyday graspable objects and had to respond bimanually (left or right) whether the object was presented correctly or upside-down. Additionally, object handles pointed to the left or to the right. Prior to each stimulus, attention was manipulated by simulating an audio source as being in front of the participant (control), to the left, or to the right side of space. In line with our expectations, reaction times were fastest when both affordance and attention corresponded to the response location. However, much to our surprise, similarly quick reaction times were also observed when both affordance and attention primed the response side opposite the response location. To put it simply, when affordance and attention were congruent, responses were facilitated, irrespective of response side. On the other hand, when they were incongruent, responses were inhibited. These results could be interpreted as evidence of a shared mechanism and could potentially place attention and affordance on the two sides of the same coin.

When using spatial memories renders them less precise

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Using a novel sequential discrimination task, this paper investigates the relationship between the *precision* of short term spatial memory (how accurately the location of an object is represented), its *availability* (how likely there is any recall of location at all) and its use in cognitive tasks. We demonstrate that the use of spatial memory, and specifically the transformation of spatial memories from one frame of reference to another, has the principal effect of degrading the precision with which an object location is represented in memory but not its availability. We then demonstrate that this effect can explain why previous research has revealed cases where participants use spatial memories exclusively—using only one source of information when more are available. We show that this is, in fact, a rational outcome of the trade-off between the benefits of combining information from more than one source and the cost, in precision, of the cognitive operations required to do so.

The categorical segmentation of body representations: a difference in tactile spatial acuity at anatomical landmarks?

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Tactile distance judgments are prone to a number of physiological and perceptual distortions. One such distortion concerns tactile distances over the wrist being perceptually elongated relative to those within the hand or arm (De Vignemont et al., 2008). This has been interpreted as a *categorical segmentation effect*: The wrist implicitly serves as a partition between two body part categories so that stimuli crossing the wrist will appear further apart. However, the effect could alternatively be explained in terms of specialized acuity at anatomical landmarks (i.e. the wrist; Cholewiak & Collins, 2003; Cody et al., 2008). To test these opposing explanations we presented participants with two tactile distances sequentially for comparison (one mediolaterally, *across* the arm, and the other proximodistally, *along* the arm). Points-of-Subjective-Equality (DV) were compared on the hand, wrist and arm, on dorsal and ventral surfaces between subjects. If the acuity account were true distances would be elongated in both axes at the wrist. If the categorical segmentation account were true there would be a selective perceived increase of the proximodistal distance at the wrist. A previously reported mediolateral bias (Longo & Haggard, 2010) was found on all body parts but, consistent with the categorical account, at the wrist the magnitude of the bias was either reduced (dorsally) or not found (ventrally) suggesting a selective proximodistal elongation. Further no evidence of increased acuity in the vicinity of the wrist was found. Therefore we conclude that the

segmentation of the body into discrete parts induces categorical perception of tactile distance.

Sensponsive architecture as a tool to stimulate the senses and alleviate the psychological disorders of an individual

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The proposed short paper describes the characteristics of sensponsive spaces that are capable of helping individuals with mild psychosomatic disorders, like depression, to gradually overcome their addiction to medication. It is an innovative multidisciplinary approach through the domains of architecture, psychology, biochemistry and information technology. Initially the paper presents the connections between architecture and human behavior and specifically the way in which the spatial qualities of the surrounding environment affect the human senses and consequently the hormonal changes and the production of the corresponding emotions. As a next step, the paper examines the parameters for the creation of sensponsive environments that can "sense" the hormonal levels of individuals and "respond" to them by transforming their spatial elements in order to make people feel better. The proposed sensponsive spaces are equipped with smart materials and sensor-actuator systems with programmed actions (haptic, olfactory, chromatic and so on). By this time, there are "intelligent" clothes that detect heart beating or the sweat of a patient and communicate the results to the hospital. Additionally, architecture already uses smart materials that demonstrate a change in their color, texture or level of sound-absorbency. Moreover, contemporary building systems are able to orchestrate the programmed function of various devices, like air-conditioning or audio-visual ones, targeting the comfort of people living in those environments. The paper concludes in the fact that sensponsive architecture can positively contribute to the creation of a more human environment helping people improve their psychological health and preventing them from irrational use of drugs.

Is it for real? Evaluating authenticity of musical pitch-space synesthesia

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In spatial-sequence synesthesia, ordinal sequences are visualized in explicit spatial locations. We examined a newly documented subtype in which musical notes are represented in spatial configurations, to verify consistency and automaticity of Musical notes-Space (M-S) synesthesia. An M-S synesthete performed a mapping pre-task (Exp. 1) used to indicate locations of 7 auditory or visually presented notes, in 2 sessions a month apart. Results revealed strong correlations between sessions, suggesting synesthetes' musical forms are consistent over time. Experiment 2 assessed automaticity of M-S synesthesia. The same synesthete and matched controls preformed a spatial Stroop-like task. Participants were presented with an auditory or visual musical note and then had to reach for an asterisk (target) with the mouse cursor. The target appeared in a compatible or incompatible location (according to the synesthete's spatial representation). A compatibility effect was found for the syneshete but not for controls. The synesthete was significantly faster when the target appeared in compatible locations than in incompatible ones. Our findings show that for synesthetes, auditory and visually presented notes automatically trigger attention to specific spatial locations according to their specific M-S associations.

Decoding urban street patterns in the human brain

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We report on an experiment that used functional magnetic resonance imaging (fMRI) and multi-voxel pattern analysis (MVPA) in order to decode the neural correlates of urban street patterns in map reading. Participants were scanned while viewing real-world examples of organic, grid and mixed street network patterns. Three-quarters of data were used to train a classifier to distinguish the subject's cognitive state while viewing the different type of street networks. The remainder of the data was then used to test the classifier's generalization performance. Results provide an important step in the understanding of pattern recognition as a fundamental component of geospatial thinking. They also provide evidence to what has been previously referred as the internalization or the urban street network (Hillier, 2003) and can have important implications for theories of urban form.

Spatial cognition and crime: the study of mental models of spatial relations in crime analysis

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Several studies employed different algorithms in order to investigate criminals' spatial behaviour and to identify mental models and cognitive strategies related to it. So far, several Geographic Profiling (GP) softwares have been implemented to analyze mobility and its relation to the way criminals are using spatial environment when committing a crime. Since crimes are usually committed in offender's high-awareness areas, this cognitive maps can be employed to create a map of the criminal's operating area to help investigators to circumscribe search areas. The aim of the present study was to verify accuracy of a specific Toolset (ArcGis) in predicting spatial mobility of a group of 39 non-criminal subjects. Data were collected asking participants to fill in a form indicating a list of places where they usually conducted daily activities (e.g., work, shopping). Results showed that the software was accurate in elaborating a GP for each subject according to the mobility area provided. Specifically, mean distance from the anchor point and the peak likelihood was 1.412 km (SD = 1.958; range = 11–8.509 m); mean distance from the anchor point and the mean centre was 3.072 km (SD = 2.552; range = 516–12.103 m) and 78.79 % of anchor points were localized in the standard distance ellipse; 70.59 % of anchor points were in the JTC top profile region; mean distance from minimum centre of minimum distance was 2.059 km (SD = 2184; range = 161–8.572 m). Future analysis will be implemented using mobility information of criminal subjects to verify if there is a

cognitive spatial strategy employed by them when planning and committing a crime.

The goal is not special: electrophysiological evidence for the simultaneous selection of goal and effector location during action planning

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The Premotor Theory of Attention (Rizzolatti et al., 1987, 1994) predicts that the intention to carry out an action will cause enhanced perceptual processing at the location of the action goal. This enhancement is often interpreted as a shift of spatial attention and is presumed to serve the purpose of selecting one goal amongst many distracters towards which to plan an action (selection-for-action, Allport, 1987 and Neumann, 1987). Early research on this effect of enhanced processing at the action goal focused on the planning of saccades, whilst more recent work has extended the principle to uni-manual movements such as reaching, pointing and grasping. Unlike saccades, however, successful planning of such uni-manual movements implies selection of an effector as well as a goal. Using a Go/NoGo paradigm, we investigated this effect by recording participants' EEG whilst cueing them to point to one of six targets arranged in an annular array. Visual processing was measured by reference to the size of the posterior N1 component of the event related potential, elicited in response to task-irrelevant visual 'probe' stimuli presented at one of the six locations in the interval between the presentation of an auditory cue and the execution of the movement. Results showed enhanced perceptual processing simultaneously at the location of the effector *and* at the location of the action goal. We conclude that action planning leads to a pattern of facilitation and inhibition in perception, which achieves the selection of all action relevant locations, not just that of the goal.

Gaze and eye-tracking solutions for psychological research

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Eye-tracking technology is a growing field used to detect eye movements and analyse human processing of visual information for interactive and diagnostic applications. Different domains in scientific research such as neuroscience, experimental psychology, computer science and human factors can benefit from eye-tracking methods and techniques to unobtrusively investigate the quantitative evidence underlying visual processes. In order to meet the experimental requirements concerning the variety of application fields, different gaze and eye-tracking solutions using hi-speed cameras are being developed (e.g., eye-tracking glasses, head-mounted or desk-mounted systems) which are also compatible with other analysis devices such as magnetic resonance imaging. This work presents an overview of the main application fields of eye-tracking methodology in psychological research. In particular, two innovative solutions will be shown: (i) the SMI RED-M eye-tracker, a high performance portable remote eye-tracker suitable for different settings, that requires maximum mobility and flexibility; (ii) a wearable mobile gaze tracking device—the SMI eye-tracking glasses—which is suitable for real-world and virtual environment research. For each kind of technology, the functions and different possibilities of application in experimental psychology are described by focusing on some examples of experimental tasks (i.e., visual search, reading, natural tasks, scene viewing and other information processing) in the theoretical framework of embodied cognition.

Sensitivity to reference frame invariance in processing topological and spatial prepositions

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Spatial prepositions describe how one object (the figure) is related in space to another object (the ground). They fall into two global classes: topological (T) prepositions (like *in* and *on*) and projective (P) prepositions (like *above* and *behind*). Differences between these groups of prepositions are found in multiple domains. Whereas topological prepositions are defined in terms of notions like inclusion and contiguity, projective prepositions are defined in terms of particular axes or angles. In language use, topological prepositions are often short words occurring with high frequency, while projective prepositions are often more complex and of lower frequency. The foregoing raises the possibility that distinct cognitive subsystems might underlie the processing of topological and projective prepositions. The present study intends to further illuminate the cognitive foundations of the distinction. We focus on the effects of reference frame transformations. While understanding of projective prepositions is thought to be sensitive to the intrinsic or absolute orientation of the ground, and hence to rotations of the ground, understanding of topological prepositions may remain invariant when the ground is rotated. To explore the T/P distinction, invariance under rotation is examined by using three different experimental designs based on sentence-scene stimuli. The influence of intrinsic and absolute reference frames on the acceptability of Dutch "*op*" and "*boven*" by rotating the scenes is investigated in a blocked (T and P sentences are presented in different blocks), a mixed (T and P sentences are presented at random) and a production design (participants can choose between *on*/*above*/none).

Category learning through action: a study with human and artificial agents

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The abilities to learn to categorize and manipulate new objects are closely related and ubiquitous in cognitive agents. To shed light on the underlying mechanisms and the relationship between these capabilities we designed an experimental comparative scenario in which human and artificial agents were asked to learn to manipulate, through a mouse pointer, unfamiliar two-dimensional objects that varied in shape, color, weight (i.e. inertia to the movement) and color intensity. Objects were grouped on the basis of their characteristic and each group was associated with a different target manipulation. The

artificial agents learned through a stochastic trial and error process in which variations to the artificial controller were introduced randomly. The controller, an artificial neural network, received as input the perceptual properties of the object and the current position of the mouse pointer and of the barycenter of the object and determined as output the movement of the mouse pointer. The comparison of the behaviors displayed by human and artificial agents allowed us to identify the role of human cognitive biases, mostly related to visual properties (e.g. shape), that may be beneficial or counterproductive for the acquisition of the task. The analysis of the performances instead showed that both humans and artificial agents used overgeneralized behaviors (i.e. they found and performed manipulations that could be applied to objects belonging to more then one category achieving good, although often sub-optimal, performance) and exploited properties that co-determine the effects of agent/environment interaction (i.e. weight) rather than visual properties.

Exploring the role of real-world size representation within interactive systems

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This position paper explores interactions with 3D objects using multi-touch surfaces. It investigates the relationship between the visual experience of a 3D object represented in real-world size in Computer Graphics (CG), and the mental representation of 3D objects explored in Cognitive Sciences, regarding both the behavioural and neural consequences. We interpret the world in real-world size, and we get a familiar relationship with objects thought their scale. For that reason, the real-world size is a relevant tool to be noticed when we built interactive systems, that we want people to engage with, in a familiar and intuitive manner. This position paper suggests that we should have in consideration natural learning processes, of visual perception and memory construction within the digital context. Although we are able to recognize objects on different scales [2], the scale of the represented object and its relationship with the context around, digital or physical will bring on each user a different set of interpretation. Using different scales to known size objects is always attached to a different meaning, and always changes the user experience. Using the real-world size representation is an important tool in contexts such as education, medicine, museology, archaeology, or other scientific fields. Furthermore we explore the real-world size representation as a method to obtain a different set of information about the objects.

Tracing the development of cross-sectioning ability in three- to nine-year old children

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Visualizing 2D cross-sections of 3D objects is a spatial skill that is widely used in the STEM (Science, Technology, Engineering & Mathematics) disciplines. Cross-sectioning assessments typically involve 2D line drawings of 3D solids, which may be difficult for children. In our new assessment, we presented 229 3–9 year old children with 3D geometric foam solids (or detailed 2D photographs of solids) that were each sliced by a cardboard "plane" through their horizontal or vertical mid-plane. For each item the child chose which of four 2D shapes the flat inside would look like if the solid pulled apart at the cardboard. Response patterns for younger vs. older children and Item Response analyses suggest that each of the foam solids has one "easier" and one "more difficult" cut. For example, some children chose "triangle" as the result of cross-sections at *both* the horizontal and vertical mid-plane of a square-based pyramid—suggesting that younger and/or less-skilled children may not actually be visualizing cross-sections or may be overly attentive to solids' faces. We created a stricter performance measure, and found that cross-sectioning ability improves across the age range, with 3–5 year olds grouping together and 6–9 year olds grouping together. We found no sex or condition (2D vs 3D) differences at any age. Cross-sectioning ability is correlated with mental rotation and spatial visualization assessments, controlling for verbal ability. Item Response Theory analyses indicate that particular items are capable of differentiating between individuals within particular ability ranges, suggesting that different sets of items may be necessary for assessing younger and older children.

Emergence of space from sensorimotor invariants: anticipatory network analysis in the context of the Tetris game

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Committing to an embodied and constructivist form of representation based on potentialities of interaction, this work evaluates O'Regan's (and originally Poincaré's) hypothesis that space is structured by the agent, as the mathematical group of reversible transforms. It seems confirmed when analyzing the results obtained with a distributed and anticipatory computational model learning sensorimotor invariants, here restricted to the discrete environment of the Tetris game for clarity and tractability purpose. An artificial agent using such model learns by interacting with the game. Its visual field is reduced to a small area of the board, but this sensory limitation is compensated by additional motor capabilities. The agent not only acts on pieces with the keyboard, but can also perform saccades across the board. It thus learns spatiotemporal visuomotor correlations, as predictors made of a visual context, action, and expected consequences on the sensors. Only considering deterministic predictors, subsets of sensory and motor dimensions are locally sufficient to describe the state of the system, thus defining a dissimilarity space. When analyzing the network resulting from the interactive learning, objects like borders or Tetrominoes (the game elements) form dense local networks of predictors sharing many dimensions. On the contrary, space appears as a transversal network of bidirectional predictors where only a few dimensions are involved. Interestingly, other concepts such as self-induced versus observed motion, controllable versus fixed blocks, symmetries and spatial transforms such as rotations are directly reflected in these networks.

Body and space in awareness and mindfulness meditation: neural correlates and neuro-cognitive modeling

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Several neuroimaging and lesion studies suggest that anterior insula (AI) and inferior parietal lobule (IPL) might play a crucial role in awareness, in recurrent interations with prefrontal cortex, anterior

cingulate cortex and widespread brain areas. AI and IPL are also involved in hemineglect and anosognosia, syndromes related to body and spatial awareness. As suggested by neurocognitive theoretical models, such as the global workspace theory (e.g., Baars, 1988) and Craig's (2009) model on interoceptive awareness, conscious access is plausibly supported by spatial or interoceptive representations, for which AI and IPL play a crucial role. In parallel lines of research, AI and IPL have been found to be implied in mirror neuron functions (e.g., Rizzolatti & Craighero, 2004) and in mindfulness meditation (e.g., Farb et al., 2007). Also based on our functional Magnetic Resonance Imaging and magnetoencephalografic findings on mindfulness-based meditation (with Buddhist monks), and related phenomenology, as well as on neurocomputational modeling investigations, we suggest a novel neurocognitive model for the emergence of consciousness with the support of body- and space-related representations in the brain, with a key role of AI and IPL. We also discuss plausible relationships between phenomenal consciousness, access consciousness and mindfulness in light of our model.

Preferences and illusions in quantified spatial relational reasoning

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"All children are standing to the left of their grandparents AND some of the grandparents are to the left of the uncles." You might have no difficulty inferring that "Some children are left of the uncles". But, what about the underlying cognitive processes? Are specific strategies used and mental models constructed? What influence do the logical connectors ANDand XOR have? An empirical study presented participants ($N = 34$) with such assertions and investigated the effects of different quantifiers (ALL, SOME), spatial relations (Left of, Right of), and logical connectors (AND, OR) on the construction of models. Results: The study reveals a clear preference for the initially constructed models—they depend on the mental model operations. The participants applied the following model construction strategies: (1) Models with chunked elements are preferred; (2)Models are constructed according to a parsimonious representation strategy; (3) Alternative models are generated according to continuous transformations on the models. Systematic reasoning errors and illusions can be identified: There are differences between the two logical connectors (53 % invalid initial models for XOR in contrast to 14 % for AND; Wilcoxon $z = 4{,}6$; $p < .001$). Error rates were smallest for using two universal quantifiers (ALL-ALL), increase significantly when using one (SOME-ALL; ALL-SOME) and again using none (SOME-SOME) (Page's $L = 436$; $z = 3{,}40$ $p < .001$). Although the different assertions allowed for multiple arrangements, difficulty can be traced back to specific quantifiers and logical connectors and a human preference for parsimonious mental model representations in complex spatial descriptions.

Spatial anxiety, spatial ability, and working memory in early elementary school

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Spatial ability is a strong predictor of students' pursuit of higher education in Science, Technology, Engineering and Mathematics (STEM) disciplines. However, very little is known about the affective factors that influence individual differences in spatial ability, particularly at a young age. The purpose of this study was to determine whether children possess anxiety about engaging in spatial activities (e.g., spatial anxiety), and if these spatial anxieties relate to spatial abilities as a function of individual differences in working memory (WM). One-hundred fifty-eight 1st and 2nd grade boys and girls from five Chicago Public Schools served as participants. We developed a new measure of spatial anxiety based on a previous assessment of children's math anxiety. We measured WM using the digit span task and spatial ability using the Thurstone Primary Mental Abilities test. Our results showed that spatial anxiety is associated with reduced mental rotation ability among students with high but not low WM. However, this WM $\times$ spatial anxiety interaction was only found among girls. We discuss these patterns of results in terms of the problem-solving strategies that boys versus girls use in solving mental rotation problems.

Moving through virtual reality without moving?

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Virtual Reality technology is increasingly used in spatial cognition research, as it offers the promise of high experimental control and interactivity in naturalistic multi-modal environments, something that is difficult to achieve in real-world settings. Even the highest technical sophistication and costs, however, do not guarantee that humans will perceive and behave the same as in corresponding real-world situations. In part, this might be due to us not being able to use the same embodied (and thus often highly automated and effective) spatial orientation processes in VR. While real-world locomotion affords automatic spatial updating of our self-to-surrounding relationships such that we easily remain oriented during simple perspective changes, the same is not necessarily true for locomotion that is only simulated in Virtual Reality. This can lead to striking quantitative and qualitative errors, especially if there are no landmarks available to help us remain oriented or recover orientation. We hypothesized that this might be related to the fact that we often don't perceive self-motion in VR, and designed experiments to test this hypothesis. In a series of experiments, participants travelled through an immersive virtual environment and were asked to point to previously-learned targets "as accurately and quickly as possible" to assess the occurrence, ease and effectiveness of spatially updating. Surprisingly, physical motion cues showed little benefit when a naturalistic environment was used, despite the lack of reliable landmark. When abstract optic flow stimuli were used, however, physical motion cues and self-motion illusions did facilitate spatial updating, thus confirming our hypothesis.

Failure of spatial representation contributes to memory decline during aging

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It has been established that episodic memory deteriorates during normal ageing. A critical component of accurate episodic memory for

events and scenes is the correct recollection of spatial relationships both from one's own perspective and inter-object relationships. A series of studies examined whether ageing might differentially affect memory for these two forms of spatial information. Older and younger participants were asked to mentally construct to-be-remembered scenes from a number of different perspectives. The two groups did not differ in the ability to remember these scenes immediately after presentation, but when presented with photographic images after an interval period, older participants revealed a significant impairment. Older adults consistently failed to reject images being viewed from an alternative perspective. In contrast, further study revealed that between group performance is equivalent when inter-object relationships are manipulated. This specific impairment was more severe than older to younger group differences in standard word recall tests, revealing a particular inability to reliably recall self–perspective information. This deficit might underlie the development of unreliable memories as we age; without accurate spatial scene reconstruction from an egocentric point of view, episodic memories are likely to be less accurate and more vulnerable to error.

Assistive/rehabilitation technology, disability & service delivery models

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Embodied cognition considers cognitive processes to be grounded in the body's interactions with the world. In a reconstitutive, dialectical process, the body of an individual with a disability and its interactions with the world can be greatly impacted by the use of assistive technologies (AT) to enhance functioning in activities of daily living, control of the environment, recreation, mobility, and employment-related skills. Academics and professionals in health and other disciplines should have a knowledge base in evidence-based practices that improve well-being and participation of people with disabilities through effective service delivery of AT. Grounded by a theoretical framework that incorporates a multivariate perspective of disability that is acknowledged in the Convention on the Rights of Persons with Disabilities (CRPD) and the World Health Organization's International Classification of Functioning, Disability and Health (ICF), we present a review of models of AT service delivery and call for future syntheses of the fragmented evidence base that would permit a comparative effectiveness approach to evaluation.

Spatial navigational impairments in hydrocephalus

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Hydrocephalus is characterised by an increase in CSF volume, which leads to ventricular swelling that exerts widespread pressure across the brain. Whilst much is known about the neuropathological consequences of the condition, there have been comparatively few studies of the cognitive impairments associated with it. Studies using standardised tests of cognitive function have identified a general pattern of impairments, with patients exhibiting particular difficulty on tests of spatial memory and executive function. Although such findings are illustrative, it is difficult to predict how these difficulties might impact upon more concrete everyday behaviours. A strong prediction is that these deficits are likely to affect daily wayfinding behaviour, and we report a study of spatial and navigational abilities in a group of patients with hydrocephalus but without spina bifida. Participants completed a range of experimental tasks assessing spatial cueing behaviour, landmark memory and route-learning, and idiothetic path integration. This patient group was compared to a control sample matched on verbal, spatial, and intelligence measures, and hydrocephalus was found to be associated with relative impairments in each of the tasks. Patients exhibited reduced sensitivity to spatial cueing, less accurate route-learning, poorer memory for landmark objects, and less accurate spatial updating (with particular impairments in the calculation of heading). Overall, these data represent the first empirical demonstration of navigational impairments in hydrocephalus, and we suggest some of the cognitive, neural, and individual differences factors that may contribute to the pattern of performance reported.

Space: a view of linguistic psychology—Evidence from English preposition: "in", "on" and "at"

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Space is a basic concept in linguistic psychology and is considered as a meta-concept in metaphor (e.g. Lakoff &Johnson, 1980) that it can transfer to different domain to understand time and other abstract concepts. Zhu (2008) pointed out that we construct the space category, which includes entity, location and displacement. Meanwhile, it reaches a conclusion that entity category is related to noun, location category is related to locatives (prepositions or adverbs in English) and displacement category is related to verb. As an important element of space category, the present empirical study takes German students as subjects and focus on English preposition "in", "on" and "at" as a part of location category. As spatial meaning of one preposition can transfer to other concepts, we follow the classification of other concepts by Radden and Dirven (2007) that according to the theory of domain, prepositional meanings have three domains: the spatial, temporal and abstract domain. Assisted by figure-ground theory (e.g. Rowe&Koetter,1978) and the theory of metaphor(Lakoff, 2006), the present study illustrated how students benefit from figure-ground theory in English preposition learning and how they use metaphor mechanism to map semantic meaning from spatial concept to other concepts. The study includes pre-test and post test. The result showed that there is significant improvement after training, for every domain and every preposition. In short, this study shows in which way students operate with spatial categories, how they transfer the spatial meaning to different concepts and in which way teachers would teach students systematically.

Variation in spatial language and cognition: exploring visuo-spatial thinking and speaking cross-linguistically

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Although human cognition is traditionally thought to be universal and language-independent (Chomsky, 1975; Fodor, 2001), recent typological and crosslinguistic research reveals the need to place linguistic diversity at centre stage in order to better understand the nature of cognitive processes (Evans & Levinson, 2009). In the domain of space, variability is realized with spatial semantic elements mapped across languages in very different ways onto lexical/syntactic structures. For example, satellite-framed languages (e.g., English) express manner in the verb and path in satellites; while verb-framed languages (e.g., French) lexicalize Path in the verb, leaving Manner implicit or peripheral (Talmy, 2000). Some languages are harder to classify into these categories, rather presenting equipollently-framed systems (Slobin, 2006), such as Chinese (serial-verb constructions) or Greek (parallel verb- and satellite-framed structures in equally frequent contexts). Such properties seem to have implications not only on the formulation/articulation levels (Hickmann, et al. 2009; Slobin, 2009) but also on the conceptualization level (Soroli, 2011; von Stutterheim & Carroll, 2006), thereby reviving questions concerning the language-thought interface. The present study investigates the relative impact of language-independent and language-specific factors on spatial representations across three typologically different languages (English-French-Greek) combining a variety of complementary tasks (production, non-verbal and verbal categorization) all coupled with eye-tracking. The findings show that typological properties of languages can have an impact on both linguistic and non-linguistic organization of spatial information (i.e., categorical choices, attention allocation patterns), open new perspectives for conceptualization and contribute more generally to the debate concerning the universal and language-specific dimensions of cognition.

Top-down strategy in rehabilitation of spatial neglect. How about the effect?

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The aim of this work is to verify the effectiveness of our treatment in patients with spatial neglect in relation to their age and to the severity of neglect. Lots of studies on rehabilitation were proposed and, in some of them, treatments based upon visual scanning abilities were described. Our rehabilitation training is aimed to induce patients to find by themselves an adequate strategy to solve spatial problems and, after that, try to let this searching strategy as automatized as possible. In all our exercises, patients should achieve a goal by means of a visuo-spatial search, finding the correct and the best functional way to scan peri-personal space. In this study, sixty patients with right brain damage and left visuo-spatial neglect underwent to this specific cognitive treatment. A neuropsychological battery, including barrage tests, geometric-shape copy, and Raven PCM-position-preference index, was administered before and after treatment. Repeated measure MANOVA on test performances showed significant main effects for age and severity of neglect; an interaction effect between these two variables was found as well. Our results confirm an effectiveness of treatment, in particular for old patients. Actually they seem to show a better recovery of neglect after cerebral stroke, even for those of them affected by a severe neglect. We argue that these data can lead to further hypotheses concerning reorganization of cognitive functions, such as visuo-spatial attention, and abilities to automatized new strategies in older patients.

Mental spacetime and embodiment

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Cognitive science has reached a stage where it can systemically consider if "conceptualizing space" always also consists of a temporal conceptual component and if "conceptualization time" always also consists of a spatial conceptual component. The possible fundamental inseparability of conceptualizing space and time is exemplified by a cognitive- linguistic analysis of what are often called "space-to-time mappings" in conceptual metaphor theory. The analysis suggests that there is always time within the source domain of "space" itself and, likewise, that there is always space within the target domain of "time" itself. The term mental spacetime is introduced to characterize "space-to-time mappings" more adequately as mappings from object spacetime (e.g., One satellite followed another) to event spacetime (e.g., New Year's follows Christmas). The newly proposed domain of spacetime (with its two subdomains object and event spacetime) can synthesize various fundamental concepts of "spatial cognition" and "temporal cognition": (i) the gaze- tour from (space) and retrospection/prospection (time) are synthesized to the moving-gaze mode; (ii) the route form (space) and the moving-ego metaphor (time) to the moving-self mode; and (iii) the survey or map from (space) and mental time watching (time) to the stationary-gaze mode. It is also examined how the moving time metaphor fits into these proposed modes. Additionally it is demonstrated that all three spacetime modes can be analyzed un terms of embodiment- they always involve the conceptualization of a mental self that is looking out at a mental scene.

Representing social interactions: how construal level affects spatial asymmetries

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The spatial representation of social interactions is grounded into bodily experiences related to everyday actions. In particular two spatial dimensions promote systematic asymmetries, that is the tendency to envisage action evolving a) from top to bottom—following gravity- and b) from left to right -following writing directions (at least in western cultures). For example, previous research showed that powerful targets are positioned on top of powerless targets (vertical dimension), and agentic targets are positioned to the left of less agentic targets (horizontal dimension). The question addressed here is whether the tendency to process information abstractly (vs. concretely) determines the adoption of these spatial mental schemata. In a set of experiments, we primed abstract (vs. concrete) mindset and

measured spatial asymmetries in horizontal and vertical representations of social targets. As spatial trajectories can be conceived as abstract mental schemata, we hypothesized and found that these trajectories are more influential in envisaging social targets when individuals think in abstract rather than concrete terms. More specifically, agentic and powerful targets were more likely to be represented respectively to the right and on top of less agentic and powerful targets when participants were primed with global, rather than local, mindset.

Effects of musical expertise, pattern complexity and manifested beat on movement kinematics during perception and reproduction of auditory rhythms

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The current study focuses on the relationships between the Rhythmic Complexity (RC) of auditory patterns and the "manifested beat" (spontaneous body movements synchronized with the beat of an auditory pattern). RC levels were computed using 5 indices: C-score (probability that a pattern will induce a pulse) and PS-measure (structural regularity) calculated on both eight- and quarter-note levels, and the subjective evaluation. 4 skilled musicians and 6 non-musicians listened to and reproduced 35 auditory patterns by clapping their hands, during three separate runs. Full-body movement was recorded using an eight-camera motion capture system at 120 samples/s. The effects of different movement features on the reproduction of rhythm were analysed and two kinematic measures were extracted: standard deviation of instantaneous speed, and total distance covered by selected body parts; the participants' performances were qualitatively evaluated against the baseline of their spontaneous tempo. We identified systematic relationships between RC and the spatio-temporal characteristics of body movement. During the listening task musicians seemed more sensitive to the RC than non-musicians and they tended to move less than non-musicians when listening to patterns with higher RC prior to reproduction. During the motor reproduction, musicians also moved more when the rhythm had a lower RC (in particular C-Score). We conclude that bodily representation of the beat is tied to the RC of the pattern presented, with particular features tied to the relationships between spontaneous tempo, manifested pulsation and the accuracy of reproduction.

Developmental shift in spatial coding in two-year-old children

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Human spatial cognition undergoes considerable development in the first decade of life. In young children qualitative shifts in spatial coding have been proposed, from an initial state of body-centered responding to a coding system that relates objectively to the environment, referred to as the egocentric-to-allocentric shift. Using a novel VR paradigm with changing camera views we investigated spatial orientation abilities in 2-year-old children. Both 30-month and 35-month-olds performed above chance level on trials consistent with an egocentric response. In contrast, children aged 35 months performed more accurately than 30-month-olds when allocentric processing was required, with a mean accuracy significantly above chance for the older children and below chance for the younger children. Neither age group benefited from landmarks present in the environment, suggesting that they made use of optic flow cues to reorient, rather than object-to-object relations. Analysis of individual differences revealed that 2-year-olds who were relatively more independent in comparison to their peers were most successful at reorientation. These results reveal a critical transition period within a few months only. During this phase children overcome the predominance in use of the egocentric response system still present in 30-month-olds, and learn to use optic flow cues for building accurate models of a 3D environment, necessary for orientation and navigation.

The cognitive benefits of viewing nature: do natural environments require less attentional processing?

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Attention Restoration Theory claims that visual exposure to nature will result in cognitive restoration. (Kaplan, 1995). This theory can be supported by evidence showing improved performance on tasks requiring directed attention following passive observation of natural environments (e.g., Berman, Jonides, & Kaplan, 2008). A popular account for this finding is that attending to the spatial patterns in nature, as opposite to that of the built environment, is effortless (Kaplan, 1995). In the present study this claim is directly tested using a go/no-go rapid visual identification task as this is an effective instrument to measure the degree of processing involved with scene identification (Fabre-Thorpe, 2011; Rousselet, Joubert, & Fabre-Thorpe, 2005). Studies will be presented that have tested the hypothesis that natural environments can be identified with higher accuracy and shorter response time than built environments. This was done using a database with images of both natural and built scenes presented at five different exposure times (range: 13-67 ms). An additional test of the hypothesis involved the use of inconsistent scenes that contained elements from the other scene category. Results demonstrate conflicting findings between the different image exposure time conditions. An interpretation to account for these contradictory findings is provided and implications for attention restoration theory are discussed.

Memory consolidation of landmarks: an fMRI study

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Successful navigation relies on recall of spatial memories from the recent and remote past. Previous imaging studies indicate that the retrieval of landmarks placed at locations relevant for navigation initially recruits the parahippocampal gyrus (PHG), and that this activation increases within the first 24 h after encoding. The present event-related fMRI study investigates how the neural representation of objects placed at relevant locations (decision points) and irrelevant locations (non-decision points) is affected by the process of consolidation over the course of one month. Twenty right-handed participants watched a film sequence of a complex virtual environment with objects located at decision and at non-decision points. Subsequently, recognition memory for different subsets of the objects was tested. Participants indicated whether they had seen the objects immediately after encoding (day 1), 24 h later (day 2), and after one month (day 30). During each session, event-related fMRI data was acquired. In line with previous findings, results indicate that the PHG is initially involved in the retrieval of objects previously located at decision points. However, after a delay of one month the retrieval of objects located at decision points selectively recruits the medial frontal gyrus. This suggests that, whereas prefrontal regions do not seem to be involved in the retrieval of recent spatial memories, they play a crucial role in the recall of remote spatial memories. The present study shows that the process of memory consolidation is sensitive to spatial information relevant for successful navigation.

Combining motor and spatial affordance effects with the divided visual field paradigm

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The affordance effect has been widely investigated employing various behavioural and brain-imaging techniques. Some studies link this stimulus–response compatibility to the Simon effect, claiming spatial association between the handle orientation of visually presented stimuli and the nearest response hand. Other authors advocate motor activation, reasoning that the brain calculates possible goals for action with the stimuli and does not simply rely on spatial association. In an attempt to compare spatial to motor activation we adapted the divided visual field paradigm, briefly presenting subjects with pictures of upside-down or properly oriented pans either in the left or right visual field (LVF and RVF). Subjects had to respond with their left and right hands either in crossed or uncrossed position, judging the vertical orientation of the pans and paying no attention to their horizontal orientations (left and right affordance) or positions in either VF. The results show a modulation of the congruency effect between visual affordance and response hand, depending on hand position (crossed/uncrossed) and laterality of response (ipsi- or contralateral to the visual field). The congruency effect amounts to motor facilitation when subjects respond with their hands uncrossed to pictures presented ipsilaterally. However, the nature of the congruency effect becomes spatial once subjects cross their hands, responding faster to contralaterally presented congruent stimuli. Overall, the data speaks in favour of both spatial and motor theories of affordance and suggests that subjects find it harder to rely on motor activation with awkward hand positions, resorting instead to judgement of spatial location.

Encoding and retrieval of object-related spatial cues during navigation: an fMRI study

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To successfully navigate, humans can use different cues from their surroundings. Rodent and fMRI studies suggest a differential involvement of specific brain regions when using different types of spatial cues, such as the hippocampus, parietal cortex, and caudate nucleus. This fMRI study looks at differences in the use of object-related spatial cues while 35 participants actively navigated in an open-field virtual environment. In each trial, participants navigated towards a target object. During encoding, three object cues (columns) with shadows were available. During retrieval, the invisible target had to be replaced while either two objects without shadows (objects trial) or one object with a shadow (shadow trial) were available. The experiment consisted of blocks, informing participants of which trial type would be most likely to occur during retrieval. Comparing encoding-related brain activity in the objects condition with that in the shadow condition revealed activity in bilateral hippocampus and medial parietal and bilateral parietal cortex. Encoding in the shadow condition compared to the object condition revealed stronger activity in right caudate nucleus. During retrieval, switch trials (incongruent with the block) during object blocks compared to switch trials during shadow blocks revealed medial frontal activation. The reverse contrast revealed higher activation in bilateral inferior frontal cortex and bilateral caudate nucleus. Between-subject analysis revealed that differential brain activation predicts performance during encoding and retrieval, also on switch trials. These data show that humans are able to adapt based on expected spatial information and recruit different brain networks according to expected and available spatial information.

The role of active locomotion in space perception

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It has been shown that active control of locomotion increases accuracy and precision of nonvisual space perception, but the psychological mechanisms of this enhancement have been poorly understood. The present study explored a hypothesis that active control of locomotion enhances space perception by facilitating crossmodal interaction between visual and nonvisual spatial information. In an experiment, blindfolded participants walked along a linear path under one of the following two conditions: (1) They walked by themselves by following a guide rope; and (2) they were led by an experimenter. Subsequently, they indicated the walked distance by tossing a beanbag to the origin of locomotion. The former

condition gave participants greater control of their locomotion, and thus it was considered as more active walking than the latter condition. In addition, before each trial, half the participants viewed a room in which they performed the distance perception task. The other half remained blindfolded throughout the experiment. Results showed that although the room was devoid of any particular cues for walked distances, visual knowledge of the surroundings improved the precision of nonvisual distance perception. Importantly, however, the benefit of preview was observed only when participants walked more actively. This indicates that active control of locomotion allowed participants to better utilize their visual memory of the environment for perceiving nonvisually encoded distance, suggesting that active control of locomotion served as a catalyst for integrating visual and nonvisual information to derive spatial representations of higher quality.

The effect of visual information on locomotion distance estimation in virtual reality

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Action affects cognition, even in the virtual reality with a simulated movement. During locomotion, visual information, texture or landmarks, generates different patterns of optic flow and supports the motion-based distance perception, while information as landmarks serves for the self-displacement process that helps people to assess the distance whenever in a static scene. However, no clear evidence has been reported on whether the existence of landmarks enhances perception during locomotion. In this study, a simulated movement was presented in each of four virtual environments with pure color, texture, landmarks or both texture and landmarks as visual cues, and participants were asked to reproduce the distance in a fifth environment with a different moving speed. Overall, participants' reproduction performance failed to show any improvement under the landmark condition or in the environment with redundant visual information. In addition, analysis was carried out to separate the contribution of distance and traveling time and the results revealed a mediated effect of the type of visual cues on the strategy participants used in reproduction. When there was texture in the environment, participants reproduced the distance highly related to the actual distance, while when there were landmarks in the environment, they were biased by locations of the landmarks and compensated their performance by using the temporal information. It is suggested that when embodied in a locomotive scenario, our static perceptual process functions less well and the motion-based estimation dominates.