iNAV 2024 Data Blitz Talks

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Session 1, June 18	Sen Cheng	A neural network model that learns to encode and retrieve memories for spatial navigation
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Session 1, June 18	Lara Gregorians	Moving through architectural spaces involves spatial and aesthetic processing
Session 1, June 18	Dori Derdikman	Opposite effects of glutamatergic and dopaminergic cells of the VTA on representational drift in the hippocampus
Session 1, June 18	Michael Bukwich	Navigating an impossible geometry in virtual space
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Session 1, June 18	Yunzhe Liu	Hippocampal ripples reflect prediction error in a valence dependent way
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Session 2, June 19	Benjamin Pitt	Spatial reference frames across axes, ages, and cultures
Session 2, June 19	Xhensjana ZENELAJ	A Brainstem Nucleus Linking the Cerebellum to the Hippocampus
Session 2, June 19	Xiuting Yang	Visual boundary cues suffice to anchor place and grid cells in virtual reality
Session 2, June 19	Deetje Iggena	The temporal dynamics of spatial representations – The consolidation of long-term spatial memories of the real world.
Session 2, June 19	Yadurshana Sivashankar	The Necessity of Motoric Engagement in Enhancing Route Memory
Session 2, June 19	Martin Seeber	Comparative neural dynamics of real-world and imagined navigation
Session 2, June 19	Maria Kozhevnikov	Immersive Virtual Reality-Based Perspective Taking: Design and Validation of a Diagnostic Tool to Assess Spatial Navigation Abilities
Session 2, June 19	Michal Gabay	The Effect of Level of Immersion and Locomotion of the Virtual Reality Modality on Spatial Learning Strategy Usage, Performance, and Experience Measures
Session 3, June 21	Reisner Volker	Locomotion-dependent effects of environmental geometry on human spatial memory in volumetric space
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Session 3, June 21	Desdemona Fricker	Directionally tuned signals in mouse subicular complex and in visual cortex during passive rotation using high-density probes
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Session 3, June 21	Clément Naveilhan	Spatial contextual information modulates affordance processing and early electrophysiological markers of scene perception
Session 3, June 21	Sophia Rekers	Spatial navigation in clinical practice—Diagnostics and treatment in patients with severe cognitive impairment
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Session 3, June 21	Pascal Malkemper	Towards the neural basis of the magnetic sense in subterranean mole-rats: behavior and recordings
Session 3, June 21	Elena Aggius Vella	Egocentric navigation network plasticity: training extends functional connectivity of V6 to frontal areas of congenitally blind people.
Session 3, June 21	Nofar Yarimi	Degraded vision leads to impaired spatial memory and neural representations of space
Session 3, June 21	Ilan Vol	Individual differences in navigating around augmented vs. real obstacles
Session 3, June 21	Emre Yavuz	Using Minecraft to elucidate the Neurobiological Mechanisms underlying Human Hunting Behaviour
Session 3, June 21	Coco Newton	Spatial navigation metrics differentiating preclinical and prodromal Alzheimer's disease: a systematic review
Session 3, June 21	Ruma Chatterji	Home Vector Degrades Over Short Time Scales during Path Integration in the Fiddler Crab, Leptuca pugilator

iNAV 2024 Data Blitz Abstracts

1. NAVIGATING MEMORY: NEURAL AND OCULAR REPRESENTATION OF MOVEMENT IN A CONCEPTUAL SPACE

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A growing body of evidence has demonstrated that brain regions with a role in navigation are also used to explore conceptual spaces. It has been suggested that the medial temporal lobes, in particular, extract and generalise the relational structure of our experiences. While prior work has explored the representation of structural knowledge, it remains unclear how we act on it. Do we use the same neural machinery to get around in physical and abstract spaces? Do other systems, such as eye movements, reflect processes of conceptual navigation?

In this fMRI study, we tested the hypothesis that the entorhinal cortex represents actions in a non-physical space. To do so, we teach participants (n=57) to associate numerical operations with specific numbers (e.g., '44' uniquely affords the actions +2 and -2). The learned structure of this number line allowed generalisation of specific operations to new numbers, which we considered as a signature of state-independent 'action' in a conceptual space.

Leveraging cross-validated representational similarity analysis, we find that the right entorhinal cortex represents potential actions ('conceptual affordances'). Meanwhile, we find that parietal and medial prefrontal regions play a supporting role in representing state identity and action magnitude. Strikingly, eye movements also track possible actions in a conceptual space: participants looked further rightwards for states which afforded positive numerical operations, relative to those which afforded negative operations.

In sum, we find that both neural patterns in the entorhinal cortex and eye movements are sensitive to the operations which allow us to explore cognitive maps. We believe this moves us closer to an understanding of how we are able to navigate our memory.

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2. A NEURAL NETWORK MODEL THAT LEARNS TO ENCODE AND RETRIEVE MEMORIES FOR SPATIAL NAVIGATION

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Numerous machine learning algorithms incorporate memory models that were inspired by episodic memory. However, almost all of them employ pre-defined and rigid mechanisms for the encoding and retrieval of memories. Usually, a pre-determined type of information is stored at each timestep regardless of whether anything interesting has happened. Here, we investigate a model based on a Memory-Augmented Neural Network, which learns autonomously what and when to store into, and retrieve from, an external memory buffer, while solving a navigation task in a simulated maze. The agent learns to navigate to an unmarked goal whose location changes at fixed intervals. As expected, the agent learns to store information in memory when it reaches the goal, and suppresses storage afterwards to avoid interference by irrelevant information. Surprisingly, even though the model receives only camera images as inputs, the information encoded in memory reflects the 2D spatial structure of the maze. Intriguingly, the outcome of memory retrieval already reflects the information about what action the agent will select next. We develop a geometrical theory which explains how the representations in the memory and the computations during retrieval give rise to the correct solutions to the navigation task. Our modeling results show how a pure memory structure, such as for example the hippocampus, can develop spatial and action representations. We believe that it is the structure of the spatial task that moulds the encoding and retrieval strategy that the agent learns, and different tasks would eventually lead to different memory strategies and representations.

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3. EGOCENTRIC AND ALLOCENTRIC RELATIONAL PROCESSING IN THE HUMAN BRAIN

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The ability to orient oneself within an environment is essential for successful navigation. However, the utility of "orienting" oneself extends beyond purely spatial relationships. Recent research investigating the neural mechanisms supporting non-spatial relational processing suggest that there is substantial overlap with canonical spatial processing networks (i.e., domain general function), although important distinctions may still exist (domain specific function). To-date, few studies have provided a systematic investigation into the degree of overlap between conceptually separable cognitive domains and their corresponding brain networks. Moreover, no study has explicitly incorporated manipulations relating to a core feature of canonical spatial processing networks: the distinction between self-referential (egocentric) and observer-independent (allocentric) frames of reference. To address this, we developed a task that directly compares distance ratings across domains (spatial, temporal, and social) and reference frames (egocentric and allocentric) frames. Participants were cued to a single domain then viewed side- by-side images of either two historical figures (allocentric) or, crucially, a historical figure and the participant themself (egocentric) followed by a distance rating for the cued domain. Participants (N=20) completed 8 fMRI scanning runs (30 trials each) and then provided confidence ratings outside the scanner. We observed substantial overlap in univariate activations for each domain. Activity in the hippocampus, posterior parietal cortex, and posteromedial cortex showed sensitivity to distance ratings for egocentric vs. allocentric judgements. These results suggest that similar brain regions support relational processing for a variety of spatial and non-spatial domains. Moreover, egocentric and allocentric reference frames appear to rely on distinct neural codes to represent these domain-general relational distances.

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4. MOVING THROUGH ARCHITECTURAL SPACES INVOLVES SPATIAL AND AESTHETIC PROCESSING

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Moving through the built environment entwines many processes simultaneously – cognitive, affective and behavioural. Sensory information tells us about an environment's characteristics and opportunities, influences how we feel, and thus impacts the series of decisions that determine how we navigate space. Real-world architectural experience incorporates spatial mapping, aesthetic valuation, and affective response.

However, whilst the neural correlates of aesthetic and affective experience are often considered in tandem, no studies to date have looked at how they relate to the neural correlates of spatial cognition.

Here I present the results from an fMRI study exploring the brain regions that support spatial and aesthetic processing of real-world architectural spaces, to understand how these networks support coding and memory of environments over the course of a dynamic journey.

Participants watch a series of first-person-view videos that walk them through different spaces, and consider either their valence or spatial layout complexity. We explore how perceived aesthetic and spatial properties of the environments relate to one another, what brain regions they activate, and how they impact memorability.

As expected, we find that key brain regions involved in valence processing activate in relation to positively valenced spaces, and that key spatial regions activate in relation to spaces with complex layouts. Notably, brain regions usually considered to be involved in spatial processing are also found to be involved in valence processing; positive valence processing engages networks supporting both affective and spatial mapping. Complexity also appears to be a driving factor of memorability; simpler spaces are recalled correctly more often.

This research extends the field of spatial cognition and navigation to include aesthetic and affective dimensions, demonstrating that these facets may in fact be deeply entwined within the experience of moving through space.

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5. OPPOSITE EFFECTS OF GLUTAMATERGIC AND DOPAMINERGIC CELLS OF THE VTA ON REPRESENTATIONAL DRIFT IN THE HIPPOCAMPUS

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The firing patterns of place cells within the hippocampus exhibit specificity to particular spatial locations, thus contributing to the representation of a spatial map within a given environment. Notably, these place cells undergo changes in representation, or remapping in response to exposure to a novel environment or to alterations within a familiar setting. Recent evidence suggests that place cells exhibit a degree of drift even in the absence of externally perceived changes within a familiar environment. Inspired by a prominent model positing a neural circuit involving the hippocampus and the ventral tegmental area (VTA) as a signal mediator for novelty and learning, we investigated the effect of VTA stimulation on the induction of place cell remapping. Employing calcium imaging techniques in the dorsal CA1 region of the hippocampus and implementing population-specific chemogenetic activations, we dissociated between the impacts of glutamatergic and dopaminergic subpopulations within the VTA on behavior and on hippocampal activity. Our findings revealed that (i) activation of the glutamatergic VTA subpopulation induced hippocampal remapping and accelerated representational drift, while (ii) the activation of the dopaminergic VTA subpopulation reduced remapping and representational drift , thereby promoting stability of the spatial map. In conclusion, our results underscore a marked functional dissociation among distinct cell populations within the VTA concerning their influence on hippocampal dynamics.

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6. NAVIGATING AN IMPOSSIBLE GEOMETRY IN VIRTUAL SPACE

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While cognitive maps provide a crucial component for spatial navigation in complex environments, it remains unknown precisely which features of reality are being mapped. We have developed a virtual navigation task wherein the structure of space is decoupled from the latent structure of experience in order to dissociate the relative contributions of these features to the formation of a cognitive map.

We trained mice to navigate a virtual environment composed of eight visually-distinct Y-junctions presented along a 2D plane. A 3D graph structure (cube) is used to determine the transition matrix governing Y-junction connectivity, thus yielding an environmental layout that would be physically impossible in Euclidian space. To obtain rewards, mice must navigate to goal locations which alternate between a fixed Home and randomly varied Away locations (Pfeiffer and Foster, 2013), thereby incentivising broad exploration of the environment while also providing a metric for targeted navigation, quantified as efficiency of trajectories leading back to the Home reward location when reward is allocated there. Early behavioural results show improvement in task performance over training, with latency to reward capture gradually decreasing across sessions in pilot mice. Our results provide a basis for upcoming neural recordings.

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7. SPATIAL REPRESENTATIONS FOR SELF AND OTHERS IN THE MEDIAL TEMPORAL LOBE OF FREELY-MOVING HUMANS

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To date, the vast majority of what is known about the brain's spatial representation system stems from research in non-human animals, or humans tested under non-naturalistic conditions (e.g., stationary participants performing tasks on a computer screen), while it remains unclear how spatial information is represented in the human brain during real-world experiences. Moreover, previous work has focused on how the brain encodes self-related spatial information (e.g., one's own location or self-motion speed), while it is largely unknown how the human brain integrates other individuals into its cognitive representation of the environment. To address these gaps in knowledge, we investigated human brain activity in clinical patients with permanently implanted intracranial electrodes, enabling us to obtain electrophysiological recordings from deep brain structures during naturalistic real-world experiences and ambulatory movement. We found that human medial temporal lobe (MTL) oscillations encode several types of spatial representations during real-world navigation, such as information about one's own location and self-motion speed, as well as a hexadirectional modulation of oscillatory low-frequency power that is indicative of grid cell population activity (i.e., grid-cell-like representations). Most strikingly, we discovered that these neural representations reflect information not only for one's self, but also serve to keep track of other people's location and movements in shared environments. Together, these findings provide evidence that the human brain uses common neural mechanisms to encode spatial representations for oneself and other individuals, and shed new light on the neural substrate underlying spatial navigation and awareness of others in dynamic real-world scenarios.

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8. SPATIAL ENCODING PRECISION: UNVEILING RETROSPLENIAL CORTEX AND HIPPOCAMPAL FORMATION NEURAL COMPONENTS

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The neural basis of spatial cognition is believed to be centered on the hippocampal-entorhinal complex. Numerous pieces of evidence regarding the neural representation of space in these brain areas strengthen this idea. However, position-correlated neural activity has been reported in a vast range of brain regions, from thalamic nuclei to neocortical areas. Among these regions, the association brain areas, besides spatial representations, can also be involved in performing spatial behavior. The retrosplenial cortex (RSC), known to play a key role in various cognitive functions, especially visuospatial behavior, is one of these association areas.

Despite the reported similarities in position-correlated activity in the RSC and HPC, simultaneous readout of both areas is lacking in the literature. In our study, we combined chronic electrophysiology recording and a head-fixed locomotion assay to simultaneously record from both areas in behaving animals during locomotion on a linear treadmill. Using four-shank Neuropixels probes, we recorded the activity of single units in different parts of the RSC (along the anterior to posterior axis) and HPC (the dorsal CA1 cells) to compare the ongoing neural dynamics in these two regions.

Analysis of single unit spikes revealed a significant difference in spatial information, although the number of position-correlated cells is almost equal. Comparing spatial information showed that the HPC's spatial information is higher than that of the RSC. We have also observed that the distribution of spatial information in the HPC is uniform, while it decreases from the anterior to the posterior in the RSC.

We conclude that although position-related activity is detectable in RSC spiking activity, the quality of spatial encoding differs from that in the HPC. The reported difference could potentially imply the different and seemingly complementary roles of the RSC and HPC in spatial cognition.

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9. NEURAL CODING OF SPACE AND GOALS: DYNAMICS OF EGOCENTRIC BOUNDARY TUNING DURING BAIT-CHASING

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Over the past decades, considerable research has delved into the retrosplenial cortex's (RSC) critical function in spatial navigation with respect to both allocentric and egocentric frames of reference. The recent demonstration of egocentric boundary vector cells (EBVCs) in the RSC in an open-field arena marked a significant advancement in our understanding of how the brain maps the environment relative to the indivual (Alexander et al., 2020; van Wijengaarden et al., 2020). Building on this foundation, the present study focuses on EBVCs as a prototypical form of egocentric neural coding to determine whether and how it changes between a static open field context and a dynamic egocentric task—specifically, pursuing a bait in the same environment. To dissect these complex neural dynamics, we employed high-density Neuropixels recordings (versions 1.0 and 2.0) along with high-resolution 3D motion capture, enabling a detailed examination of EBVCs properties. Our initial findings suggest that, amid pursuit, subsets of EBCVs maintain their coding of enviromental boundaries, while other subsets alter their tuning between open-field exploration and bait-chasing scenarios, specifically aligning their firing activity towards the bait. This behaviour suggests a sophisticated balance between goal-directed actions and a maintained awareness of environmental boundaries, possibly reflecting a strategy to avoid collisions while targeting the bait. This adjustment indicates a nuanced neural representation of space and goal-oriented behaviour, suggesting that neural coding can change dynamically to meet behavioral demands in changing environments.

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10. HIPPOCAMPAL RIPPLES REFLECT PREDICTION ERROR IN A VALENCE DEPENDENT WAY

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Backward replay plays a critical role in assigning credits during reinforcement learning, in both physical and non- spatial spaces. While rodent studies have established a tight relationship between replay and hippocampal ripples, this link is not as clear in human.

With stereo electroencephalography (sEEG) recordings, epileptic patients (n = 28) engaged in a three-arm task (Liu et al., 2021), requiring both local learning (i.e., learning from direct experience) and nonlocal learning (i.e., indirect learning based on inference). In total, there were 125 hippocampus contacts and 2358 neocortex contacts.

Hippocampal ripples were sensitive to the prediction error (PE), and exhibited valence-dependency. Specifically, the ripple rate (RR) increased in rewarded trials compared to the unrewarded. This effect was further modulated by the outcome of the previous trial, with a higher RR in rewarded trial following unrewarded trial (i.e., positive PE) compared to unrewarded trial following rewarded trial (i.e., negative PE). Besides, the neocortex showed peri-ripple activations (PRA), with the limbic system network and the default mode network exhibiting strong activations, mirroring the pattern seen in RR.

Intriguingly, hippocampal ripples also responded to the arm novelty, with the highest RR in the least frequently visited arm (i.e., rare arm). Behavioral modeling supported this neural observation, showing that arm novelty influences the calculation of gain in replay prioritization. This prioritization process incorporates not only policy improvement, as previously described, but also the value of information, which peaks for rare arm.

These preliminary findings emphasize the critical role of human hippocampal ripples in credit assignment. Yet, the specific computations involved are still to be fully understood. We intend to expand our analysis in the coming months, particularly by distinguishing the neural-computational mechanisms of local versus nonlocal learning.

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11. UNCOVERING SPATIAL COGNITIVE MAPS IN ZEBRAFISH USING BRAIN-WIDE IMAGING IN FREELY MOVING ANIMALS

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Cognition emerges when the brain transforms sensory information into abstract mental constructs or flexible internal representations. This internal cognitive representation of the external world is the basis for abstract thought, reasoning, and generalized intelligence. A prime example of this process is the mammalian ability to form spatial cognitive maps of the external environment. However, evidence for spatial maps (e.g. place cells) has yet to be convincingly identified in any species outside of mammals and birds. Thus, when and how spatial cognition emerged during evolution remains a central mystery of neuroscience. Using a state-of-the-art tracking microscope to image brain-wide activity at cellular resolution in freely swimming larval zebrafish, we computed the spatial information of neurons throughout the zebrafish brain. We find that the zebrafish telencephalon contains a network of place cells forming an internal representation of space. The place cell network in zebrafish exhibits striking similarities to mammals, as evidenced by multimodal integration of self-motion and visual input, experience- dependent refinement of the spatial map, and spontaneous offline reactivation of place cell ensembles. This recent discovery raises the possibility that spatial cognition arose in a compact circuit over 400 million years ago, setting up an initial condition for the subsequent elaboration and expansion of cognitive capabilities in mammals. Furthermore, the compact brain of larval zebrafish presents a unique opportunity to combine simultaneous neural recordings of the entire spatial computational network with the complete synapse-scale connectome of the underlying circuitry, to uncover the mechanistic principles underlying spatial cognition.

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12. FUNCTIONAL DEVELOPMENT OF THE GRID CELL NETWORK IN THE ENTORHINAL CORTEX

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Grid cells are principal cells in layers II/III of the medial entorhinal cortex (mEC) whose activity in rodents, as animals explore an open field environment, is characterised by local peaks of high activity arranged in a repeating pattern of equilateral triangles. This pattern can be described by its wavelength (distance between peaks), orientation (angle of peak locations to an arbitrary axis) and phase (peak location). On the population level groups of grid cells are organised into modules whereby cells in the same module have similar wavelengths and orientations but a different phase.

Previous work in rats has shown that in early life adult-like grid cell firing emerges during the 4th week after birth. However, very little is known about how the modular organisation of grid cells on the population level might develop, including the relative contributions of age and experience. Here we use neuropixels probes to record ensembles of grid cells from the mEC of 3 to 5-week-old rats in an attempt to track the emergence of grid cell firing in young animals and characterise how and when the population level organisation of grid cells into modules occurs. We also investigate how age and the animals' experience of different environments contribute to these maturation processes. Our results indicate that different modules emerge concurrently and grid cells in all modules show experience-dependent rescaling upon repeated exposure to an environment. Unlike place cells, whose population level properties (e.g. theta sequences or offline hippocampal replay) appear approximately one week after their location specific firing, our results indicate that grid cells show the hallmarks of their population organisation from the time point of their emergence. This occurs broadly within the developmental window during which hippocampal dependent memory first emerges.

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13. VISUAL BEHAVIOR DURING SPATIAL EXPLORATION IN VR EXPLAINS INDIVIDUAL DIFFERENCES IN SPATIAL NAVIGATION TASK PERFORMANCE USING A GRAPH-THEORETICAL MODELING APPROACH OF EYE TRACKING DATA

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Spatial orientation and navigation are useful abilities on a daily basis. However, large individual differences exist in spatial navigation performance, yet satisfying explanations about the origin of such differences are lacking. In this work, we model the performance of a pointing-to-building task with the eye tracking data recorded during free spatial exploration of a city in virtual reality. We find that gaze graph diameter explains 40% of the variance in participant's mean task performance.

In this study, we measure the eye-tracking data of 26 participants who freely explore a large city (244 buildings) in virtual reality for 150 min. After the exploration, participants perform a pointing-to-building task from different locations in the same city. For the analysis, we transform the eye-tracking data into gaze-graphs and calculate graph- theoretical measures. We then model participants' mean task performance with a linear model using global gaze- graph measures (R2=0.41). Moreover, a linear model with graph diameter only results in an R2 of 0.4; consequently, graph diameter can explain 40% of the variance in mean task performance of participants. In contrast, a linear model using participant's responses to the FRS questionnaire shows no predictive power in regard to participants' mean task performance.

Overall, our results show visual behavior, specifically gaze-graph diameter, to be a strong predictor of individual differences in spatial navigation performance. In contrast, the self-evaluation of the participants via the FRS questionnaire did not hold a significant predictive value. Ultimately, applying a graph-theoretical analysis introduces a new approach to eye tracking analysis that opens exciting opportunities for spatial navigation research and provides a novel perspective on individual differences in spatial navigation performance.

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14. THE NUCLEUS REUNIENS DRIVES HIPPOCAMPAL GOAL-DIRECTED TRAJECTORY SEQUENCES FOR ROUTE PLANNING

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Goal-directed spatial navigation requires accurate estimates of one's position and destination, but these estimates are still not sufficient. An animal is often required to plan a navigational route because a direct path to the goal is not necessarily available. Despite its importance, the neural circuits supporting route planning ability remain poorly understood. Previous studies have implicated the orbitofrontal cortex in representing an animal's destination, and the hippocampus in representing its own position as well as goal-directed paths. We hypothesize that interactions between these regions, mediated by the thalamic nucleus reuniens (RE), are critical for planning navigational routes. To test this hypothesis, we used a navigation task in which rats were required to take obstacle avoidance routes to a given destination without relying on sensory cues under minimum light conditions. Optogenetic silencing of the RE resulted in impairment of the animal's route planning ability as it took a longer non-smooth path but correctly reached a goal location, highlighting a specific role of the RE in route planning but not goal recognition. Recordings from CA1 neuronal activity revealed that obstacle avoidance routes were represented by their brief sequential spiking or replay when the animal was at the starting position, but these representations were largely abolished by RE silencing. Our results together point to the key role of the RE in driving hippocampal replay sequences to sweep future goal-directed routes, supporting the animal's ability to navigate to a desired destination by avoiding known obstacles in the environment.

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15. EXPLORATION BEHAVIOR AND COGNITIVE MAP: THE KEY POINT OF SPATIAL INDIVIDUAL DIFFERENCES

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In our daily lives, exploring new environments is a common experience from which we form or enrich our cognitive map of the environments. However, there is little research investigating mental representations derived from free exploration; research has focused mainly on participants learning predetermined routes. Additionally, little is known about individual factors that may be associated with exploration behavior. Some studies suggest that people prefer to revisit familiar places, while others enjoy exploring new ones (diffusion). The present study aims to investigate whether individual exploration behavior is related to mental representations and whether other individual differences, such as visuospatial factors in terms of visuospatial working memory ability (VSWM) and self-reported wayfinding inclinations (self-efficacy and pleasure in exploring and spatial anxiety), play a role. A sample of 152 participants completed a VSWM task and questionnaires assessing their self-efficacy and pleasure in exploring and spatial anxiety; they freely explored a virtual city using a joystick in a CAVE environment, instructed to learn paths and buildings, and completed a sketch map task (as a measure of cognitive map). The results confirmed that the sketch map drawing task accuracy is related to individual VSWM ability. However, accuracy seems not related to individual exploration behavior (revisiting and diffusion). Furthermore, individual patterns of exploration were found to be related to self-reported wayfinding inclinations, with individuals reporting higher spatial anxiety exploring the environment less. Overall, the present study sheds new light on the complex interplay between mental representations of environments, individual differences in visuospatial factors, and exploration behavior, suggesting that individual differences in exploration behavior may offer valuable insights.

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16. NEURAL CODING OF EPISODIC AND SPATIAL REPRESENTATIONS IN DEVELOPMENT

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Navigation and episodic memory are both fundamental cognitive processes that rely on the hippocampus and its connection to other cortical areas. However, the extent and nature of interdependence is unclear. We investigated how they relate by testing

children (8-13 years, i.e., over the age at which skills are refined towards adult levels) and young adults in a natural, real-world environment. On Day 1, participants completed two encoding experiences (1) a walking tour punctuated by events; and (2) sitting in a room and experienced comparable events. We assessed knowledge of the tour environment using three measures: route knowledge, location mapping, and JRD. We also measured episodic recollection using free recall and recognition. On Day 2, participants underwent an fMRI session where they viewed images of the objects they saw on the tour and in the room, as well as new objects. We found that spatial and episodic memory overlapped across two latent factors. The memory structure factor included measures that require simultaneously representing all or part of the environment (route, mapping, free recall, spatiotemporal). The perceptual/factual/locale factor included perceptual and semantic recognition along with JRD (which taxes egocentric and allocentric navigation). Univariate BOLD analysis identified regions most likely to support encoded representations across both factors: right hippocampus (RHC), lateral occipital (LO), and entorhinal (ERC), perirhinal (PRC), and parahippocampal cortices. Pattern analysis revealed stable tour similarity in the anterior RHC related to better memory structure. Stable differentiation of encoding representation in the ERC related to better memory for both factors. Further, there were age-related changes in spatial representations in the ERC, PRC, and LO. In sum, we found that episodic memory and spatial representations are intertwined in the real world- humans seldom operate either only spatially or only episodically.

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17. SPATIAL REFERENCE FRAMES ACROSS AXES, AGES, AND CULTURES

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Spatial cognition is fundamental to human behavior, but the way people conceptualize space varies across cultures and over development. When remembering how objects are arranged, some people typically use egocentric space, defined by the sides of the body (e.g. to the right), whereas others tend to use allocentric space, defined by features of the environment (e.g. toward the mountains), but the reasons for this variation remains unresolved. We propose that both cultural and developmental variation in these spatial frames of reference (FoRs) reflect differences in people's ability to reliably discriminate left-right space, which is common only among educated adults. We tested this hypothesis in samples of US children (ages 4-8), US adults, and indigenous Tsimane' adults living in the Bolivian Amazon. Participants performed tests of spatial memory and language on both the lateral (left-right) and sagittal (front-back) axes. Results show the pattern predicted by differences in spatial discrimination.

On the sagittal axis, where egocentric discrimination is easy, participants in all three groups preferentially used egocentric solutions, but the groups diverged on the lateral axis: US adults, who have relatively good left-right discrimination abilities, continued to prefer egocentric solutions, whereas both US children and Tsimane' adults, for whom left- right discrimination is difficult, preferred allocentric solutions, using different FoRs on different axes. These results challenge claims that a single FoR predominates in a given culture or developmental stage. Rather, FoR use varies flexibly within the same individual, among both children and adults. The pattern of variation we observe across axes, ages, and cultures suggest a common principle governing this cognitive diversity: When representing a spatial relation, people may use whichever spatial continuum they can best discriminate, whether it is defined egocentrically or allocentrically.

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18. A BRAINSTEM NUCLEUS LINKING THE CEREBELLUM TO THE HIPPOCAMPUS

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Place cells, primarily located in the hippocampus, fire as an animal moves through specific areas of its environment, and are thought to form an internal representation of space. This process depends on information originating from both internal and external sources, enabling the animal to accurately navigate by updating its position and orientation relative to its surroundings. However, how such information is processed and integrated to hippocampal circuitry remains unclear. Recently, we have reported the critical involvement of the cerebellum in stabilizing hippocampal place cells during active navigation, in light and dark conditions. We hypothesize that the cerebellum, known for processing multimodal sensory signals, assists in disentangling self-motion information from environment-related information. It would thus allow to weight their respective contribution to spatial and directional coding which shapes place memory formation and supports navigation. Nevertheless, the pathways and neural mechanisms underlying cerebellar influence on hippocampal activity remain enigmatic. By combining monosynaptic anterograde viral injections in the cerebellum with monosynaptic retrograde tracer injections in the hippocampus, we have identified a new disynaptic pathway linking these two structures via a brainstem nucleus. Currently, we are investigating its functional role through optogenetic silencing of cerebellar projections to the brainstem nucleus while recording the activity of the brainstem nucleus and hippocampus in freely-behaving mice.

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19. VISUAL BOUNDARY CUES SUFFICE TO ANCHOR PLACE AND GRID CELLS IN VIRTUAL REALITY

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The hippocampal formation contains neurons responsive to an animal's current location and orientation, which together provide the organism with a neural map of space. Spatially tuned neurons rely on external landmark cues and internally generated movement information to estimate position. An important class of landmark cue are the boundaries delimiting an environment, which can define place cell field position and stabilise grid cell firing. However, the precise nature of the sensory information used to detect boundaries remains unknown. We used 2-dimensional virtual reality (VR) to show that visual cues from elevated walls surrounding the environment are both sufficient and necessary to stabilise place and grid cell responses in VR, when only visual and self-motion cues are available. By contrast, flat boundaries formed by the edges of a textured floor did not stabilise place and grid cells, indicating only specific forms of visual boundary stabilise hippocampal spatial firing. Unstable grid cells retain internally coherent, hexagonally arranged firing fields, but these fields 'drift' with respect to the virtual environment over periods >5 sec. Optic flow from a virtual floor does not slow drift dynamics, emphasising the importance of boundary-related visual information. Surprisingly, place fields are more stable close to boundaries even with floor and wall cues removed, suggesting invisible boundaries are inferred using the motion of a discrete, separate cue (a beacon signalling reward location). Subsets of place cells show allocentric directional tuning towards the beacon, with strength of tuning correlating with place field stability when boundaries are removed. In conclusion, our results demonstrate that purely visual boundaries can stabilise hippocampal spatial representations. We also report the first evidence that hippocampal place cell responses can be modulated by sensorimotor feedback.

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20. THE TEMPORAL DYNAMICS OF SPATIAL REPRESENTATIONS – THE CONSOLIDATION OF LONG-TERM SPATIAL MEMORIES OF THE REAL WORLD.

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The way we consolidate spatial information over time is key to understanding spatial navigation in our daily lives. Much of the current research focuses on the early stages of memory formation in a period of hours to a few weeks after encoding. How spatial representations change over months to decades, on the other hand, is rarely investigated for methodological reasons and has not yet been researched for spatial navigation experiences.

Here we present the "Berlin Zoo Task", an instrument for investigating the change of spatial representations over time, and its application in a study on the consolidation of navigation experiences in the real world, which deals with time delays that go beyond the classical tasks of spatial memory.

Using the "Berlin Zoo Task", we show that the consolidation of spatial information acquired during navigation in the real world persists over decades. We also show that different types of spatial representations in the ego-allocentric spectrum are transformed differently over longer periods of time and that time is one predictor of several to explain spatial memory performance. Our approach thus provides a new tool to study the consolidation of spatial information over time periods that were previously inaccessible and provides insights into the enduring transformation process of spatial representations.

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21. THE NECESSITY OF MOTORIC ENGAGEMENT IN ENHANCING ROUTE MEMORY

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Given the increasingly prevalent use of navigational aids such as Google Maps, it is important to examine whether reliance on such devices helps or hinders our memory for spatial routes. For example, navigational devices limit the need for decision-making, which might be critical for the formation and retention of memory for a route travelled. Using virtual reality (VR) we examined whether visual navigational guidance during initial exploration of a city hindered such memory. Participants (n = 54) explored 12 virtual environments in VR for 40s each, with the goal of finding a star. Navigation Strategy was manipulated within-subjects, randomly, and required either actively self- initiating decision-making about the route of travel (active condition) or following a visually-guided route (guided condition), both with volitional control of movements using a VR compatible steering wheel, or passively viewing a pre-determined route of travel. Participants later re-entered each virtual city, and were asked to "reproduce" the exact route they had traveled. There was an effect of Navigation Strategy on route memory such that self-directed (active) and visually-guided conditions similarly benefited performance relative to passive viewing. Critically, we found no significant difference between active and guided conditions on route memory performance, suggesting that decision-making required for active but not guided navigation, does not underlie the memory benefit. Instead, the results show that motoric engagement of head, body, and arm movement during encoding, more so than decision-making, benefits route memory. Findings suggest that navigational aids that offer route guidance may not dampen memory for those particular routes as long as the motor system is engaged during initial encoding.

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22. COMPARATIVE NEURAL DYNAMICS OF REAL-WORLD AND IMAGINED NAVIGATION

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Recollecting the progression of events is relevant not only for episodic memory but also for envisioning future behaviors based on experience. Previous research in freely-moving rodents proposed a central role of the medial temporal lobe's (MTL) involvement in spatial navigation and the formation of novel episodic memories. Here, we study whether real-world navigation and episodic memory paradigms elicit functional similarities in the human MTL, which might generalize to imagined navigation.

Taking benefit of recent neurotechnological developments, we examined intracranial electroencephalography (iEEG) recorded from a chronically implanted device in five individuals receiving responsive neurostimulation therapy. Participants learned to navigate two routes, including four turns each, in an indoor room (14.6 × 13.5 m2) fully equipped with motion capture. After each real-world walk, participants walked on a treadmill while imagining walking these routes in their minds. In agreement with previous reports, transient theta oscillations were evident in each participant at spectral peaks in the 4-10 Hz frequency range. Short-lasting theta bouts frequently occurred prior to upcoming turns and formed temporal dynamics that encode the spatial geometry of the routes consistently across trials (30-35, left/right walks each). During imagined navigation, we found theta bouts occurring at specific time points resembled the routes' geometry, similar to the real-world dynamics. This resemblance was absent during sole treadmill walking that we used as a control condition. These

findings demonstrate the capability of the MTL to internally generate structured theta dynamics relevant to memory retrieval and spontaneous imagination when environmental cues are minimal. Altogether, our results open novel avenues for studying real-world spatial navigation, episodic memory, and imaginable future behaviors.

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23. IMMERSIVE VIRTUAL REALITY-BASED PERSPECTIVE TAKING: DESIGN AND VALIDATION OF A DIAGNOSTIC TOOL TO ASSESS SPATIAL NAVIGATION ABILITIES

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Spatial abilities, encompassing allocentric and egocentric processing, are critical for various real-world tasks. Allocentric spatial ability involves the mental rotation of objects, while egocentric spatial ability entails imagining perspective changes. However, conventional spatial assessment tools primarily focus on allocentric abilities, limiting their predictive validity for domains, such as spatial navigation, requiring egocentric processing. To address this limitation, an immersive 3D Virtual Reality-based Perspective-Taking Ability (3D iVR PTA) test was successfully designed as a novel diagnostic tool to assess egocentric spatial ability, and its internal and predictive validities were examined. The results revealed that an immersive environment itself is an important factor in measuring egocentric spatial ability. Furthermore, our findings suggest that the immersive 3D iVR PTA task is the most accurate measure of egocentric spatial ability among currently available instruments. Our findings also indicate that immersive 3D iVR PTA emerged as the most reliable predictor of large-scale navigational performance. Conversely, conventional spatial ability tasks (Paper Folding and Mental Rotation) and non-immersive 3D perspective-taking tool showed no predictive power for real-world spatial navigational performance.

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24. THE EFFECT OF LEVEL OF IMMERSION AND LOCOMOTION OF THE VIRTUAL REALITY MODALITY ON SPATIAL LEARNING STRATEGY USAGE, PERFORMANCE, AND EXPERIENCE MEASURES

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The extensive increase in the utilization of virtual reality (VR) systems in many fields emerged also for spatial learning. However, the effect the VR modality level of immersion and locomotion interface have on spatial learning strategy usage is yet to be assessed.
To address his gap, we translated to humans the classic T-maze task (Barnes et al., 1980), where three spatial learning strategies were observed: place, cue, and response. We compared 3 conditions: wearing a VR headset while physically walking vs. standing in place and using a controller, and a 2D screen display using a mouse and a keyboard.
During probe trials, a turn to one of the maze arms represented an explicit choice in the strategy tested over the two others. Each strategy testing probe trial was preceded and followed by a regular probe trial identical to a training trial.
Analysis was performed on 46 valid participants, and a standard p-value of 0.05 was considered.
We defined learning pace as the number of training trials to reach the learning criterion and learning effectiveness as the number of successful probe trials that were identical to training trials. Walking obtained both significantly higher learning pace and effectiveness compared to 2D.
The probability for an explicit choice of response strategy (turn left/right) was significantly lower in the VR walking condition relative to both other conditions. Moreover, the probability of using the place strategy significantly increased in the second session relative to the first only in the VR walking condition.
Presence questionnaires obtained significantly higher values for spatial sense of presence, engagement, and ecological validity/ naturalness in the VR walking condition relative to 2D.
Our preliminary results suggest that modality characteristics affect spatial learning and should be carefully considered during VR task design. Our future analyses of eye-tracking data may add deeper insight and understanding to these findings.

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25. LOCOMOTION-DEPENDENT EFFECTS OF ENVIRONMENTAL GEOMETRY ON HUMAN SPATIAL MEMORY IN VOLUMETRIC SPACE

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Representing places in multi-dimensional space constitutes a key function of the cognitive map. In 2-D environments, spatial representations are strongly influenced by boundaries and can be deformed by stretching and squashing environmental dimensions. In 3-D environments, the sensitivity to spatial information along the vertical dimension depends on the navigator's mode of locomotion, with surface-dwelling animals being less sensitive to vertical information than flying animals. Here, we focus on how locomotion mode and environmental geometry interact in influencing human spatial memory in volumetric space. We implemented a mixed design manipulating spatial dimension (horizontal vs vertical), deformation type (stretch vs squash) and locomotion mode (walking vs flying), combining motion capture and immersive virtual reality technology. During an object-location memory task in 3-D, we asked participants to replace objects at previously learned target locations within an environment that was either familiar or geometrically deformed. We found that recalled locations in the flying group are consistent with predictions of boundary-based computational models that we extended from 2-D to 3-D, while the behavior in the walking group is better explained by models that emphasize a ground-based reference frame. We observed opposing effects of the two locomotion modes on spatial memory, with the flying group showing a horizontal advantage and the walking group showing a vertical advantage. These differences were attenuated or enhanced in the deformed environments, depending on the environment's geometry. Our results suggest that during virtual flying without gravity, humans, like other surface-dwelling animals, exhibit a horizontal advantage in the representation of volumetric space. This anisotropy aligns with geometric aspects of the environment and seems to be compensated or even reversed in the naturalistic, walking condition where participants could use body-based cues.

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26. HIPPOCAMPAL TIMESTAMP FOR GOALS

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Our brain must manage multiple goals that differ in their temporal proximity. Some goals require immediate attention, while others have already been accomplished, or will be relevant in the future. Here, we examined how the hippocampus represents the temporal distance associated to different goals, using a novel space-themed paradigm during 7T functional MRI (n=31). The hippocampus has an established role in mental time travel and a capacity to organize information along its longitudinal axis based on representational scale. Previous work has documented a functional transformation from fine-grained, detail rich representations in the posterior hippocampus to coarse, gist-like representations in the anterior hippocampus. These representations often differ in their temporal component, but it is unclear whether time itself is represented independently in the hippocampus, regardless of granularity or level of abstractness. We therefore tested whether the hippocampus dissociates goals based upon their temporal distance from the present.
We hypothesized that the hippocampus would discriminate between goals relevant for one's current needs from those that are removed in time along the long axis, with temporally removed past and future goals eliciting more anterior activation. To test this hypothesis, our participants embarked on a mission to Mars during which they had to track goals that were fixed in all properties except their temporal distance from the present. We observed a distinct dissociation along the axis of the hippocampus, where temporally removed goals from both the past and future activated the left anterior hippocampus and current goals activated the left posterior hippocampus. This demonstrates that the timestamp attached to a goal is a key driver in where the goal is represented in the hippocampus and extends the scope of the hippocampus' long axis system to the goal temporal mapping domain.

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27. DIRECTIONALLY TUNED SIGNALS IN MOUSE SUBICULAR COMPLEX AND IN VISUAL CORTEX DURING PASSIVE ROTATION USING HIGH-DENSITY PROBES

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Head-direction (HD) cells function as the brain's compass system. HD activity is generated based on vestibular signals and controlled by visual landmarks. How multisensory signals are processed during passive rotation remains unclear, with the pre- and postsubiculum as a prime candidate for the integration of vestibular based anterior thalamic and visually dominated retrosplenial cortical signals.

We used a novel paradigm where vestibular and visual cues are precisely controlled. Head-fixed mice were rotated on a motorized stage in a pseudo-random fashion, covering all angles. Visual cues were projected on a surrounding dome-like screen. We recorded neuronal activity of single neurons and populations of neurons in pre-, post-, parasubiculum and subiculum, and in visual cortex, using Neuropixels probes.

The protocol included a control condition, in the recording room, and test conditions, where a single visual landmark was projected onto the dome. Recording in darkness let us examine the stability of directional signals in the absence of landmarks. Angular tuning was quantified by dividing the number of spikes by the occupancy per bin, and the Rayleigh vector (R) was calculated for each cell.

We found 606 well separated units from subicular areas (n=8 mice), of which 61% showed directional tuning ($R>0.3$, $p<0.05$). Some units showed mixed selectivity, tuned to HD and to angular head velocity. Tuning curves of subicular HD cells showed that the HD system was controlled by visual landmarks under the dome, following cue shifts between conditions as expected. No directional tuning was observed during the darkness condition. Nevertheless, pairwise correlation analysis showed maintained coherence of activity of HD cells, but much less so in visual cortex. Thus these two cortical areas differ fundamentally in their signal processing. Future work will provide new insights on multisensory integration in the subicular complex and the HD function in head-fixed paradigms.

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28. AN EXPERIMENT DESIGN TO ISOLATE SPATIAL UPDATING PROCESSES IN STATIONARY HUMAN BRAINS

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Spatial updating of knowledge of one's own location relative to surrounding objects from self-movement is a key component of navigation, and an ability that appears to decrease in Alzheimer's disease. A triangle completion task is commonly used to behaviourally assess spatial updating relative to the start (a.k.a. path integration), but a naturalistic experimental paradigm to isolate the neural processes of spatial updating in immobile participants is lacking.

Here we developed an fMRI-compatible virtual navigation experiment consisting of three tasks: first, a baseline spatial memory task in which participants move to hidden objects using both spatial updating and environmental information; second, a spatial updating task in which participants are passively moved relative to environment objects; third, a control task involving identical motion but in which the relative locations of environmental objects remain unchanged. In the second and third tasks the participant responds by turning and moving directly to a named object.

Online behavioural pilots revealed an opposite turning bias for the update and control condition, with accuracy and reaction time well-matched in both conditions, resulting in a neatly controlled experiment that could isolate the spatial updating process without confounding difficulty. Furthermore, we manipulated the number of potential target locations between 1 and 3, which independently affects difficulty, and could affect the cognitive strategies for spatial updating. The new paradigm also allows measurement of the precision of head direction and grid-like representations with a varying degree of spatial updating and environmental information available. In addition to revealing the neural mechanisms of path integration, there exists a potential for assessing the functional integrity of relevant neural structures such as the hippocampus, entorhinal and parietal cortices in clinical populations.

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29. SPATIAL CONTEXTUAL INFORMATION MODULATES AFFORDANCE PROCESSING AND EARLY ELECTROPHYSIOLOGICAL MARKERS OF SCENE PERCEPTION

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Scene perception and path identification are two closely related cognitive processes that are essential for human spatial navigation. Supported by a common cerebral network, they allow us to rapidly process visual information and plan our movements in complex environments. Recently, a scene-selective region (SSR) in the dorsal visual stream, the occipital place area (OPA), has been proposed to be involved in the automatic detection of navigational affordances (i.e., the potential visible paths in a scene). However, these results were obtained using a passive scene perception paradigm, and possible interactions with prior spatial knowledge, such as a location of a goal to retrieve remain unexplored. To investigate this, thirty young adults performed a desktop-based virtual reality task in which artificial visual scenes with either 1, 2, or 3 navigational affordances (i.e., doorways) were presented in two conditions while EEG activity was recorded. The first condition was a scene memory task in which participants indicated whether the presented image was similar to the previous one. The second was a spatial memory task in which participants had to retrieve the position of a goal (e.g., center, right, or left) relative to a previously learned location,. Our results indicate that increasing the number of doorways only impaired the accuracy for the spatial memory task. ERP results showed a similar pattern of activity for both tasks, but with increased P2 amplitude in spatial memory compared to scene memory. Surprisingly, we reported no modulation of the P2 component by the number of affordances in either task. Taken together these result of a modulation of the early markers of visual scene processing suggest that the dynamics of SSR activity are influenced by prior spatial knowledge about the scene, such as the location of a goal, and that these information seem to interact with the automatic processing of available navigational affordances.

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30. SPATIAL NAVIGATION IN CLINICAL PRACTICE—DIAGNOSTICS AND TREATMENT IN PATIENTS WITH SEVERE COGNITIVE IMPAIRMENT

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Reliable spatial navigation abilities are crucial for everyday functioning and often impaired in patients with neurological disorders. Despite the potential of extended reality approaches commonly used in research settings, qualitative judgements of navigation ability remain the standard in clinical settings. Furthermore, navigation training in neurological rehabilitation rarely harnesses technological advancements and is highly resource intensive. Particularly patients with severe cognitive impairments require high-frequency training to realize their full rehabilitation potential, which remains challenging in current rehabilitative settings.

To bridge this gap between research and clinical practice, we present the VIENNA Young web app, a tool for spatial navigation assessment in young and middle-aged adults. VIENNA Young is easy to apply, freely available to clinicians and researchers and comes with extensive normative data. By using passive navigation in 15 different virtual environments, it ensures that navigation performance can be quantified even with existing motor and episodic memory impairment.

Additionally, we introduce PAN-Assistant, a navigation training and assistance platform developed through participatory research with patients with severe spatial navigation deficits and their treatment team. The PAN- Assistant showcases encompass indoor and outdoor environments utilizing high-resolution 3D scans and accessible forms of virtual and augmented reality (head-mounted display, tablet, and wearable showcase), customized to meet the specific needs of diverse people. Furthermore, a trainer interface enables tracking and adjustment of training difficulty, thereby ensuring assistance as needed.

Together, we aim to demonstrate how spatial navigation research and extended reality approaches can directly benefit patients with cognitive impairment using these two approaches in form of a clinically applicable assessment and tailored spatial navigation training.

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31. BEES LEARN LOCAL CUES DIFFERENTLY THAN DISTAL PANORAMA CUES IN A SPATIAL MEMORY TASK

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Bees are excellent navigators with an elaborate spatial memory. As central place foragers, bees return to their hive from different locations and behavioral results suggested that they use a cognitive map for navigation. However, which visual features are stored in the insect brain to facilitate navigation remains unclear. Behavioral experiments show that the visual panorama guides insects to their goal. To return to a goal location, insects try to match their view with a memorized panoramic snapshot of the goal’s vicinity. According to this strategy, each terrestrial landmark is thought to be part of a panorama and that insects do not discriminate between local and distal cues. To test whether bees indeed do not process local cues as single entities, but rather as part of a panorama, we designed a spatial memory task. In a circular LED arena, presenting either local (3-D objects) or distal visual cues (2-D visual patterns), bees learned the location of a rewarded feeder. Our results show that the bees found the feeder by using distal cues presented at the arena's inner wall and 3-D objects placed on the arena's floor. Surprisingly, in test trials, when bees were confronted with novel cues in addition to the recently learned ones, the bees differently responded to added local than to distal cues. Additionally, when setting local and distal cues in conflict, the bees' decisions were primarily driven by the position of local cues. Our results are consistent with findings from the hippocampal formation of vertebrates and suggest that there are two memory traces in the bee brain, one for learning local cues and the other for distal cues. With tetrode recordings from the brain of freely walking bees, we currently aim to find the neural correlates of local and distal cue processing.

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32. UNTANGLING CUE CONFLICTS: UNDERSTANDING SPATIAL CUE INTERACTION IN NAVIGATION THROUGH THE BAYESIAN CAUSAL INFERENCE APPROACH

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Spatial navigation involves the integration of various cues. This study employed the Bayesian causal inference (BCI) model to investigate navigation behavior in cue conflict situations, where visual landmarks and optic flow cues provided conflicting information about spatial locations. We explored how landmark instability influenced the underlying cognitive process of spatial navigation. One-hundred-and-forty participants were assigned to three groups: relatively stable landmark, unstable landmark, and unstable landmark plus explicit awareness of landmark instability. Behavioral results showed that increased landmark instability alone did not reduce navigators' reliance on landmarks. Adding explicit awareness of landmark instability reduced navigator's reliance on landmarks. In addition, landmark instability plus its explicit awareness decreased spatial localization precision when participants relied on landmarks exclusively. The BCI model provided a good account of the data. Echoing with the behavioral results, the modeling results showed that when made explicitly aware of landmark instability, participants reduced reliance on unstable landmarks via two ways: first, sensory noise level was increased for unstable landmarks, which naturally resulted in a lower weight assigned to landmarks in the common-cause judgment; second, a lower weight was assigned to unstable landmarks in the

different-cause judgment. Surprisingly, landmark instability did not affect participants' prior belief of a common cause, even when explicit awareness of landmark instability was imposed. Finally, while the cue-weighting strategy in the same-cause judgment is determined by objective cue reliability, the cue-weighting strategy in the different-cause judgment correlated with participants' subjective evaluation of relative cue quality. Together, our study highlights the BCI model as a comprehensive framework to examine cognitive mechanisms underlying spatial cue interaction during navigation.

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33. TOWARDS THE NEURAL BASIS OF THE MAGNETIC SENSE IN SUBTERRANEAN MOLE-RATS: BEHAVIOR AND RECORDINGS

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The ability to sense the Earth's magnetic field and use it for orientation and navigation is widespread in the animal kingdom. However, the neuronal mechanisms underlying this sensory ability are still poorly understood. African mole-rats are subterranean mammals that spend their entire lives in the darkness of a sophisticated maze of underground tunnel systems. To guide their straight burrowing and aid navigation in total darkness, it was suggested more than 30 years ago that they use magnetic cues. Our aim was to replicate this finding and identify the brain regions and neurons that encode magnetic cues in this mammalian model.

First, we sought to establish a robust behavioral assay to demonstrate the perception of magnetic fields. We set up a maze experiment, similar to one of the famous experiments conducted by Edward Tolman, and found evidence supporting the hypothesis that mole-rats use the ambient magnetic field as an allocentric reference when navigating in total darkness.

Next, we hypothesized that mole-rat brains contain spatial neurons, but unlike epigeic rodents, inputs from the somatosensory and perhaps the magnetosensory system predominate over visual cues. To test our hypothesis, we performed single-unit recordings in the hippocampus CA1 of freely moving mole-rats as they explored a dark environment under different magnetic conditions. In these experiments, we discovered place cells and we will present preliminary results on their firing properties.

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34. EGOCENTRIC NAVIGATION NETWORK PLASTICITY: TRAINING EXTENDS FUNCTIONAL CONNECTIVITY OF V6 TO FRONTAL AREAS OF CONGENITALLY BLIND PEOPLE.

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Retinotopically organized visual area 6 (V6) processes optic flow in animals and humans. We previously demonstrated that V6 is a sensory independent area involved in egocentric navigation. Indeed, V6 of congenitally blind (CB) people encodes auditory input for egocentric navigation similarly to the way V6 of sighted people encodes visual cues. In the current study, rest functional connectivity was used to investigate training induced brain connectivity changes in CB participants. CB participants were scanned during resting state sessions before and after a three-day training period learning to navigate in mazes using the EyeCane, a sensory substitution device (SSD). Before training, functionally defined area V6 is connected with areas of the dorsal network while it is anti-correlated with mediotemporal areas, suggesting a 'division' between egocentric and allocentric spatial reference frames. After training, however, V6 extends its connectivity to areas of the dorsolateral prefrontal cortex (9-46d) and anterior cingulate (24pr). These newly established connections may underlie the long-term plasticity observed in area V6 for processing auditory navigation cues, potentially reflecting the adaptation following training with the EyeCane and facilitating the acquisition of maze navigation skills. Our findings demonstrate that training can alter connectivity and induce long term plasticity in the dorsal stream. Since frontal areas are strongly involved in higher-order cognitive processes and in active control of planned behaviour, results suggest that training the dorsal stream could be explored as a potential strategy to mitigate cognitive decline, especially for Alzheimer research since degeneration affects mainly the navigation network until reaching frontal areas.

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35. DEGRADED VISION LEADS TO IMPAIRED SPATIAL MEMORY AND NEURAL REPRESENTATIONS OF SPACE

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Visual cues play a key part in human spatial memory, enabling distal detection of goals, landmarks and mapping out an environment. What happens to our spatial memory and its underlying neural representation when these cues are degraded, such as when foggy conditions obscure visual information?

Patients played a spatial memory virtual navigation game while undergoing invasive brain recordings (iEEG). The patients performed the task with and without fog degrading their visual input.

Behaviorally, spatial memory degraded under degraded visual input. On the neural level, we found that oscillatory power in the theta band in the medial temporal lobe increased significantly under degraded vision especially in patients with worse performance. We also found significant grid-like representations in the entorhinal cortex during regular vision that was impaired by fog.

These results demonstrate the importance of visual cues for spatial memory, and shed light on the effect of vision degradation on human neural representations of space.

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36. INDIVIDUAL DIFFERENCES IN NAVIGATING AROUND AUGMENTED VS. REAL OBSTACLES

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Navigating around an obstacle is a common spatial activity. However, what happens when these obstacles are virtual - e.g., added to our environment via augmented

reality tools - and can be perceived only visually? Do humans treat them the same as real obstacles? How do they view them?
To test this, participants walked down real hallways while wearing an augmented reality display, with physical and virtual obstacles partially blocking their path, and with their movements recorded. Our main measures are the user's subjective reports and the effects of obstacles' physicality on movement patterns - how much distance did participants keep from each type of obstacle?
We found that users clustered into a large majority (~80%) who treated the virtual and real obstacles in a similar fashion and avoided both with equal distances, while a smaller group treated them differently, keeping much less distance from them and often walking right through them. This was reflected also in their subjective resorts, though interestingly not with a full overlap between subjective description and actual behavior.
These results are part of an important baseline for understanding human spatial behavior in mixed reality, offer a useful tool for testing the basic science of spatial interaction and multisensory interaction, and offer practical potential both for rehabilitation and for the design of mixed reality interfaces. Finally, our findings demonstrate the importance of individual differences in user reactions to augmented content, and the way it affects their spatial performance.

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37. USING MINECRAFT TO ELUCIDATE THE NEUROBIOLOGICAL MECHANISMS UNDERLYING HUMAN HUNTING BEHAVIOUR

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Recent research has focused on spatial coding of other moving agents or moving objects (Danjo et al., 2018; Omer et al., 2018; Stangl et al., 2020). Oscillatory power in the medial temporal lobe (MTL) of a seated observer is sensitive to the spatial location of a watched moving other individual (Stangl et al., 2020). The hippocampus also encodes predictions about when a moving target will hit a boundary on a 2D display (Polti et al., 2021). Using a 2D display and joystick to control an icon chasing other icons, monkey dorsal anterior cingulate cortex activity can predict a moving target's future location (Yoo et al., 2021). However, it remains untested whether the encoding system for distance and direction to stationary goals in the human brain extends to moving goals. A classic situation where tracking moving goals occurs is in hunting behavior (Goodroe and Spiers, 2022). How encoding of distance and direction to moving targets and broader brain dynamics relate to hunting terrain remains unexplored. Recent unpublished work from the Spiers Lab has created a VR hunting task where participants chase a moving goal whose path is altered by a moving blocker agent, requiring participants to update internal representations of learned routes and future goal positions. Preliminary analysis suggests interesting roles for the dorsolateral prefrontal and frontopolar regions in coding future goals. Here, we extend this approach to multi-agent hunting, where the target hunted is a human-controlled avatar, using the video game Minecraft. In this task, two human players will work together to chase after another human-controlled character, the ‘prey’, whilst recording their brain activity using fNIRS and fMRI, creating an environment that realistically simulates group hunting. *We are about to start collecting data from a second batch of participants. We will have analysed the data by the time of the iNAV conference.

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38. SPATIAL NAVIGATION METRICS DIFFERENTIATING PRECLINICAL AND PRODROMAL ALZHEIMER’S DISEASE: A SYSTEMATIC REVIEW

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Despite increasing evidence of impaired spatial processing in early Alzheimer’s disease (AD), it is unclear precisely which spatial behaviours and associated metrics can classify people in different stages of the AD trajectory, from asymptomatic at-risk through to preclinical and prodromal stages. Given a pressing need to diagnose AD earlier for emerging therapies, establishing which spatial metrics and which digital devices suitable for future deployment at scale in clinical practice can capture them is critical. We addressed these knowledge gaps via a systematic review, searching two databases (PubMed/Web of Science; October 2022) following PRISMA guidelines with keywords for different dementia types combined with prodromal, preclinical and genetic or disorder risk factor terms. We included studies that collected digital or physical objective measures of wayfinding, orientation, memory, reference frame translation, route learning or path integration.
27 articles were included from 316 screened abstracts. None investigated non-AD dementias. From the 29 different tools utilised, 143 metrics were extracted, of which 51 showed early diagnostic potential (36%). We qualitatively harmonised these into 21 distinct summary metrics covering four domains of active or passively tracked spatial behaviours (allocentric, egocentric, path integration or GPS driving). Across these,

metrics capturing decreased navigation efficiency (i.e. distance/time to find goals) and accuracy (i.e. distance/angle from goal) were most frequent. Egocentric better differentiated prodromal than preclinical groups. Path integration and passive GPS tracking metrics showed promise for identifying at-risk individuals but were relatively under-explored.
We outline how the ability to quantify these measures with different devices mitigates against the risk of obsolescence arising from future technological advances, and discuss requirements for future clinical use.

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39. HOME VECTOR DEGRADES OVER SHORT TIME SCALES DURING PATH INTEGRATION IN THE FIDDLER CRAB, LEPTUCA PUGILATOR

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As animals execute behaviors like foraging, they must navigate with respect to the space around them. One such navigation mechanism is path integration, whereby animals recall their starting point by continuously measuring and summing distances and directions of their movements to create a single “home vector” in memory which allows a straight-line return home. As with any biological process, path integration is not perfect and is subject to errors that can affect the accuracy of the home vector. A relatively under-examined source of error is the short-term temporal degradation of the vector memory. Many invertebrates rely on path integration, but with few exceptions, it remains unknown how the home vector degrades over time. To investigate how long the home vector memory lasts, foraging excursions were examined in fiddler crabs (Leptuca pugilator). These are central place foragers that go on foraging excursions of up to a few meters at low tide during both the day and night, returning home between excursions to make physical contact with their burrow entrance. The excursions generally last 3-5 minutes, with fewer than 3% lasting more than 10 minutes, hinting that their path integration utilizes only short-term memory. To behaviorally test the time over which the home vector memory degrades, foraging fiddler crabs were magnetically trapped and detained in their original position and orientation for different amounts of time: < 1 minute, 5 minutes, and 15 minutes. Once released, their homing accuracy was measured in both distance and direction. Results suggest that the home vector memory is unaffected by detention of < 1 minute but is fully degraded by 15 minutes. This indicates that the memory required for path integration in fiddler crabs is very short-lived and may explain the temporal pattern of foraging excursions.

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