ABSTRACTS

Abstracts and authors of the *9th International Conference on Spatial Cognition: Segmentation and Binding in Spatial Cognition* (ICSC 2024)

1. Abstracts of Keynotes

KEYNOTE 1:

Information and meaning

Federico Faggin

In 1948 Shannon published a seminal paper that gave birth to information theory. To measure "information" it is only necessary to recognize the symbols, irrespective of their meaning. However, the purpose of information for us is to carry meaning. If a symbol has no meaning there is no information. This theory brought information into the materialistic worldview that has come to dominate science and society. Recently, large language models like ChatGPT and Gemini, are generative artificial intelligence programs that allow us to ask questions and have answers that at times are more meaningful than those we could get from a well-read human being. Are we then machines like the computers that run Gemini? The author will explain how training a computer with neural networks can create programs that appear intelligent. Surprisingly, this explanation requires a new theory of consciousness and free will that restores to the universe and to us the meaning and purpose that materialism stripped away.

KEYNOTE 2:

Orienting of attention and spatial cognition

Michael Posner

University Oregon, United States

Humans orient to their sensory world through foveation of target location or through covert shifts of attention. Orienting provides primacy to the selected location and in humans improves the precision of discrimination and increases the opportunity for segmentation and binding. All of these functions are mediated by common brain networks that include frontal, parietal and subcortical areas. Covert orienting can serve to prioritize processing the target even increasing its subjective intensity and its acuity. Cells exist that can conjoin features without attention, but reporting the conjunction appears to require orienting to it. An understanding of the pathways that connect attention networks to memory networks may allow us to enhance orienting and thus improve spatial cognition.

KEYNOTE 3:

Towards neuroadaptive navigation assistance to reduce spatial de-skilling

Sara Irina Fabrikant

University of Zurich, Switzerland

Maps have been invaluable navigation aids for millenia and thus critical for human survival. Increasing popularity of and dependence on current smart navigation technology, however, has shown to divert our attention from the environment and influence innate spatial abilities. To mitigate this, I propose neuroadaptive mobile maps that respond in real-time to navigators' cognitive task demands and visuo-spatial attention needs. In doing so, responsive displays may not only help us to maintain navigation efficiency, but more importantly, to also scaffold spatial learning. The proposed responsive navigation solution must strike the appropriate balance between welcomed mobility efficiency gains while limiting human spatial deskilling. Leveraging neuroadaptive cartography, we can ensure to remain effective navigators, empowered to explore the world with confidence.

KEYNOTE 4:

How are segmentation and binding computed and represented in the brain?

Christoph von der Malsburg

Frankfurt Institute for Advanced Studies, Germany; University of Zurich/Swiss Federal Institute of Technology Zurich, Switzerland; ZHAW School of Engineering, Switzerland

As the Gestalt Psychologists observed a hundred years ago, our brain has the ability to extract from the sensory input as well as represent to

our mind arrays of sensory elements that somehow relate to each other and that can, in their entirety, be subsumed under a particular abstract form, a "gestalt." This raises questions: How are sensory elements represented by neurons in our brain? How is the relatedness of sensory elements determined (the segmentation problem)? How are the relations of these elements expressed (the binding problem)? How is the subsumption of coherent arrays of elements under a comprehensive abstract form determined (the problem of comprehension) and how is this subsumption expressed in neural terms? I will describe a conceptual framework that gives answers to these questions.

KEYNOTE 5:

Visual working memory: From random arrays of colored squares to complex, spatially structured natural scenes

Steven J. Luck

University of California, Davies, United States

The visual system stores information in working memory approximately 100,000 times each day, and the storage capacity of visual working memory is a fundamental limit on cognitive abilities. When visual working memory first became widely studied in the 1990s, experiments used either simple artificial displays (e.g., random arrays of colored squares) or photographs of complex natural scenes. Over time, however, experiments using simple artificial displays came to dominate the field, and current quantitative models of visual working memory are limited to already-parsed discrete objects that vary along a small number of simple dimensions and have no spatial structure. Now that neural network models of the perception of natural scenes are widely available, it is time for models of visual working memory to go beyond simple artificial displays. We have developed an approach for modeling the representation of natural scenes in working memory, which makes quantitative predictions about behavioral performance and patterns of neural activity. Although far from perfect, this approach is a first step toward understanding how complex, spatially structured natural scenes are stored in working memory.

KEYNOTE 6:

Spatial memory and frames of reference: How deeply do we rely on the body and the environment?

Tina Iachini

University of Campania Vanvitelli, Italy

How do we mentally represent the world out there? Psychology, philosophy and neuroscience have given two classical answers: as a living space where we act and perceive, dependent on our bodies; as an enduring physical space with its feature, independent of our bodily interactions. The first would be based on egocentric frames of reference anchored to the body, while the second on allocentric frames of reference centred on the environment itself or on objects. This raises some questions concerning how deep the reliance on the body and the environment is when using these reference frames, and whether they are affected differently by the duration of time and the scale (small or large) of space. To answer these questions, I have brought empirical evidence of the effect of motor interference, blindness, environmental characteristics and temporal factors on egocentric and allocentric spatial representational capacity. The results suggest that egocentric

representations are deeply rooted in the body, with its sensory and motor properties, and are closely linked to acting now in small-scale or peripersonal space. Allocentric representations are more influenced by environmental than by bodily characteristics, by visual than by motor properties, and seem particularly related to large-scale or extrapersonal space. In line with neurophysiological evidence and a Kantian perspective, it appears that we are endowed with an internal spatial representation system ready to structure environmental information for our purposes. To what extent this system is innate and pervasive in cognition and what is its relationship to the neural 'positioning' substrate discovered by O'Keefe and colleagues requires further scientific investigation.

KEYNOTE 7:

Geometry and function in spatial terms: Core and more

Barbara Landau

John Hopkins University, United States

Theories of the meanings of spatial terms often focus on geometric properties of objects and locations as the key to understanding meaning. For example, in English, "The cat is on the mat" might engage geometric properties characterizing the figure ('cat', a point) and the ground ('mat', a plane) as well as the geometric relationship between the two objects ('on', coincidence). However, substantial literature suggests that geometric properties are far from sufficient to capture the meanings of many spatial expressions, and that instead, functional, force-dynamic properties of objects (e.g. support, containment) may be crucial to the meanings of these expressions. I will argue that both approaches are necessary to understanding the variety of spatial terms that appear in language, and will illustrate this by suggesting several new 'divisions of labor' within the locative expressions of a language. These divisions of labor have many consequences, including the ease of acquisition of each type in first or second language acquisition, the extent and kind of cross-linguistic variation from each type, and possibly the neural substrate underlying the two types.

KEYNOTE 8:

AI and the mysteries of visual experience

Jerome Feldman

University of California, Berkeley, United States

Machine learning, aka AI, is famously making remarkable advances in a wide range of applications. This has led to ubiquitous discussions on the social implications of current AI and on the prospects for AGI (General AI) in our lifetime. However, there has been no concomitant progress on scientific understanding of human intelligence. This paper will focus on some remaining unsolved questions of visual experience. These include the fact that every time we open our eyes we see a rich scene that has no plausible neural substrate. We will also discuss the famous binding problem – how the brain can combine activity in many disparate circuits to produce consolidated behavior and experience. The current AI practice of ignoring human intelligence is scientifically irresponsible. It is also potentially dangerous because being human involves much more than AI's ability to solve problems.

KEYNOTE 9:

Binding in working memory: Cognitive and neural mechanism

Zaifeng Gao

Zhejiang University, China

The binding problem is a pivotal issue within the domain of working memory (WM) and remains a central topic of contention among various WM models. In this talk, I will encapsulate a decade's worth of understanding into the mechanisms of feature binding within WM, as gleaned from research conducted in my laboratory. I will begin by noting that discussions on binding in WM have traditionally focused on voluntary binding. However, it is crucial to acknowledge that WM involves two distinct forms of binding: involuntary and voluntary, each characterized by unique processing dynamics. Through our application of psychophysics and ERP experiments, we have identified two separate pathways for the formation of implicit bindings within WM. Regarding voluntary binding, our extensive psychophysics studies have shown that its maintenance within WM requires an additional allocation of object-based attention, rather than merely requiring more central executive or spatial attention. Furthermore, I will discuss the cognitive architecture of the storage buffer for voluntary binding in WM. Our findings, derived from structural equation modeling and psychophysics experiments, suggest that WM does not possess a dedicated storage space for bindings, such as an episodic buffer. Instead, bindings share the same storage space as other WM features. Finally, I will explore the neural underpinnings of voluntary binding processing in WM. Using fMRI and TMS, we have endeavored to elucidate the core brain networks involved in the processing of conjunctive and relational bindings within WM, highlighting the critical brain regions common to these two distinct types of binding.

KEYNOTE 10:

Object perception in a multimodal context

Mohan Matthen

University of Toronto, Canada

In a unimodal context, perceptual segmentation is the drawing of boundaries. Visual objects are differentiated from others by chromatic boundaries; tactual objects by boundaries of texture, hardness, and other haptic properties; auditory objects by complex spatiotemporal melodic and harmonic discontinuities. But when we consider natural objects—in other words, material objects—such boundaries are not ontologically fundamental. The boundaries of material objects are defined by the material cohesion of atoms or, in the case of organisms, by biological unity. Material objects are perceived in multiple modalities—I can see a mango, feel it in my hand, hear it when it falls to the ground, etc. The multimodal perception of such objects demands cross-modal binding of unimodal boundaries. The thesis that I develop in this paper is that cross-modal binding is generally dictated by the properties of material objects.

KEYNOTE 11:

Segmentation and binding in perceptual organization and visual aesthetics

Johan Wagemans

KU Leuven, Belgium

Perceptual organization consists of a range of processes that create the basic units of our perceptual awareness such as groups of elements, bounded surfaces, figures against background, spatial relations in scenes, and so forth. They define the proto-objects that allow us to interact adaptively with the world and that can be recognized, categorized or named. Binding and segmentation are two of the basic processes involved in perceptual organization as they determine what becomes grouped together and separated from other things. Because binding is based on similarity and segmentation is based on dissimilarity, both processes go hand in hand. In this keynote lecture, I will clarify the approach taken by Gestalt psychology in understanding perceptual organization. I will also point out that contemporary vision science and visual neuroscience fail to do justice to the richness of the phenomenology of perceptual organization, and miss several of the key ingredients. The notion of Gestalts is often misunderstood. There are many different kinds of perceptual grouping and Gestalts that need to be distinguished to be able to develop a refined theory of the underlying mechanisms. Finally, I will demonstrate how segmentation and binding also play a fundamental role in our perception and aesthetic appreciation of images and artworks.

2. Abstracts of Symposia

SYMPOSIUM 1: General abstract

Near and far memories: Learning and memory within and beyond peripersonal space

Convenor: Claudio Brozzoli

Lyon Neuroscience Research Center, France; University Claude Bernard Lyon I, France

Despite the fact that the space in which we perceive objects and events around us appears continuous, the brain distinguishes between the space near the body, also known as peripersonal space (PPS), and the space far from us. This differentiation occurs thanks to an evolutionarily ancient mechanism implemented in a specific network of sensorimotor neurons (located in parietal, premotor, and subcortical areas), initially identified in monkeys and later in humans. PPS can be viewed as a buffer zone between the self and the world, better preparing us for defensive purposes and for guiding voluntary actions and navigation. However, the role of PPS in learning and memory, essential processes for defensive, appetitive actions and navigation, has only recently been researched. This symposium aims to present and discuss recent findings focusing on the contribution of PPS to learning and memory, offering a convergent view of the behavioral impact of PPS on perception, language, navigation, and the underlying neural mechanisms. Experts in the field will discuss the role of PPS representation in visual learning. Discriminating objects' shapes is faster in PPS than in distant space. This closeness advantage has been observed for both low-level (size, orientation) and high-level (face identification) visual features. New results presented in this symposium show the role of PPS representation in visual learning, highlighting its contribution to implicit associative learning of dangerous stimuli. PPS allows learning the dangerous nature of stimuli near the hand and transferring this association to different hand positions, showcasing hand-centered learning. Similarly, recent results will be discussed in support of a direct impact of PPS on visual perceptual learning, addressing whether learning differs depending on where events take place, near or far from the observer. By utilizing the "Ponzo Illusion" to create depth perspective, the authors have shown that different learning processes may be specifically associated with different sectors of space. Furthermore, our sensorimotor experience in space affects language, influencing the lexical choice of demonstratives used to refer to objects around us: "this" apple is typically understood to be closer to the body compared to "that" one. This symposium will discuss novel results indicating that

sensorimotor learning to control a target extends the use of proximal demonstratives even when the referent is far from the body. From a broader perspective, spatial memory is crucial for navigation, raising questions about how egocentric and allocentric perspectives interact while navigating memorized spatial maps, and how this is implemented in areas contributing to peripersonal space representation. The symposium will provide neuroimaging evidence, acquired through functional magnetic resonance imaging, of the superior and medial parietal cortex's role in egocentric navigation, while the entorhinal cortex encodes directions based on an allocentric reference frame. These results link egocentric perspective navigation of memorized maps to areas coding for PPS. In conclusion, we propose an integrated view of spatial cognition, learning and memory, suggesting that peripersonal space representation, a multisensory-motor interface enabling appetitive and defensive actions as well as navigation within the world around us, crucially contributes to the acquisition and retrieval of memories.

SYMPOSIUM 1: Submission 33

Spatial demonstratives out of reach: Physical control influences demonstrative choice in the far space

Angelo Mattia Gervasi[1,2], Anna Maria Borghi[1,3], Francesco Mannella[3], Luca Tummolini[3]

[1]*Sapienza University of Rome, Italy;* [2]*Lyon Neuroscience Research Center, France;* [3]*Institute of Cognitive Sciences and Technologies, National Research Council (CNR), Italy*
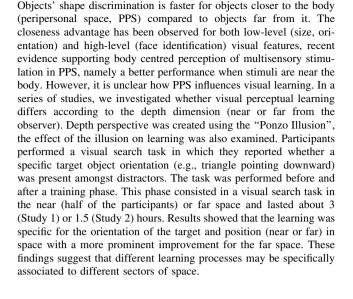
Background: Demonstratives like *this* and *that* are expressions that are used to coordinate attention on a referent by encoding a spatial contrast between near and far from the speaker. Recent experimental studies have linked this contrast to the perceptual distinction between peripersonal and extrapersonal space and have revealed that demonstrative usage is influenced by the presence of the referent in the speaker's reachable space. Still, the effect of non-spatial factors questions the sufficiency of such explanation. *Aims*: We propose that the linguistic contrast maps onto a more abstract contrast between being in physical control/not in control of the referent. Importantly, physical controllability includes reachability but is not limited to bodily contact. *Methods*: In an experiment in Italian, participants (N = 20) performed a perceptual discrimination task with two colored stimuli (red and blue circles) and were asked to indicate the stimulus with a target shape (e.g. a circle with two gaps) using demonstratives (questo\quello). In the task, one of the stimuli was movable with the mouse, while the other one moved independently. The target shape became visible only if the movable stimulus reached a specific region in the screen. Therefore, to solve the task, participants had to learn via trial and error how to change its shape. *Results and Conclusions*: Results show that participants used this more often to refer to the target stimulus when they learned to control its shape and demonstrate that physical control by the speaker influences demonstrative use even when physical contact with the referent is not relevant.

SYMPOSIUM 1: Submission 37

Visual perceptual learning is enhanced by training in the illusory far space

Antonio Zafarana[1,2], Alessandro Farne[3,4], Luigi Tame[1]

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Objects' shape discrimination is faster for objects closer to the body (peripersonal space, PPS) compared to objects far from it. The closeness advantage has been observed for both low-level (size, orientation) and high-level (face identification) visual features, recent evidence supporting body centred perception of multisensory stimulation in PPS, namely a better performance when stimuli are near the body. However, it is unclear how PPS influences visual learning. In a series of studies, we investigated whether visual perceptual learning differs according to the depth dimension (near or far from the observer). Depth perspective was created using the "Ponzo Illusion", the effect of the illusion on learning was also examined. Participants performed a visual search task in which they reported whether a specific target object orientation (e.g., triangle pointing downward) was present amongst distractors. The task was performed before and after a training phase. This phase consisted in a visual search task in the near (half of the participants) or far space and lasted about 3 (Study 1) or 1.5 (Study 2) hours. Results showed that the learning was specific for the orientation of the target and position (near or far) in space with a more prominent improvement for the far space. These findings suggest that different learning processes may be specifically associated to different sectors of space.

SYMPOSIUM 1: Submission 46

Disentangling reference frames in the neural compass during memory retrieval

Léo Dutriaux[1], Yangwen Xu[3], Nicola Sartorato[4,5], Simon Lhuillier[6], Roberto Bottini[2]

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The neural system that encodes heading direction in humans is found consistently in the medial and superior parietal cortex and the entorhinal-retrosplenial circuit. However, it is still unclear whether heading direction in these different regions is represented within an allocentric or egocentric coordinate system. To investigate this problem, we first asked whether regions encoding (putatively) allocentric facing direction also encode (unambiguously) egocentric goal direction. Second, we assessed whether directional coding in these regions scaled with the preference for an allocentric perspective during everyday navigation. Before the experiment, participants learned different object maps in two geometrically similar rooms. In the MRI scanner, their task was to retrieve the egocentric position of a target object (e.g., Front, Left) relative to an imagined facing direction (e.g., North, West). Multivariate analyses showed, as predicted, that facing direction was encoded bilaterally in the superior parietal lobule (SPL), the retrosplenial complex (RSC), and the left entorhinal cortex (EC). Crucially, we found that the same voxels in the SPL and RSC also coded for egocentric goal direction. Moreover, when facing directions were expressed as egocentric bearings relative to a reference vector, activities for facing direction and egocentric direction were correlated, suggesting a common reference frame. Besides, only the left EC coded allocentric goal direction as a function of the subject's propensity to use allocentric strategies. Altogether, these results suggest that heading direction in the superior and medial parietal cortex is mediated by an egocentric code, whereas the entorhinal cortex encodes directions according to an allocentric reference frame.

SYMPOSIUM 1: Submission 87

Associative learning in peripersonal space: Fear responses are acquired in hand-centered coordinates

Claudio Brozzoli

Lyon Neuroscience Research Center, France; University Claude Bernard Lyon I, France

Space coding affects perception of stimuli associated to negative valence: threatening stimuli presented within the peripersonal space (PPS) speed up behavioral responses compared to non-threatening events. However, it remains unclear whether the association between stimulus and its negative valence is acquired in a body-part centered reference system, a main feature of the PPS coding. Here we tested the hypothesis that this associative learning takes place in hand-centered coordinates and can therefore remap to other positions in space, according to hand displacement. We used a Pavlovian fear-learning paradigm to associate a visual stimulus, *vertically projected on a table* (light circle, the conditioned stimulus, hereafter CS) with an aversive stimulus (an electrocutaneous shock) applied on the right hand only when the CS was displayed close (CS+, *2 cm from the index finger*), but not far from the hand (CS-, *30 cm away*). Measuring the skin conductance response (SCR), we observed a successful learning of the negative value of the CS+, with a higher anticipatory fear response associated to it. Noteworthy, when participants kept their hand in a novel position, higher SCR was observed for visual stimuli displayed close to this new position, which was far from the hand during the conditioning phase and never associated to the aversive stimulus. By revealing a hand-centred (re)mapping of the conditioning effect, we provide support to the possibility of establishing associative learning in hand-centered coordinates. We suggest that the threatening valence of an object also depends on its basic spatial relationship with our body.

SYMPOSIUM 2: General abstract

Spatial cognition, neuroscience, and architecture: A conversation about the impact of built environments on cognition and emotion

Convenors: Giovanni Vecchiato[1] & Nicola Bruno[2]

[1]Institute of Neuroscience, National Research Council (CNR), Italy; [2]Department of Medicine and Surgery, University of Parma, Italy

We aim to initiate a conversation about the impact of built environments on human cognition and emotion. Architects and art historians have long assumed that the built features of interiors constrain not only the practical use of a space but also its impact on users' mental states and psychological well-being. The symposium will focus on such aspects and on the interplay of peripersonal space (PPS), defined as the multisensory representation of the space around the body that enables interaction, and extrapersonal space (EPS). The proposed talks will provide different perspectives, varying among academic disciplines and professional backgrounds. We will reconcile different concepts of space by identifying a common root in the concept of affordance, thus by considering a moving person exposed to different possibilities of experience at changing spatial locations, strictly depending on individual distributed patterns of perception and behavior. An example of such observer-environment relation is provided by the macro-affordance effect, producing a facilitation effect for the execution of walking-related actions in response to modification of the EPS. It reflects an implicit coding of spatial features of the environmental layout and observer–environment relationships, preferentially guiding a walking-related exploration of the built environment. We argue that the built environment transcends static states and representations, thus comprising a multitude of complex signals relevant to human cognition. Accordingly, the symposium will explore how architectural rhythms may foster neural entrainment, which affects working memory and perception, analyzing how real-world architectural configurations impact the interplay between the brain, body, and surroundings. In such an interplay, we will contribute with a theoretical and empirical framework forstudying architectural atmospheres' role on first impressions of space, integrating self-report assessments and neurophysiological measurements. We will then examine PPS's neural and computational mechanisms in humans, along with its primary functions and properties, thus showing its dynamic nature and optimization for body-environment interactions. We will explore the reciprocal relationship between PPS and social interactions, emphasizing its involvement in social cognition and susceptibility to social modulation. We will further explore such top-down influences on the PPS boundary by testing how the alteration of cognitive states produced by variations of architectural forms impact our space of interaction. The relationship between EPS and PPS could have a social ground, possibly depending on the individual architectural experience. Next, moving between lab-based investigations and large naturalistic datasets, we will show how the results from an empirical virtual reality study using brain, body, and behavioral measures informed a 'real world' replication using a longitudinal dataset that investigated the relationship between academic performance and the size of the rooms the assessments were conducted within. We will present several examples of how to translate neuroscientific research into architectural design and how such environmental changes affect human behavior. Ultimately, contributions will foster our understanding of the mutual and intimate relationship between body and space and immersive and interactive technologies as tools for architectural design.

SYMPOSIUM 2: Submission 28

Shared rhythms between the brain and the environment

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While moving through our built environment, the omnipresent patterns on the floor and wall become enacted and thus discharged as rhythms in the visual field. Such rhythmic stimuli are known to have an entraining effect on neural populations. Neural entrainment is the alignment of intrinsic brain oscillations with external rhythmic cues, and is known to affect cognitive processes, such as working memory and perception, by altering neural dynamics. We argue here that the built environment transcends static states, representations, and isolated variables, but instead comprise ongoing interconnected signals that foster resonance that affects working memory and perception. By conceiving our interaction with space as rhythmic, it changes how we analyze space relative to the human body and brain. Analyzing space should thus occurs through analyses that reveal entrainment, cross-frequency coupling, and phase resetting. In this study, we take advantage of the sensitivity to environmental rhythms, such as recurring architectural structures, to impact perception and working memory. Our analysis examines how real-world architectural configurations impact neural dynamics, cognitive functions, and behavior, underscoring the integral role of everyday rhythms in shaping the interplay between the brain, body, and surroundings.

SYMPOSIUM 2: Submission 56

The macro-affordance effect: Characteristics, neural correlates and role in the built environment

Giorgia Committeri & Annalisa Tosoni

University G. d'Annunzio of Chieti-Pescara, Italy

The original Gibsonian notion of affordance was inspired by real-time interactions between animals and their extended natural environment. Using an incidental priming paradigm based on repeated presentation of pictures of a virtual reality environment framed from different distances from the observer, we have described a behavioral facilitation effect for the execution of a footstep action, taken as proxy of walking, in response to distant vs. near objects/locations in the extrapersonal space (EPS). Based on the parallelism with the well-known "micro-affordance" effect within the peri-personal space (PPS), the effect has been referred to as "macro-affordance" effect. Later works have shown that the effect is implicitly activated and preferentially guided by the framing distance of the environmental layout rather than by distance of isolated objects in the environment. More recently, we found that the effect (a) generalizes to pictures of real-world scenes in which distance is not metrically manipulated, (b) is guided by both spatial (far vs. near distance) and semantic (built vs. natural environments) aspects and (c) is not associated with "micro-affordance" within the same individuals, in line with the dissociable nature of PPS and EPS. Finally, neurophysiological studies that we conducted through Transcranial Magnetic Stimulation (TMS) and electroencephalography (EEG), demonstrated that the effect is instantiated within foot-related sensory-motor and dorso-medial parietal regions, through mechanisms of motor anticipation and subsequent prediction error. The whole findings suggest that the "macro affordance" effect can be conceived as a measure of preferential body-space interaction for the walking-related exploration of the large-scale, built environment.

SYMPOSIUM 2: Submission 67

Exploring emotional and neurophysiological responses to architectural atmospheres

Elisabetta Canepa[1], Martina Putzolu[2], Edoardo Poratelli[3], Zakaria Djebbara[5], Kutay Güler[6], Luca Andrighetto[4], Anna Fassio[2], Bob Condia[7], Andrea Jelic[8], Laura Avanzino[2], Valter Scelsi[1]

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Background: Since our actions are spatially situated and emotionally driven, first impressions are crucial to extract information from our surroundings. Atmosphere is what we immediately and overall feel before focusing on details. Although multidisciplinary research on architectural atmospheres is expanding, how we experience atmospheres—via our bodies—remains indefinite. *Aim*: Through the interplay of architecture, psychology, and physiology, we explore the priming potential of architectural atmospheres on our first impressions of space. *Methods*: Participants (n=40) walked through four virtual-reality iterations where a corridor connected an empty room to an exhibition space. The starting and ending rooms never changed, whereas the corridor's light varied: dark, blue, amber, and bright. By integrating self-reports with physiological measures (heart rate and skin conductance), we investigated whether and, if so, how the corridor's atmosphere primed participants' impressions of the subsequent room. Before the virtual-reality test, a 5-minute resting-state electroencephalogram recorded participants' functional brain networks, and questionnaires analyzed their emotional intelligence, personality, and empathy traits. *Expected results*: First, we hypothesize the dark corridor has the most priming effects, thus replicating a previous experiment. Second, we expect connectivity indexes of various resting-state networks (e.g., salience, visual, and parietooccipital) to correlate to self-reported impressions of the ending room and heart-rate and skin-conductance behaviors. Third, we foresee correlations among individual characteristics, neurophysiological correlates, and atmospheric responsiveness (conscious and nonconscious). *Conclusions*: Atmosphere exists and primes our lives—even when moving through a corridor. This work intents to provide evidence-informed insights into how design features affect our emotions and first impressions.

SYMPOSIUM 2: Submission 68

From laboratory to real world: The impact of built environment scale in controlled and naturalistic settings

Isabella Bower

University of South Australia, Australia

Understanding brain activity and behavioural outcomes linked to built environment exposure is important, as it may affect underlying cognitive processes. This presentation explores the role of interior built environment scale on cognitive performance by exploring the results from a lab-based investigation and large naturalistic dataset. In the first study, 66 participants were exposed to indoor rooms of various scales using virtual reality and indoor environmental quality monitoring, while using electroencephalography to record neural responses. Our results showed enlarged room scale increased power spectral density across the beta bandwidth, frontal midline power in the gamma bandwidth, and enhanced theta connectivity across the left temporoparietal region and right frontal region. Given the link between high-frequency oscillatory activity and higher order cognitive tasks, a follow-up study was conducted to test the results in a real-world setting with a cognitive task. The second study used historical data of 15,400 higher-education students' examination scores and measurements of the rooms where the assessments were conducted within. Using a linear mixed model and accounting for students' coursework performance, the results indicated examination performance was reduced in rooms with elevated ceiling heights. Combined, the results from these two studies help us understand the role of interior built environment scale on brain activity and cognitive performance. Importantly, the findings provide evidence of how the scale of the buildings we occupy affects brain activity and our ability to perform tasks, suggesting we may be able to optimise cognitive functioning through building design, which could lead to major benefits for society.

SYMPOSIUM 2: Submission 85

The impact of architectural experience on interaction possibilities

Giorgia Guerra[1], Nicola Bruno[1], Giovanni Vecchiato[2]

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It has been demonstrated that architectural space, experienced through a virtual reality promenade, elicits a motor potential exerting an early effect on the processing of body expression. Capitalizing on these results, we investigate how perception of interaction possibilities are influenced by the manipulation of architectural features. Specifically, we aim to clarify the role of the extrapersonal space representation in shaping human interactive experiences and social cognition. To this aim, we analyze how changes in architectural features influence the plasticity of peripersonal space (PPS). Participants experience a virtual reality promenade through architectural spaces varying in sidewalls distance, as well as ceiling and windows height. Simultaneously, they performed an audio-tactile interaction task in which they were asked to respond as fast as possible to tactile stimulation applied to the trunk, while task-irrelevant auditory stimuli approach the same body part. The distance within which multisensory facilitation of reaction times occurs can be taken as a proxy of PPS boundaries. Moreover, the presentation of an avatar within such architectural spaces serves to explore the social role of architecture on the plasticity of PPS. We also test potential effects of cognitive expertise and professional training. Using high density electroencephalography we investigate the neural correlates underlying PPS' mapping in social and non-social conditions within changing architectures. We spend most of our time in architectural environments, engaging in numerous physical and social activities. Thus, our work could provide guidelines for designing interior spaces optimized for social interactions.

SYMPOSIUM 2: Submission 102

The built environment through the lens of psychophysics

Sergei Gepshtein

Salk Institute for Biological Studies, United States; Academy of Neuroscience for Architecture, United States

Designers of the built environment seek to deepen their understanding of human perception and behavior. The scientific method offers one manner of achieving that through the means demonstrated in psychology, cognitive science, and neurosciences. Adopting this approach to design is gaining momentum, opening new avenues for the application of established scientific concepts and methods. Significantly, the interaction with design alters the science, too, by triggering new scientific questions. I will address two such questions, in which psychophysics plays a central role. The first question concerns the structure of the "space" of the built environment: the apparent void that dwells between material objects. This space is organized in terms of specific possibilities of perception and action, and not by distance metrics used in physics and cosmology. I will show how rethinking the classical psychophysical theme of contrast sensitivity helps to understand and represent this structure, in a way that is new to both design and science. The second question concerns architectural proportion. Traditionally central to architectural thought, this theme was later marginalized because of the unclear motivation for choice of specific proportions and the lack of detailed understanding of their effects. By reframing this question scientifically we alert the designer to the fact that only those proportional relations matter for experience that can be distinguished by perceptual systems. The capability for making such distinctions depends on the viewing distance and the angle of observation. These basic notions have been neglected by prior research of proportion in both science and design.

SYMPOSIUM 2: Submission 109

Multisensory environments and their implications for design

Isabella Pasqualini

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Spatial interactions within the human environment, influenced by design, have the potential to subjectively shape perception, behaviour, mood, and well-being. While designers often rely on their intuition to generate design concepts, the vast potential of understanding the environmental influence on mental states and behaviour can significantly enhance and uplift design practice. Bodily self-consciousness builds the foundation of human experience through self-identification with and self-location within the boundaries of one's body. Past investigations conducted with virtual interiors have shown that perspective and depth sensations impact bodily self consciousness and, in turn, are mediated by multisensory space (Pasqualini et al., 2012; 2013; 2018). Further studies confirmed the relevance of multisensory space on architectural perception involving geometrical, atmospheric, or social parameters. Integrating our findings from the Lab into a hybrid research process merging neurocognitive studies with art and design practice, we aim to validate our initial hypothesis regarding the profound implications of cultural influences on environmental perception. Background emotions, such as familiarity, identity, and safety, are deeply rooted in the cultural context, not only the spatial and social design layout. Moreover, mood, as a specific, momentaneous, and subjective expression of self, seems to be a significant indicator. Our artistic research aims to challenge the idea of a universal design approach to spatial cognition, emphasizing the need for a contemporary interdisciplinary approach to design practice through empirical science to maximise inclusion, for instance, in terms of healthy ageing and neurodiversity.

SYMPOSIUM 2: Submission 138

Designing and evaluating architectural experiences

Tommaso Bertoni[1], Federica Sanchez[2], Ashwanth Ramkumar[2], Elena Giancarli[1,2], Anna Custo[1,3,4], Manuel André Bottiglieri[2], Cristian Catania[2], Andrea Serino[1,5]

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Architecture design often relies on implicit knowledge of how the brain represents space. Some multidisciplinary projects have attempted to link cognitive neuroscience and architecture. This work demonstrates that it is possible to apply brain function mechanisms to design architectural spaces and study human experiences within them. For a large furniture exhibition (Salone del Mobile, Milan), architects from a company in Milan proposed a novel exhibition pavilion layout design. Unlike the traditional grid-based layout with horizontal-vertical axes, the proposed design was more natural, ecological, and landmark-based. We hypothesized that this novel design would facilitate an easier, more enjoyable, and less stressful visit, enhancing memory and navigation of the exhibits. To test this, we conducted a virtual reality-based experiment where participants explored two

virtual pavilions: one with the novel design and one with the traditional design (N=30, within-subjects design). We evaluated: 1) subjective experience (e.g., stress, motivation...) via visual analogue scales; 2) memorability of the exhibits via a delayed recognition task; 3) navigation via a delayed digitalized localization task; and 4) neuro- and psychophysiological parameters using EEG and ECG. Results indicated that participants experienced less stress, higher motivation, better memory, and improved navigation accuracy in the novel design pavilion. They also showed higher alpha synchronization in occipital areas. The experiment was then adapted and replicated on a different sample (N = 140, between-subjects design) with physical visits to the realized pavilions, yielding similar results: significantly better subjective experiences, less fatigue, more distributed navigation and memories of the exhibits. This study exemplifies the successful integration of neuroscience and architecture in designing and evaluating architectural experiences.

SYMPOSIUM 3: General abstract

Visual short-Term memory binding in normal ageing and Alzheimer's disease

Convenors: Mario A. Parra[1] & Sergio Della Sala[2]

[1]Department of Psychological Sciences & Health, University of Strathclyde, United Kingdom; [2]Human Cognitive Neuroscience, Psychology, University of Edinburgh, United Kingdom

Visual Short-Term Memory binding (VSTMB) refers to the ability to temporarily hold features and properties that define objects' identities within conjunctive representations. Research on VSTMB in the fields of normal ageing and dementia has gained traction over the last two decades. Contrary to associative memory, the ability to hold stimuli and their relations, VSTMB has proved insensitive to normal ageing. Following these observations, tests tapping into VSTMB have been adapted for the assessment of people with or at risk of developing Alzheimer's disease (AD), proving successful in detecting and predicting this common type of dementia. The dissociable nature of VSTMB and associative memory has shed light on the neural underpinnings of these memory functions and their sensitivity and specificity to pathological ageing variants, such as AD. Questions remain regarding the forms of binding that remain preserved throughout the lifespan and those that decline early in neurodegenerative diseases. Also, the role of memory binding in exploring the continuum of neuropathological stages from normal ageing to AD remains unclear. In this symposium, our speakers will present studies reporting on the differential impact of ageing on relational and conjunctive short-term memory binding. They will explore the role of contextual information in the differential sensitivity of binding to normal ageing and neurodegenerative diseases, highlighting the influence of semantic information. The contributions such methodologies can make to accurately and timely define boundaries between normal and abnormal ageing and inform on the association between brain pathology and cognition will be highlighted. Finally, we will reflect on the relevance of theory-driven approaches on binding in normal and pathological ageing to address gaps in these fields.

SYMPOSIUM 3: Submission 123

Multisensory environments and their implications for design

Mario A. Parra

Department of Psychological Sciences & Health, University of Strathclyde, United Kingdom

Background: The Joint Program for Neurodegenerative Diseases (JPND) suggested that efforts should also be directed to harmonise promising cognitive tests. The group recommended the Short Term Memory Binding (STMB) Test, which assesses the ability to temporarily hold objects' features (colours and shapes) individually or integrated within the conjunctive representations. We have investigated if such a memory marker can inform about the different stages of AD continuum. That is, whether VSTMB deficits are observable in preclinical and prodromal stages (Aim 1). We have also investigated if such a sensitivity holds regardless of the disease variants (sporadic and familial AD) (Aim 2). Moreover, we have explored if, by combining the VSTMB test with biomarkers such as Eye-Tracking (ET), we could reveal neurocognitive features of AD that can hold biomarker properties (Aim 3). Methods: Aim1: involved 150 participants from the UK (Controls = 70, MCI = 80) and 264 from the GERO project, Chile (HC = 37, SCC = 117, MCI = 79, ADD = 31). Aim2: In collaboration with the Neuroscience Group, University of Antioquia, Colombia, we involved 334 participants (Controls = 210, Mutation Carriers = 124). Aim 3: The STMBT combined Eye-tracking (ET) was administered to 71 participants (from Aim 2). Results: Aim 1: STMB deficits are detectable from the very early stages of AD (subjective cognitive complaints). Aim 2: Such deficits were prominent in asymptomatic Mutation Carriers and were the only detectable impairments. Aim 3: When combined with ET, the methodology accurately classified 98% of affected subjects. Conclusion: The VSTMB test detects AD preclinically. Such deficits are associated with neuropathological changes linked to this type of dementia.

SYMPOSIUM 3: Submission 125

Temporary memory binding, normal and pathological: An overview

Sergio Della Sala

Human Cognitive Neuroscience, Psychology, University of Edinburgh, United Kingdom

Individual features can be bound in memory by means of two mechanisms: relational and conjunctive. Relational binding refers to the ability to associate stimuli in memory, whereby the individual elements forming such associations retain their original identity. Conjunctive memory binding, on the other hand, refers to the ability to integrate stimuli or their features into unified representations. The dissociation between relational and conjunctive bindings has been shown in a series of single-case studies of patients with specific impairments on relational but not on conjunctive binding and vice versa This dissociation is relevant because it translates into distinct aging effects and associations with different brain areas. A further

crucial dissociation is between long-term learning of conjunctive bindings and temporary combinations of features that may change on a moment-to-moment basis. Temporary conjunctive binding offers the basis for constructing short-term memory binding tests assessing the ability to hold conjunctions between surface features, such as objects and their colors (i.e., binding condition) relative to the ability to hold each of the individual features (i.e., single feature condition). Impairments in performance of these tests have been considered cognitive markers of Alzheimer's disease. However, to be considered as a cognitive marker for AD, properly powered longitudinal designs and studies that clearly relate conjunctive memory tests with biomarkers (amyloid and tau) are still needed.

SYMPOSIUM 3: Submission 131

Integrating object semantics into naturalistic contexts across healthy and pathological cognitive ageing

Moreno I. Coco

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The binding of low-level features in visual short-term memory has been consistently observed to be impaired in individuals suffering from dementia, even in the prodromal stage. However, contextually richer visual information, e.g., photographs, may activate compensatory processes, stemming from predictive mechanisms, leading to preserved binding in this neurodegenerative population. In this talk, I will present data from eye-tracking change detection studies showing that semantic information of objects (e.g., a toothpaste vs. a torch in a bathroom scene) guides early overt attention and mediates the binding of objects' identity and location in visual short-term memory, across ages and independently of the neuropathology.

SYMPOSIUM 3: Submission 132

Conjunctive and relational visual short-term memory binding in normal ageing

Christine Bastin

University of Liège, Belgium

In long-term memory, there are age-related differences in relational binding, but not in conjunctive binding. Following the view that the same type of representation supports short- and long-term memory, we conducted a series of 4 experiments to assess whether the same dissociation is found between relational and conjunctive short-term memory binding. Groups of young and older adults (n = 30 in each group in Experiment 1, 32 in each group in Experiment 2, 20 in each group in Experiment 3, and 24 in each group in Experiment 4) studied shape-colour or object–colour pairs in a relational condition in which items were linked to colour patches and a conjunctive condition where colour was integrated into the items. Memory for bindings was tested with different tests across experiments: a reconstruction task, a single-probe recognition memory task or a multiple-probe recognition memory task. Additionally, in a few studies, we assessed the contribution of controlled and automatic memory processes to performance with the Process Dissociation Procedure. The results showed that in the single-probe recognition memory task, an age-related associative deficit was observed in the relational binding task, but not in the conjunctive binding task. However, in reconstruction and multiple-probe recognition tasks where the retrieval of both relational and conjunctive bindings relied primarily on controlled memory processes, age-related differences was found in the two conditions.

SYMPOSIUM 4: General abstract

Empowering lives: Navigating the future of assistive technology

Convenors: Giulio Lancioni[1] & Lorenzo Desideri[2]

[1]Lega Filo D'Oro Research Center, Italy; [2]Sigmund Freud University, Italy

Assistive technology (AT), from spectacles to robots, is intended to facilitate people's participation in education, labor market and civil life and thus is seen as a tool to help them live healthy, productive, independent, and dignified lives. This symposium aims to provide an overview of AT innovations, from cognitive support tools and brain-computer interfaces (BCIs) to technological solutions for individuals with neurological impairments and multiple disabilities, each offering insights into the challenges and opportunities in the field. The first paper by Marcia J. Scherer discusses the implications of technology complexity and overload for people with cognitive disabilities. It describes the evolution from single-purpose devices to multifunctional digital technologies that aid in various cognitive functions and also points out the risks of cognitive and sensory overload attached to these technologies. Scherer advocates for a balanced approach to AT for cognition, emphasizing the need for standards and best practices that enhance cognitive functions without causing additional challenges. Angela Riccio and colleagues explore the use of brain-computer interfaces (BCIs) as an AT solution for individuals with severe motor disabilities and disorders of consciousness. This paper underscores the potential of BCIs to provide an alternative communication channel, enhancing or restoring the ability to interact with society. Despite promising evidence, the authors note that BCIs have yet to be fully integrated into AT portfolios, highlighting the need to bridge the translational gap between BCI development and practical application. Through the lens of the embodied cognition approach, the third contribution by Raffaele Di Fuccio aims at presenting the application in special education of solutions aimed at combining the potentials of haptic interfaces within mixed reality. These solutions, generally named Tangible User Interfaces (TUIs), proved effective in enhancing the effectiveness of rehabilitation interventions and the training of spatial kills of vulnerable populations. The final contribution, from Fabrizio Stasolla and co-authors, provides a selective overview of technological solutions for persons with neurological impairments and multiple disabilities. It examines the range of technology-based programs available (from those targeting adaptive responding to those focusing on communication skills and spatial orientation), and explores their impact on the participants and their caregivers. In essence, the paper presents an overview of technology-based interventions, noting their potential to support independence, self-determination, and quality of life for individuals with complex needs. The contributions collectively showcase the dynamic interplay between technological advancements and the live experiences of individuals with intellectual, cognitive, or multiple disabilities. The symposium provides an informative picture to researchers on a selection of the latest advancements in AT that can significantly enhance independence, communication, and quality of life.

SYMPOSIUM 4: Submission 13

Technology complexity and overload: Effects on people with cognitive disabilities

Marcia Scherer

Institute for Matching Person & Technology, United States; Department of Physical Medicine and Rehabilitation, University of Rochester, United States

Background: Regardless of etiology of cognitive disability, cognitive functions like remembering, learning, decision-making, and problem-solving can be affected and then enhanced through the use of assistive technologies for cognition (ATC). We have evolved from single-purpose products like medication reminders and voice recorders to multi-function digital technologies that aid in geolocation, information management, and multimodal learning. As feature-filled products are becoming ubiquitious, the risk of cognitive and sensory overload increases, posing a new set of cognitive challenges. *Objectives*: To delineate the risks of cognitive overload for people with cognitive disabilities and discuss ways to support them with ATC without interfering with a person's sensation, orientation, focus and attention. To provide an overview of current best practices in cognitive rehabilitation with the support of technology. To highlight the need for an integrated team approach in order to identify and best meet the needs of individuals and their significant others. *Method*: A review of research, current and desirable clinical practice standards, and user experiences with various ATC as exists in the relevant literature. *Results*: Technology development is dynamic, not static. Standards for cognitive rehabilitation and support provision are evolving at the same time as new advances, thus complicating the development of such standards, policies and guidelines. Yet, enough evidence exists of successes as well as potential problems and pitfalls to offer some guidance for moving forward. *Conclusion*: Cognitive support technologies are only useful to individuals if their cognitive functions are enhanced and not overloaded. Indicators exist to help guide future developments and refinement.

SYMPOSIUM 4: Submission 14

Technological Solutions for helping persons with neurological impairments

Fabrizio Stasolla[1], Anna Passaro[1], Mariacarla Di Gioia[2], Antonio Zullo[2]

[1]University of Benevento Giustino Fortunato, Italy; [2]Universitas Mercatorum of Rome, Italy

Background: Persons with neurological impairments (e.g., neurodevelopmental disorders, neurodegenerative diseases, acquired brain injuries, and/or rare genetic syndromes) and severe to profound multiple disabilities may experience significant problems dealing with environmental requests. Beside intellectual disabilities, communication difficulties, sensorial deficits, and/or extensive motor disorders are commonly acknowledged. Because they have a very limited and poor behavioral repertoire, they constantly rely on caregivers and families with a relevant increased burden in daily settings. To overcome this issue, one may envisage the use of technological solutions aimed at supporting their independence and self-determination, with positive outcome on their quality of life. *Objectives*: To explore the technological solutions available in the Literature for helping individuals with neurological disorders and multiple disabilities. To provide an overview of the technology-based setups in research and clinical practice. To emphasize the effects and suitability of such programs on the participants involved and their families or caregivers. To assess the outcomes on participants' positive participation and constructive engagement. *Method*: A selective overview of the newest empirical contributions available along last decade on the specific topic was carried out, according to PRISMA guidelines. Six main categories of targeted behaviors were identified, (a) adaptive responding, (b) challenging behaviors, (c) Communication skills, (d) locomotion, (e) Occupation and Leisure, and (f) spatial orientation. *Results*: Data were encouraging and promising although sporadic failures occurred. Implications of the findings were critically discussed. Some useful insights for future research and practice were

highlighted. *Conclusion*: Technology-based interventions may successfully be used for supporting people with neurological impairments.

SYMPOSIUM 4: Submission 136

Brain-computer interface as an assistive technology solution for people with severe motor disabilities and disorders of consciousness

Angela Riccio[1], Mariagrazia D'Ippolito[1], Valentina Galiotta[1], Valentina Caracci[1,2], Ilaria Quattrociocchi[1,2], Jlenia Toppi[1,2], Floriana Pichiorri[1], Emma Colamarino[1,2], Febo Cincotti[1,2], Donatella Mattia[1]

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Background: Assistive Technology (AT) provides for access to communication and interaction, empowering people with disabilities for an effective participation in the society (Andrich et al., 2013). The BCI translates brain signals into output commands in real time (McFarland and Wolpaw, 2017) independent of physiological peripheral pathways, thus providing an alternative channel to enhance/restore communication. Despite the experimental evidence that current EEG based BCIs can provide communication and interaction for people with severe disability (Riccio et al., 2011, 2015,2016), they are still not included in the portfolio of AT solutions (Riccio et al., 2022). *Objectives*: To provide an overview of current scientific efforts to bridge the translational gap between BCI development and end-users in order to turn BCI into an assistive/rehabilitative device. *Method*: We reviewed studies focused on the development and validation of innovative BCI devices for people with brain disorders, including disorders of consciousness. *Results*: Current evidence of BCI system efficacy indicated that BCI technology can provide people with severe motor disabilities with a brain-controlled assistive device, replacing communication and interaction with the environment. However, it has not been demonstrated that people with no residual communication behavior, such as completely locked-in (CLIS) patients and patients with disorders of consciousness (DOC) can effectively benefit of BCI for communication purposes. The dynamic passive-BCI-based detection of the fluctuation in responsiveness (windows of responsiveness) in DOC people is promising in identifying time windows in which they can potentially communicate. *Conclusion*: The BCI could improve the accessibility of modern AT and make personal AT solutions fully inclusive.

SYMPOSIUM 4: Submission 137

Tangible user interfaces in educational settings: A multisensory approach embracing the digital and real world

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Recently, there has been significant interest in the field of education towards Extended Reality (XR) technologies, encompassing virtual reality, mixed reality, and augmented reality. Contrary to virtual reality, mixed reality (MR) and augmented reality (AR) offer immersive experiences that blend real-world elements with virtual stimuli, engaging multiple senses simultaneously. Within XR, haptics plays a crucial role, targeting either kinetics or tactile perception. The haptic system (HS) refers to the sensory system of the hands or feet, integrating touch with motor activity. Research in haptics seeks to understand the intricate relationship between tactile feedback and

motor responses when interacting with external stimuli. Amidst this landscape of immersive experiences, a particularly promising aspect lies in the utilization of haptic interfaces within mixed reality. This involves incorporating real-world physical objects as fundamental representations and controls for digital information, enhancing user interaction. This concept is exemplified by Tangible User Interfaces (TUI). TUI has shown significant potential in facilitating learning activities, catering to both typically developing children and individuals on the autism spectrum. Literature underscores the efficacy of multisensory stimulation and technology in fostering neuroplasticity and supporting cognitive rehabilitation. Moreover, embodied cognition theory suggests that our cognitive processes are deeply intertwined with our sensorimotor experiences. Integrating multisensory experiences into digital storytelling through the use of TUIs can significantly enhance the effectiveness of rehabilitation interventions and the training of spatial skills. Spatial learning as a domain in cognitive development, and Tangible User Interfaces (TUIs) as an interaction approach for promoting constructional learning processes of very young children. By incorporating tactile feedback, olfactory cues, and gustatory sensations into digital storytelling activities, TUIs is able to create a more immersive and interactive experience for individuals undergoing educational settings, leading to improved engagement, motivation, and outcomes. This approach not only offers targeted interventions but also provides flexibility for implementation, as it can be easily accessed and utilized at home through mobile devices. The potential of the Tangible User Interfaces is broad and the main features are: 1) Scaffold learners; 2) Support cognitive development; 3) Promote initiative; 4) Think beyond boundaries; 5) Encourage communication and collaboration; 6) Return to reality, beyond reality. The proposal aims to present the different potentials of the Tangible user interface in educational settings, providing the limits and potential in their educational applications.

SYMPOSIUM 5: General abstract

Factors that mediate between environment and spatial cognition

Convenors: Bill Palmer[1], Alice Gaby[2], Joe Blythe[3], Tom Ennever[2,4], Clair Hill[5], Laurits Stapput Knudsen[1], Eleanor Yacopetti[2]

[1]*University of Newcastle, United Kingdom;* [2]*Monash University, Australia;* [3]*Macquarie University, Australia;* [4]*University of Surrey, United Kingdom;* [5]*University of New South Wales, United Kingdom*

The topographic features of the environment we live in do not map perfectly onto spatial categories encoded in the human mind. However, a range of studies have shown spatial cognition, both static conceptual categories and dynamic practices such as wayfinding, to be sensitive to specificities of the local environment to some extent. This symposium explores the range of factors that foster or disrupt this relationship between the environment and spatial cognition. Previous research has shown language to be one such factor (Levinson et al. 1992; Pederson et al. 1998; Majid et al. 2004; Senft 2007), other studies have emphasized the role of demographic variables including gender (Harris & Gitterman 1978; Wolbers & Hegarty 2010; Halpern 2012; van der Ham, Dijkerman & van Stralen 2021), occupation (Maguire et al. 2000; Shapero 2017), education (Adamou and Shen 2017; Lin 2022) and socio-economic status (Wassmann & Dasen 1998; Mishra, Dasen & Niraula 2003; Dasen & Mishra 2010). The Sociotopographic Model (STM) attempts to model the roles of sociocultural practices and language use in mediating between the environment, the linguistic system, and spatial cognition (Palmer et al. 2017, Lum et al. 2022). However, much more remains to be learned about the precise mechanisms at play, including which sociocultural practices most powerfully influence spatial cognition, the role played by social networks in the diffusion or maintenance of

spatial frames of reference in both language and cognition, the degree to which linguistic categories exist independently of the corresponding conceptual categories, and the extent to which the interface between cognitive and linguistic representations are mediated by language use, even if only in the form of 'internal monologue', self-directed speech, or [meta]linguistic reflection. This symposium advances knowledge on factors mediating between environment and spatial cognition by bringing together new cognitive and linguistic findings from current research by leading investigators in diverse disciplines ranging from anthropology and phenomenology to linguistics and cognitive neuroscience. These include novel findings in gesture, pointing practices, wayfinding, mental maps, environment-anchored toponyms, motion, cultural adaptation, and sensitivity to the earth's magnetic field. Papers included present novel data from Indigenous Australia, Mesoamerica, South America, the Middle East, North Asia, and Southeast Asia. The findings presented in this symposium cast important light on the way humans respond to their environments across a range of cognitive modalities, and the sociocultural, perceptual, and behavioural factors that mediate in that relationship.

SYMPOSIUM 5: Submission 9

Geocentric languages and the perception of the earth's magnetic field

Felicity Meakins

University of Queensland, Australia

Background: Like many Australian languages, Gurindji expresses spatial relations according to cardinal directions even in small-scale space, e.g., "there's a fly on your west shoulder". This attention to geocentric cues has cognitive effects that show that Gurindji people have an extraordinary mental map of the world anchored in the trajectory of the sun. Human neurophysiology has been shown to contain a hard-wired geomagnetic sensory system but no humans have been shown to have a conscious awareness of geomagnetism. However experimental work has only been undertaken on English speakers who do not use cardinal terms in small-scale space. *Aims*: We aim to investigate whether Gurindji people's attention to geocentric cues is reflected neurologically, i.e., whether Gurindji people have a hard-wired magneto-reception ability akin to migratory animals. *Methods*: We use three methods to investigate potential conscious Gurindji magneto-reception in 50 Gurindji participants compared with 50 English participants: 1. Shell task where participants attempt to detect a magnet placed under one of four cups in a double-blind experiment, 2. Electronic shell task, 3. Push button task designed to test whether participants can detect a magnetic-field shift in a Faraday Cage. *Results*: We find that in all of these tasks 15 Gurindji participants perform significantly better on these tasks than do the English participants who all perform at chance. *Conclusion*: These results indicate that some Gurindji people have the ability to detect geomagnetism which we attribute to their complex cardinal direction system and its use in small-scale space.

SYMPOSIUM 5: Submission 19

Mental maps and environmental experience: An analysis of the wayfinding culture of Evenki reindeer herders and hunters

Pablo Fernando Velasco

University of York, United Kingdom

Background: The diversity of human cultures of wayfinding has led to diverging views within anthropology, which can be divided into two

overarching theoretical camps: 'mental maps theory' (we position ourselves within mental maps to navigate) and 'practical mastery theory' (we navigate by mastering our surroundings and learning the paths therein). Lurking in the background of the debate is that these antagonistic conceptions of navigation reflect radically different ways of conceiving the experience of the places through which we navigate. *Aims*: This paper explores the link between navigational processes and the experience of place by considering the case of Evenki reindeer herders and hunters. *Methods*: We build on our ethnographic fieldwork, including semi structured interviews and participant ethnography, and employ an interpretative phenomenological analysis. *Results*: Our analysis shows how the idiosyncratic wayfinding methods of the Evenki involving a particular gait, path networks, and vast hydrological and toponymical knowledge– result in a unique experience of place in which the Evenki experience themselves as free individuals moving through an environment that is alive and rife with possibility. *Conclusion*: Our results show that Evenki wayfinding methods allow them to navigate without a need for integrating egocentric and allocentric frames of reference (e.g. their use of paths operates entirely egocentrically). As a result, the Evenki experience themselves as free individuals moving through an environment that is alive and rife with possibility. This analysis reveals the ways in which wayfinding processes relying predominantly on route knowledge, as opposed to survey knowledge, affect environmental experience.

SYMPOSIUM 5: Submission 25

Spatial language, cognition, and environment across Negev Arabic tribal varieties

Letizia Cerqueglini

Department of Hebrew Language and Semitic Linguistics, Tel Aviv University, Israel

Background: I explored geography's effects on spatial language and cognition in Ẓullām and 'Azāzmih, Negev Arabic varieties spoken in different environments. I considered the 45–65 age group, which experienced the shift away from nomadism that transformed Traditional Negev Arabic (TNA) into local varieties. *Aims*: Linguistic and sociocultural practices impact the relationship between spatial cognition and environment (Levinson et al. 1992; Lum et al. 2022; Majid et al. 2004; Palmer et al. 2017). I tested the hypothesis that Ẕullām and 'Azāzmih exhibit different geography-based linguistic and cognitive spatial structures. *Methods*: I tested frames of reference (FoRs, Levinson 2003) in static scenes on the horizontal plane. Forty Ẓullām/'Azāzmih speakers were tested linguistically with a modified version of the 'Man & Tree' test (Cerqueglini 2022) and cognitively ('Recognition,' 'Reconstruction' tasks; Levinson 2003). *Results*: Linguistically, absolute FoR is active, as in TNA (Cerqueglini 2022). Nevertheless, 56% of female and 12% of male Ẓullām informants developed a local geomorphic up/down (fōg/tiḥt) opposition anchored on a local northeast/southwest hilly slope, while 12% of female and 9% of male 'Azāzmih informants developed a geomorphic front/back (guddām/'ugb) axis anchored on the southeast/northwest course of local wadis. Cognition is exclusively absolute, except 12% geomorphic responses among Ẓullām women. *Conclusion*: A sedentary lifestyle fostered local strategies, especially among the Ẓullām (who reside closer to cities than the 'Azāzmih) and women, less mobile than men, confirming Halpern (2012), van der Ham et al. (2021), and Shapero (2017). As in TNA (Cerqueglini 2022), cognition seems only partially influenced by language.

SYMPOSIUM 5: Submission 27

Generic landscape terms in Seri placenames and how well they correspond with the places being named

Carolyn O'Meara & Oscar Castillo Tapia

National Autonomous University of Mexico, Mexico

Background: Seri is a language isolate spoken by around 1000 traditionally semi-nomadic hunter gatherers in northwestern Mexico. Previous work has documented 600+ toponyms, including simple (monomorphemic) or complex (multimorphemic) forms, frequently naming temporary campsites. Many toponyms include generic landscape terms. *Aims*: We test the hypothesis that generic landscape terms found in Seri toponyms correspond to the type of topographic feature being named. To explore this, we analyze a set of recurrent landscape terms present in Seri toponyms to see if they match the toponym's referent. *Methods*: We collected data and compiled a database of georeferenced Seri toponyms and then selected generic landscape terms of interest that were recurrent in the toponyms: iifa 'peninsula' vs. iyat 'point', xtaasi 'estuary' vs. inoohcö 'bay', iime 'home/nest' vs. icaheme 'camp'. We chose pairs of landscape terms that were similar semantically based on their English translation. *Results*: We found that the type of landscape entity referred to by the toponym does not always correspond with the meaning of the generic landscape term found in it. More relevant factors related to the presence of certain landscape terms include the size of the topographic referent (based on maps), cultural use of the named place (e.g., campsites), or whether the named place is in the sea or on the mainland. *Conclusion*: A compositional approach to understanding reference in toponyms is not sufficient. It's necessary to take into consideration sociocultural aspects related to the use of named places, as well as perceptual properties, like size.

SYMPOSIUM 5: Submission 32

Pointing practices amongst Kukatja speakers and what they reveal about underlying preferences in spatial cognition

Thomas Ennever

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Background: Speakers of different languages are known to exhibit different preferences in their use of conceptual frames of references (FoRs). One major parameter of variation involves a preference either for egocentric terms like 'left' or 'right' or for geocentric terms like 'north' or 'uphill'. Seminal studies in this field hypothesised that certain properties of gestural practice would also align with this distinction (e.g. Levinson 2003:216–279) but only a handful of studies since have tested this systematically (e.g. Marghetis, McComsey & Cooperrider 2020). *Aims*: This talk explores how pointing practices amongst speakers of Kukatja (Pama-Nyungan, Australia) (a community of speakers who prefer geocentric spatial strategies in language) accord with these early hypotheses. *Method*: This study utilises a corpus of video-recorded, narrative recounts tagged with geospatial information. All manual points within a sub-corpus of 35 minutes were coded for a range of properties (use of the gesture space, handshape, intended referent, inter alia). Attention is given to discussing what types of points can be said to invoke a single, particular FoR. *Results*: Evidence is found for Kukatja pointing practices which exhibit all of the properties hypothesized by Levinson to characterise gestural practise among preferentially 'geocentric' speakers. This includes not only the expansive use of the gesture space but also two novel subtypes of so-called 'transposed

points' (Le Guen 2011). *Conclusion*: Pointing practices amongst the Kukatja reveal a preference for a geocentric encoding of projective space: a preference that is thus multimodal; pervading both verbal language and gesture.

SYMPOSIUM 5: Submission 34

Semantic content and informational values of Nahuatl toponyms: A possible role in cultural adaptation to landscape?

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Background: A function of toponyms is to integrate points in space as coordinates in mental maps, but they also often predicate semantic content about places, e.g. presence of landscape features or natural resources. Work on Nahuatl toponyms has studied the grammatical structure of place names documented in colonial sources, but Van Essendelft (2018) proposed an adaptive function of informational content in Nahuatl toponyms. *Aims*: Adopting a perspective from landscape ethnoecology, this paper evaluates VanEssendelft's adaptive hypothesis, using a database of toponyms that better reflects the types of Nahua place names in everyday communicative use, and a form of analysis that better reflects their grammatical and informational structure. *Methods*: The present study focuses on a set of toponyms in everyday use collected using ethnolinguistic methods (landscape walks, interviews) in two Nahuatl speaking communities: Tequila Veracruz (n=109) and Hueyapan, Morelos (n=125). Toponyms are categorized by semantic content, and relative frequencies of different semantic categories are compared. *Results*: In both communities the most frequent types of semantic content were landscape features and ecotopes, but they differ in the frequencies of types of semantic content represented in their toponymies, which may reflect differences in landscape types and abundance of hydrological features. *Conclusion*: The informational content supports a potential adaptive function as one of the informational functions of toponyms, both for communicating resource locations and for land recognition for traveling. This suggest that toponyms can have a cognitive function of integrating resource locations as waypoints in mental maps.

SYMPOSIUM 5: Submission 40

Environmental sensitivity and conceptual representations of geocentric spatial terms in Wik-Mungkan (Australia)

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Background: In psycholinguistic research, absolute spatial Frames of Reference (e.g. cardinal directions like English north) is central to claims about spatial cognition and language (e.g. Levinson 2003; Levinson & Wilkins 2006; Majid et al. 2004; Pederson et al. 1998; Tversky 1996; Tversky & Taylor 1998). Recent research on similar terms has demonstrated that supposedly absolute systems are often intimately anchored in the environment, not based on abstracted spatial axes (Palmer 2015; Gaby et al. 2017). *Aims*: This paper investigates the conceptualization of directional terms traditionally translated as 'north', 'east', 'south', 'west' in the Australian language Wik-Mungkan. Data analysis aims to identify environmental factors influencing conceptualization of geocentric terms in Wik-Mungkan. *Method*: Using multimodal geotagged data recorded in the Cape York community of Aurukun, the terms are analysed based on the denoted direction and location of the utterance, probing their underlying spatial conceptualization. *Results*: The results demonstrate that

empirically that these geocentric terms are sensitive to the physical environment, to such a degree that there is overlap between directions covered by different terms when environmental anchors of the terms are competing. Identified environmental anchors include an inland/coastwards axis; sun; river; significant landmarks; and alignment of the road network. *Conclusion*: Integrating denotational geotagged data from various contexts with language consultants' insights, we demonstrate that conceptualization of the Wik-Mungkan terms are highly sensitive to environmental context, mediated by human interaction with environmental features, in ways consistent with both the Topographic Correspondence Hypothesis (Palmer 2015) and sociotopographic model (Palmer et al 2017).

SYMPOSIUM 5: Submission 50

New findings on the interaction of environment and spatial cognition

Bill Palmer[1], Joe Blythe[2], Tom Ennever[3,4], Alice Gaby[3], Clair Hill[5]

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Background: Cross-cultural and cross-linguistic diversity in spatial behaviour is well-established. Recent research now also reveals considerable diversity within communities, correlating with group-level and individual demographic variables. Sociotopography (Palmer et al 2017) models the interaction of factors including perception of landforms, cultural interaction with environment (land use, subsistence mode, built environment, wayfinding practices, etc), cultural adaptation, neurological responses, education, age, gender, and language. However, the role of all these factors in mediating between environment and spatial cognition remains under-investigated. *Aims*: We will identify factors mediating between environment and spatial cognition by synthesising recent results with new results presented in the ICSC symposium on this topic, for which this is a position paper. *Methods*: Data were elicited through a combination of established and novel linguistic and non-linguistic tasks, including Man&Tree, Ball&Chair, geotagged navigation narratives, recognition and recall tasks, geotagged pointing tasks, and Faraday Cage tests. These results were subject to meta-analysis. *Results*: We draw together new cognitive and linguistic findings from Indigenous Australia, Mesoamerica, South America, the Middle East, and North Asia, across disciplines from anthropology and phenomenology to linguistics and cognitive neuroscience, including novel findings in gesture, pointing practices, wayfinding, mental maps, environment anchored toponyms, cultural adaptation, and sensitivity to the earth's magnetic field. *Conclusions*: The new findings synthesised here cast important light on the way humans respond to and manipulate their environments across a range of cognitive modalities, and point to future interdisciplinary directions in developing understanding of the diverse factors that interact in constructing conceptual representations of space.

SYMPOSIUM 5: Submission 60

Re-framing frames of reference: 30 years of man and tree

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Background: Spatial Frames of Reference (FoR) are conceptual strategies for specifying spatial relations between objects and have

been central to many investigations of the relationship between language and cognition. Director-matcher tasks like the widely-used "Man-and-tree game" (Levinson et al., 1992) have been pivotal in eliciting FoR data comparable across studies. However, variation in task design and data coding between studies has under-recognized implications for their true comparability. *Aims*: This paper investigates the impact of task design and data coding on macro-level findings. We assess variation in task design across a range of studies to motivate proposals on future data collection practices. *Methods*: We conduct a comparative meta-analysis of 30+ studies using Man-and-Tree and similar director-matcher tasks (e.g. Ball-and-Chair), establishing procedural approaches and data-coding used. *Results*: Substantial variation exists in implementation of the tasks over the last 30 years. Studies differ notably in experimental setup (e.g., participant numbers; how the game is allowed to progress; how participants interact with each other) and data coding (e.g., unit of analysis as conceptual representation or linguistic item; omission of certain data points). We demonstrate that these methodological differences have non-trivial effects on results, shaping research findings about the linguistic conceptualisation of space. We identify an emerging set of 'best practices' for running such tasks. *Conclusion*: Task design and data coding have significant implications for macro-scale comparisons of spatial language and cognition. As relevant studies are often conducted with small numbers of participants, the way games are run and coded greatly influences subsequent generalisations.

SYMPOSIUM 5: Submission 61

When up is down and down is up: Local topography, landmarks and absolute frames of reference in Ancash Quechua

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Background: Speakers of "relative" languages like English are familiar with spatial ambiguities like front/back and left/right (mine or yours?). Because such ambiguities depend on Frames of Reference, they vary cross-linguistically. This paper addresses an ambiguity in Ancash Quechua speakers' use of Absolute terms like "uphill" and "downhill." Speakers sometimes confront ambiguity between abstracted absolute and geomorphic (Bohnemeyer et. al 2015) senses of up/down, e.g. when the overall landscape ascends eastward, but the immediate eastward slope is downhill. *Aims*: The aim is to use studies of Quechua to help understand the sources and nature of differences in spatial ambiguities and their pragmatics. *Methods*: We juxtapose a micro interactional analysis of the pragmatics of spatial communication in naturalistic recordings with a cognitive experimental task for spatial memory ("Chips Task," Levinson 2003) conducted with speakers in Peru. *Results*: Speakers in the same community with distinct environmental engagements (i.e., farmers/herders) differ significantly in FoR preference on a spatial memory task. Because speakers recognize the extent of one another's environmental awareness from social cues, they tailor spatial descriptions accordingly. The interactional analysis suggests that the recognizable social differences implicated in a cognitive study (Shapero 2017) play a central role in the pragmatics of absolute spatial ambiguities. *Conclusions*: Spatial ambiguities not only differ in kind cross-linguistically, but also in the degree to which social information informs their pragmatics. The paper demonstrates how social considerations interact with other factors, like the distance of speakers

from the described scene, and the degree of contradiction between local and canonical topography.

SYMPOSIUM 5: Submission 73

Between brain and terrain: Investigating linguistic representation of environments during motion

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Background: Recent research addresses human representation of space and environments in language and cognition, showing significant differences across communities. So far, however, the inquiry has been mostly restricted to the relationship between environment and static linguistic, cognitive and sociocultural features and systems. Less understood is their relationship in direct, dynamic interaction, as when speakers move through and communicate about terrain. However, moving situations are different: they involve everchanging affordances, complex motor activities, and influx of sensory information that influence our communication about the environment. Therefore, moving situations are likely to elucidate questions concerning the factors that generate diversity. *Aims*: In this work, we explore linguistic representations of the environment in in-situ communication on the move across different spatial categories in language: motion verbs, landscape terms, place names, and demonstratives. We illustrate this with novel language data from two highly mobile speech communities, Dâw (Brazil) and Jahai (Malaysia). *Methods*: Dâw and Jahai interactions were recorded with GPS-equipped action cameras while speakers were walking. This allowed for multifactorial annotation of extra-linguistic information on the moving speech event and analyses of linguistic representations of the terrain uttered in the actual environment. *Results*: Our data show that embodied experiences in the environment activate specific parts of grammars and lexicons (e.g., motion verbs), that are: i) prone to surface in, and encode, real world contexts; ii) sensitive to the dynamic character of moving discursive ecologies. *Conclusion*: Moving scenarios offer a promising way forward in understanding the dynamics, diversity and rationale of environmental representation in language.

SYMPOSIUM 5: Submission 108

Reference frames in Mesoamerica: Evidence of cultural evolution

Juergen Bohnemeyer[1], Donelson Katharine[2], Elena Benedicto[3], Alyson Eggleston[4], Alejandra Capistrán Garza[5], María de Jesús Selene Hernández Gómez[6], Nestor Hernández Green[7], Samuel Herrera Castro[8], Randi Moore[1], Carolyn O'Meara[8], Enrique Palancar[9], Gabriela Pérez Báez[10], Gilles Polian[11], Rodrigo Romero[8], et al.

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Background: Frames of reference provide a unique window into the dynamics of cultural transmission in spatial cognition. *Aims*: We investigated the impact of linguistic, sociodemographic, and environmental factors on frame use in the Mesoamerican linguistic and cultural area. The experiments described below were carried out with speakers of six Mesoamerican languages, two indigenous control groups from adjacent regions, and speakers of rural varieties of Mexican and Nicaraguan Spanish and European Spanish from Barcelona. *Methods*: We used standard experiment designs for testing frame use in nonverbal cognition and language: a memory recall array-reconstruction task ('New-Animals', Bohnemeyer, 2011) (N=216) and a referential communication picture-matching task ('Ball-and-Chair', Bohnemeyer, 2008) (N=212). *Results*: We previously reported partial results obtained through regression modeling (Bohnemeyer et al., 2015). Here we present a comprehensive analysis based on machine learning classifiers, which are more suitable to the properties of the datasets (Tagliamonte & Baayen, 2012). We find an endemic allocentric bias in all indigenous populations and a linguistic preference for relative frames in the Spanish speakers. Formal education and frequent use of L2-Spanish, but also frequent reading and writing, boost relative frame use in the indigenous languages. First language emerges as by far the strongest predictor of recall memory performance in all populations. *Conclusion*: The findings support the hypothesis of a global cultural shift from allocentric to relative frame use. Independent evidence for such a shift comes from research on the spatial cognition of non-human primates and human infants (Haun et al., 2006, Nardini et al., 2006, Shusterman & Li, 2016) and the study of adult populations with no extrinsic linguistic bias (Bohnemeyer et al., 2015).

SYMPOSIUM 6: General abstract

Low-dimensional spatial mappings of conceptual knowledge in human brain and behavior

Convenors: Carlotta Isabella Zona[1] & Simone Vigano[2,3]

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The neurocognitive mechanisms that allow humans and intelligent species to acquire, store, and use their knowledge of the world have been subject of intense debate. Cognitive (neuro)scientists have proposed that we might organise such knowledge in low-dimensional models that capture the structural relations between items in memory, facilitating learning, recall, and flexible behaviour (Shepard, 1962; Gärdenfors, 2000; Bellmund et al., 2018; Behrens et al., 2018). Paradigmatic examples are those of numbers and temporal events, that we tend to organise in ordered linear structures (mostly oriented from left-to-right in Western cultures) (e.g., Santiago et al., 2007; Casasanto & Bottini, 2014; Dehaene et al., 1993), but recent experiments show similar effects also for more abstract information, such as payout probability of unrelated visual stimuli (Luyckx et al., 2019). Recently, brain-imaging evidence has indicated that this mapping of conceptual knowledge onto low-dimensional schema might be supported by brain mechanisms and structures that are typically associated with interacting and navigating the physical environment (for a review see Bottini & Doeller, 2020). For instance, linear structures underlying the representation of numbers are mostly represented in parietal circuits and are reflected in horizontal eye movements during fluency tasks or mental arithmetic (Loetscher et al., 2010; Knops et al., 2009; Dehaene et al., 2003). Similarly, learning to organise novel visual (Constantinescu et al., 2016), odor (Bao et al., 2019), semantic (Viganò et al., 2021), or social (Park

et al., 2020) stimuli along two-dimensional maps for solving decision making problems is supported by the hippocampal-entorhinal system, wherein distance in 2D conceptual spaces is reflected by similarity in neural activity patterns and in hexadirectional modulations of brain activity. Yet, the precise extent to which the structuring of such "conceptual spaces" exploits mechanisms typical of our spatial interaction with the world is far from established, and our understanding of the behavioural correlates of this low-topographic mapping of conceptual knowledge is still limited. What is the link between low-dimensional brain representations of conceptual spaces and human behaviour? Is this internal organisation of stored information into low-dimensional models reflected in the way we use our knowledge to interact with the world? The symposium aims to foster a cross-disciplinary dialogue amongst scholars investigating the neural mechanisms supporting the organisation and use of low-dimensional conceptual spaces, and how such mechanisms manifest in human behavior. Furthermore, the symposium represents a forum to exchange knowledge on novel methodological approaches to explore the behavioral signatures of low-dimensional "cognitive maps".

SYMPOSIUM 6: Submission 17

Structural abstraction and behavioral flexibility

Seongmin Park

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Generalizing past experiences to new situations is a key attribute of human intelligence, yet it continues to pose a significant challenge for many psychiatric patients, as well as for many AI systems. While standard reinforcement learning offers a computational framework to comprehend decision-making processes in the brain, it falls short in explaining how the brain extrapolates previous experiences to facilitate novel and flexible decision-making. A promising approach to achieving this behavioral flexibility involves the development of an internal model known as a "cognitive map"—a combined structural representation that outlines the relationships between entities learned from separate experiences. However, the mechanisms by which the brain constructs low-dimensional representations and utilizes the cognitive map to enhance generalization and flexible decision-making remain poorly understood. Here, we aim to illuminate these processes through human neuroimaging studies and neural network modeling. Our findings reveal that the brain structures the relationships between discrete entities into a graphical format, situated within Euclidean space. Additionally, we demonstrate how the geometry of the cognitive map dynamically interacts with evolving task objectives to support flexible decision-making. We present evidence demonstrating that the brain can generalize previously acquired abstract knowledge structures to address new challenges, similar to discovering uncharted shortcuts in spatial navigation. Taken together, our findings contribute to a more profound understanding of complex human cognition that extends beyond the capabilities of conventional models.

SYMPOSIUM 6: Submission 21

Behavioral signatures of the hexagonal mapping of conceptual spaces for number retrieval

Carlotta Isabella Zona , Daniel Janko , Martin H. Fischer

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The hexagonal activation pattern of grid cells in entorhinal cortex supports navigation in physical as well as conceptual spaces. Our research aims to identify behavioral correlates of a grid-like spatial

organization of conceptual knowledge. Participants (n = 68) listened to spoken numbers (1-12) and pointed on a large touchscreen to a central dot, then to the location of the number on a clockface. To ensure reliability of results, we compared different sampling frequencies (spoken numbers increased by either one or 0.5 steps, e.g., 1, 1.5, 2) and also tested blindfolded participants. We hypothesized pointing behavior to be modulated by the (mis)alignment of target locations with the hexagonal grid. We thus examined whether targets spaced 60° from one another yielded common behavioral signatures in terms of variable and constant angular error, as well as response speed, with no hypothesis as to the patterns' direction. Targets aligned with a 60° phase yielded lower variable angular error and faster pointing. Constant error was unaffected by phase, suggesting that the observed effects were not caused by specific pointing biases, but by larger pointing variance. These results provide first preliminary evidence for behavioral effects in pointing to locations along a 60° symmetry and warrant further investigation.

SYMPOSIUM 6: Submission 36

Spontaneous eye movements reflect the representational geometries of conceptual spaces

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Background: Functional neuroimaging indicates that the human brain can represent the relational structure of concepts in memory using coding schemes typical of spatial navigation. Aim: However, it's unclear if we can infer internal conceptual geometries solely from observable behavior. Methods: To answer this question, we engaged participants in verbal fluency tasks where they had to randomly mention numbers, colors, and animals, while we monitored their spontaneous gaze behavior with an eye-tracker. Results: In the "numbers" block, left and right eye movements correlated with signed numerical differences between mentioned numbers, consistent with the left right 1D geometry of the number space (mental number line). In the "colors" block, we observed that Euclidean distances between colors in subject specific psychological spaces (reconstructed using MDS from similarity judgments) correlated with distances covered by bidimensional eye movements: the closer two colors were in the color wheel, the smaller the distance between their corresponding gaze fixation in visual space, consistent with the 2D ring-like geometry of the color space. Lastly, in the "animals" block, we observed that 1D horizontal eye movements correlated with low-dimensional similarity in a linguistic "frequency space": the more similar (or different) the frequency values of two mentioned animals in language, the more participants looked to the left (or right). Conclusions: These results suggest that the representational geometries used to internally organize conceptual spaces might be reflected in our spontaneous gaze behavior.
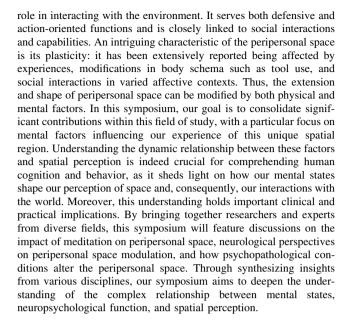
SYMPOSIUM 7: General abstract

Mind over space: How mental training and psychopathological conditions alter the peripersonal space

Convenor: Luca Simione

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The peripersonal space, a region surrounding the body extending the sense of self beyond physical boundaries of the body, plays a crucial role in interacting with the environment. It serves both defensive and action-oriented functions and is closely linked to social interactions and capabilities. An intriguing characteristic of the peripersonal space is its plasticity: it has been extensively reported being affected by experiences, modifications in body schema such as tool use, and social interactions in varied affective contexts. Thus, the extension and shape of peripersonal space can be modified by both physical and mental factors. In this symposium, our goal is to consolidate significant contributions within this field of study, with a particular focus on mental factors influencing our experience of this unique spatial region. Understanding the dynamic relationship between these factors and spatial perception is indeed crucial for comprehending human cognition and behavior, as it sheds light on how our mental states shape our perception of space and, consequently, our interactions with the world. Moreover, this understanding holds important clinical and practical implications. By bringing together researchers and experts from diverse fields, this symposium will feature discussions on the impact of meditation on peripersonal space, neurological perspectives on peripersonal space modulation, and how psychopathological conditions alter the peripersonal space. Through synthesizing insights from various disciplines, our symposium aims to deepen the understanding of the complex relationship between mental states, neuropsychological function, and spatial perception.

SYMPOSIUM 7: Submission 124

Early traumatic experiences alter peripersonal space in children

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Background: Far from being a fixed phenomenon, spatial cognition is a highly plastic cognitive function porous to environmental experiences. In this framework, childhood trauma shapes the way individuals perceive and interact with the spatial environment, influencing their sense of safety, comfort, and ability to navigate the world around them. Aim: The aim of the present paper is to investigate the influence of childhood maltreatment on peripersonal space (PPS) representation. PPS is indeed a sector of space serving both defensive and action-oriented functions and whose size is strongly influenced by individual traits and environmental interactions. Method: A group of Sierra Leonean youths exposed to maltreatment and a control group of healthy participants were asked to perform an audio-tactile integration task (Serino et al., 2015) typically used to measure PPS size and boundaries demarcation. Participants also filled cross-cultural adapted clinical scales to evaluate post-traumatic stress disorder symptoms. Results: Compared to controls, youths exposed to maltreatment showed a narrower PPS. No differences were found in PPS boundaries demarcation. Furthermore, the narrow the PPS, the higher the post-traumatic stress disorder symptoms. Conclusion: The present study reveals that being exposed to early traumatic experiences specifically alters the multisensory integration processing governing PPS representation, raising interesting reviews of some of the clinical sequelae frequently associated with such experiences (e.g., dissociative phenomena, interpersonal deficits, spatial deficits).

SYMPOSIUM 7: Submission 126

Your space or mine: Trait anxiety affects the peripersonal space plasticity in a social context

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Background: Peripersonal space (PPS) is a highly plastic sector of space surrounding our body. However, to date, nothing is known about PPS plasticity after a social motor interaction, and whether individual traits, such as anxiety, modulate it. *Aim*: We investigated PPS plasticity after a social cooperative interaction and whether trait anxiety could influence it. *Method*: A novel social motor training aimed to shift participants' peripersonal space (PPS) boundaries was developed. Participants manipulated objects within their reaching space without tools, collaboratively helped by a confederate using a tool in her extrapersonal space. A control involved individual tool-use in extrapersonal space. Additionally, we are currently conducting an additional experiment to test the impact of the simple closeness of another person. Participants estimated PPS boundaries via a visuo-tactile task before and after trainings. *Results*: Social cooperative motor training shifts PPS's boundaries even if participants' motor actions are confined within their PPS. Crucially, we found that low anxiety individuals expand their PPS, whereas high anxiety individuals show PPS shrinkage. *Conclusion*: Our results show for the first time that the actions of others and where they take place represent crucial factors triggering PPS expansion, suggesting that others can function as 'social tools' affecting the dynamic borders of our PPS. This paper will also present preliminary data on schizophrenic patients where the same task described above was performed. Results show how the greater PPS shrinkage following the social task, the higher the scores at the positive symptoms and anxiety traits.

SYMPOSIUM 7: Submission 128

Different effects of focused-attention and open-monitoring mindfulness meditation on peripersonal space

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Background: Peripersonal space (PPS) represents the dynamic, multisensory area surrounding the body. Its malleability is evidenced through changes due to tool use or social interactions, positioning PPS as relevant in exploring the concepts of self and otherness within sensory and cognitive domains. *Aim*: Building on the existing literature highlighting both the cognitive and bodily effects of mindfulness meditation (MM), this study investigate the effect of two MM techniques, i.e., focused-attention meditation (FAM) and open-monitoring meditation (OMM), respectively related to bodily and cognitive modulation. *Method*: We utilized a multisensory audio tactile task to assess the sharpness and extent of PPS boundaries. Forty-eight non-meditators were divided into two groups; each performed the PPS task before and after a 15-minute session of either FAM or OMM. *Results*: Post-meditation, the FAM group showed a significant reduction in PPS boundary sharpness without changes in extent, indicating altered sensory boundaries. Conversely, no significant changes were observed in the OMM group. *Conclusion*: The findings highlight distinct immediate effects of FAM and OMM on PPS, suggesting that FAM may lead to a softening of sensory boundaries that define the self-other interface. This study enhances understanding of how specific meditation practices influence the subjective spatial experience of self, offering insights into their differential impacts on cognitive and bodily modulation.

SYMPOSIUM 7: Submission 129

Multisensory processes are selectively modulated by different interactions with the environment

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When interacting with the environment humans need to integrate information coming from different senses. This is particularly relevant when interacting with other individuals of which we need to predict the movements in order to be able to coordinate with them. If and how interpersonal interactions based on different sensory channels differently modulate cross-modal interpersonal sensory integration processes, both at the behavioural and at the neural level, remains an open question and appears to be relevant to understand the mechanisms that contribute to establish a shared sensorial space between individuals. To study interpersonal multisensory integration mechanisms we asked pairs of participants to engage in three different behavioural tasks where they were asked to interact with the partner's hand movements. After the interaction, cross-modal interpersonal sensory integration processes were measured by means of visuo-tactile interference effects realized on ones' own and the partner's hand. Our results suggest an improvement in subjects' performance following an highly ecological condition where multiple sensory modalities are simutenously engaged, compared to control ones. At the neural level, our univariate and multivariate analyses highlight that 1) different interpersonal interactions modulate the topography of the electrophysiological indices of top-down attentional processes when prioritizing the information coming from one sensory channel over another, and 2) the evoked responses elicited by identical visuotactile stimuli change following interpersonal interactions based on different sensory channels. These results potentially pave the way to new approaches to social neuroscience, focusing on plastic changes in neural representations following different interpersonal interactions.

SYMPOSIUM 8: General abstract

Spatiotemporal binding of mental representations across different spatial scales

Convenors: Alastair D. Smith[1], Carlo De Lillo[2], Laura Piccardi[3,4]

[1]University of Plymouth, United Kingdom; [2]University of Leicester, United Kingdom; [3]Sapienza University of Rome, Italy; [4]San Raffaele Cassino Hospital, Italy

Accurate understanding of the world around us, and of the location of our bodies within it requires integrating spatiotemporal information and combining multisensory mental representations. Critically, these integration processes unfold over different timescales and different spatial scales, depending on the representation that is being built and the behaviour that it supports. This symposium will explore a variety of contexts that illustrate the nature of different spatiotemporal forms, integration and binding, including their limits. The trade-off between the mental capacity for simple and complex search templates and the

demands associated with foraging in spaces of different scales will be examined. Learning and remembering information at an environmental scale often requires the integration of representations established over greater durations, and examples will be explored in paradigms that test large-scale spatial memory, navigation, and foraging-like search. We will also discuss the binding of emotional content to environmental features, and how configural mental representations for simulated behaviours might support future learning. The symposium will draw on common themes across these different spatial and behavioural contexts, focusing on the conditions associated with successful and unsuccessful performance.

SYMPOSIUM 8: Submission 42

Feature integration in foraging: Exploring the visual guidance of large-scale search behaviour

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Background: Psychological assays of human search behaviour primarily focus on the visual search paradigm. Despite suggestions that it represents a simple and controlled model of naturalistic foraging behaviour, relatively few studies have directly addressed the interaction of search and foraging processes in large-scale space. *Aim*: We developed a novel hybrid of visual search and foraging to assess how large-scale search is guided by visual properties of the array, and whether feature integration modulated foraging decisions. *Method*: In an immersive virtual reality environment, participants freely explored an array of containers arranged in patches, collecting as many hidden targets as possible. In single feature search, targets were hidden beneath containers of a particular colour, and in conjunction search, they were beneath containers of a particular colour and shape. Across four experiments, the distribution of targets and the instructions provided were manipulated, and participants also completed a battery of cognitive assessments. *Results*: Participants gathered more targets when search was guided by a single feature, irrespective of the provision of a verbal search template. The distribution of targets also reliably affected the trade-off between patch exploitation and exploration, also regardless of instruction. Individual difference analyses revealed that executive function was associated with inspection of uncued items, whilst spatial working memory predicted erroneous revisits. *Conclusion*: These data suggest that visual attention drives search strategy, even in a search context that requires greater organisation of information and behaviours than traditional two-dimensional tasks. Relationships between efficiency and cognitive abilities indicate potential underpinnings for optimal foraging behaviours.

SYMPOSIUM 8: Submission 44

Different mental representations in human spatial navigation

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Background: Spatial navigation requires memory integration of different mental representations. Memory supports navigation, providing information about landmarks and routes. In particular, landmarks are unique items that help create a travel plan. *Aim*: In this study, the hypothesis that memory for landmarks improves when navigators are required to plan a (new) travel, but not when they are asked to remember a past travel, object-based, was faced. *Method*: A between-subjects design was used. Participants were asked to recall a list of words containing both landmarks and non-landmarks (everyday objects) in two different temporal perspectives: past (remember the last time you took a walk in the historic center of a city – no planning group - NPG), and future (plan a walk in the city center–planning group - PG). *Results*: The FG recalled more objects than the PG. Specifically, the FG retrieved the same number of non-landmark objects but more landmarks than the PG. This result confirms that memory for landmarks is enhanced when navigators are required to plan travel and suggests that topographic memory would be enhanced using landmarks. These results may explain differences in performing navigational tasks and cast some light on the key role of the relation between memory and planning in spatial navigation. *Conclusion*: The study highlights the key role of landmarks in binding mental representations on a large scale, which helps navigate successfully. Future studies might explore the binding issue in navigation considering the integration of multimodal information through a temporal perspective.

SYMPOSIUM 8: Submission 55

The influence of emotions on spatial cognition: from route learning to egocentric and allocentric reference systems

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Background: Emotions may influence how individuals represent spatial information. However, some studies show that positive emotions, but not negative emotions, improve spatial memory, while others show the opposite or no significant effect. *Aim*: Clarify the relationship between emotions and spatial cognition. *Method*: Study 1: 150 university students (Age$_{mean}$: 20.50) learned a route containing emotional images (from IAPS) and then had to remember spatial information about the landmarks and the route. Study 2: 120 university students (Age$_{mean}$: 21.72) memorized the location of triads of 3D geometric stimuli. Crucially, 40 participants viewed emotional images (from IAPS) before encoding, 40 participants during retention, and 40 participants before retrieval of spatial information. In all conditions, participants judged the distance of a stimulus relative to themselves (egocentric judgment) or relative to another stimulus (allocentric judgment) (i.e., Ego Allo task). Study 3: 40 university students (Age$_{mean}$: 20.80) performed the Ego-Allo task with triads of emotional images (from IAPS). Study_4: 40 university students (Age$_{mean}$: 21.45) performed the Ego-Allo task with geometric stimuli but in rooms that induced positive or negative moods. *Results*: Participants were more accurate in spatial judgments when stimuli and rooms had positive than negative valence. However, depending on the different processing stages of neutral stimuli, positive and negative images affected egocentric and allocentric spatial judgments differently. *Conclusion*: How emotions affect spatial cognition depends on the type of object (neutral vs. emotional), the role of the emotional event (distractor/target), and the environment in which spatial encoding occurs (pleasant vs. unpleasant).

SYMPOSIUM 8: Submission 57

Target switching behaviour in small/large scale foraging: complexity, speed and the hard currency of travelling distance

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Background: In naturalistic foraging, multiple prey-types can be suitable targets. Typically, complex (cryptic) preys, requiring a conjunction of features to be detected, are searched in long runs where the same prey-type is selected consecutively, before switching to a different one. This is considered evidence of limited working-memory capacity for keeping complex search images in the focus of attention. Previous findings show that explicitly imposing a time-limit on search induces more switches between targets suggesting that working-memory capacity can be flexibly enhanced. *Aim*: Our first experiment assessed if costs implicitly imposed by foraging in large-scale immersive virtual reality environments elicited an increase in switching frequency. Four additional experiments aimed at disentangling the contribution of travelling time and distance on switching behaviour. *Method*: In 5 foraging experiments testing undergraduates, we manipulated search type: feature vs conjunction; environment: 2-dimensional and 3-dimensional; the distribution of targets: dense (short-distance) and sparse (long-distance) and the speed of movement: fast and slow. *Results*: Search for complex preys resulted in a lower frequency of switching. Moreover, foraging in 3D induced a higher frequency of switches (experiment one). Both travelling time and distance affected switching behaviour in 2D foraging (experiments 2 and 3). By contrast, exclusively distance led to an increase in number of switches in 3D (experiments 4 and 5). *Conclusion*: Humans self-regulate search behaviour based on demands implicitly imposed by different instances of foraging. They flexibly trade cognitive load for discounts in search time and, especially, travelling distance when the search environment makes the latter particularly costly.

SYMPOSIUM 8: Submission 72

Individual differences in spatiotemporal binding of mental representations

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In this study, we explore the formation of cognitive maps through varying navigational strategies, providing experimental evidence for three unique map types. After navigating an unfamiliar route, participants sketched the layout and completed wayfinding tasks, including pointing to non-visible landmarks and identifying shortcuts. Analysis of their sketches and task performance revealed distinct mapping strategies: procedural, allocentric, and egocentric. Each strategy led to the formation of cognitive maps with differing spatiotemporal variations. Procedural mappers generated cognitive maps with linear sequences of landmarks, capturing temporal but not spatial relationships, thus missing spatiotemporal integration. In contrast, allocentric mappers produced sketch maps from a third-person, orientation-free perspective, integrating spatial features like route segments and environmental boundaries into a coherent global layout, yet without temporal elements. Egocentric mappers, by employing path integration and egocentric landmark processing at each route segment, developed maps that integrated both spatial and temporal information, thereby uniquely achieving spatiotemporal binding. The results highlight the differential impact of navigational strategies on cognitive map formation, and the distinct spatiotemporal variations that emerge.

SYMPOSIUM 8: Submission 86

The spatial layout of doorways and environmental boundaries shape determine interference between object-location bindings

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Physical boundaries in our environment have been observed to define separate events in episodic memory, but there is little evidence that the spatial properties of boundaries exert control over event memories. We conducted four experiments in which we adapted manipulations involving boundaries that have been demonstrated to influence spatial representations for use in an episodic object memory paradigm. Participants were given 15 min to freely explore an environment that contained 36 objects, equally dispersed among six discriminable buildings. In a subsequent test of object-location binding, participants were required to indicate where they remembered encountering the objects. In Experiment 1 the spatial properties of the building boundaries were identical; however, in Experiment 2 the boundaries were differentiated by their geometric shape and the location of the doorways in the buildings, and we observed a shift from a bias towards remembering the positions of objects within a building but not the building itself (Experiment 1), to a bias towards remembering which building an object was in but not the location within the building (Experiment 2). In Experiment 3, the buildings shared the same geometry but were differentiated by the locations of doorways, and we observed no significant differences between response types. Finally, in Experiment 4, the buildings were uniquely shaped but shared the same doorway location, and we observed a bias towards remembering the positions of objects within a building. Our data suggest the location of doorways in boundaries and, to a lesser extent, boundary geometries influence recall of multiple object-location bindings.

3. Abstracts of Talks

TALKS: Submission 1

Language affect English and Mandarin Speakers' Space Perception Tendencies

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The questions of whether aspects of language shape spatial cognition in general and whether English and Mandarin speakers differ in figure-ground perception sequence (i.e., ground before figure or figure before ground) have attracted much attention and controversy. We conducted two experiments which recruited English and Mandarin speakers as participants to address these issues. Experiment 1 measured the explicit influence of language on figure-ground perception sequence. The experimental paradigm used a priming task in which participants were asked to process a linguistic prime (an existential sentence which depicts a figure-ground relation) and a non-linguistic target (an animation which displays a figure-ground relation). Experiment 2 explored the implicit influence of language on figure-ground perception sequence. The experimental paradigm

employed a non-linguistic task in which participants were asked to form a new picture with the given two pictures, i.e., one representing figure and one ground. Converging evidence yielded from the two experiments demonstrate that tendencies of space perception do vary across linguistic communities. Mandarin speakers exclusively exhibit ground-before-figure sequence (100%). An overwhelming majority of English speakers (86.78%) show figure-before-ground sequence, but a minority of them (13.22%) favor ground-before-figure sequence. These tendencies of space perception can be approximately predicted by linguistic figure/ground patterns in Mandarin and English respectively. Findings of the present study bolster (though not absolutely) the Linguistic Relativity Hypothesis, which suggests that one's native language can influence habitual thought. However, it should also be noted that Linguistic Relativity Hypothesis might not thoroughly accommodate the subtle individual variations among English speakers in their figure-ground perception sequence.

TALKS: Submission 2

Testing a neuroassessment task for spatial attention skills in combat sports

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Background: Performance data can serve as a valuable tool for assessing the strengths and weaknesses of athletes, evaluating their developmental progress, customizing training methods to individual needs, and estimating their overall potential. However, challenges arise in the practical application of skills evaluation due to outdated methodologies and imprecise metrics for measuring performance and skills. *Aims*: The aim of this study was to test a task tapping on spatial attention abilities in combat sports athletes using an ecological neuroassessment methodology. *Methods*: We compared athletes engaged in combat sports (CS) vs. other sports (OS; e.g, tennis, basketball) through a neuroassessment protocol focused on attention skills. Computerized tasks were complemented with electrophysiological recordings, specifically electroencephalography (EEG) and event-related potentials (ERPs). This study focuses on spatial attention by employing an ecological digitalized cueing task where participants were required to block hand and foot strokes originating from various locations, preceded by either valid or invalid cues. *Results*: Data analysis revealed reduced response times coupled with a decrease in the amplitude of the parietal P3 ERPs component for valid trials compared to invalid trials in combat sports. Furthermore, an increased peak-to-peak latency for the central P3 component was observed in combat sports compared to other sports for invalid trials. *Conclusion*: Consistent with the neural efficiency hypothesis, the findings suggest internally coherent profiles across various dimensions of attention regulation performance, emphasizing the potential of the proposed neuroassessment methodology in elucidating cognitive aspects of athletic performance in combat sports.

TALKS: Submission 4

Navigating virtual environments with sustained sensory clashes

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Background: Segmentation and binding of our environment is typically viewed across space but can also happen across sensory channels if we perceive it differently, and potentially with clashes, through them. Humans typically utilize vision in a dominant role for navigation and set it as the scaffolding for their perception of their environment. However, what happens when vision becomes actively unreliable? *Aims*: Will this induced sensory information impair user performance compared to navigation based on the reliable senses, be suppressed, or be used advantageously? Will users be able to segment their representations across sensory channels or will these representations inherently influence each other? While such scenarios are rare in the real world, this question has important implications for multisensory integration in extended reality applications - e.g. virtual walls that a user sees but can walk through. *Methods*: We created virtual mazes which could be solved via audio or visual cues. We then manipulated the reliability of these sensory channels by including invisible walls which are not perceived but still blocked passage, and ghost walls which could be perceived but did not block participants. Participants navigated the exact same layouts under all conditions and could solve these levels by ignoring the unreliable sensory modality and using only the other. *Results*: Participants easily completed these mazes using vision-only, and with some difficulty via audition-only. Partially unreliable vision degraded performance, though still above audio-only demonstrating utilization of the unreliable visual cues. Mazes whose entire visual input was false degraded performance to the level of audio only, though participants subjectively reported it as easier then audio-only and did not close their eyes indicating that they still relied on vision. Testing a control in which visual information was both false and constantly moved, preventing its use as landmarks or optic flow, indeed caused participants to close their eyes, disregarding the false vision, but was accompanied by confounding nausea. In parallel, auditory incongruencies were easily suppressed across all unreliable auditory conditions. *Conclusions*: This demonstrates human attachment to visual information, even when mostly or completely false, and the ability to glean practical advantages from it unless it is completely stripped from usability. More broadly it lays a foundation for testing multisensory integration of sustained false sensory channels, and has implications for mixed reality design. In the context of spatial segmentation, it demonstrates the relative power of different sensory representations, and the way sensory influences leak across these representations.

TALKS: Submission 5

How do augmented obstacles influence humans' spatial behavior?

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Background: As we navigate, we constantly percieve objects in our surroundings and then plan our routes towards or around them. But what happens when the objects are virtual - i.e., added to our environment via augmented reality - and can be perceived only visually? *Aims:* Here we specifically focus on obstacles and ask if users' spatial behavior is affected by the obstacles' physicality? *Methods:* To test this, we developed a pass-through augmented reality system that requires participants (n=34) to walk down a hallway with physical and virtual obstacles partially blocking their path, with their movements recorded. Our main measures are the distance participants kept from each type of obstacle as they passed between them or walked around them, and the user's subjective reports. *Results:* We found that a large majority of users (~80%) treated virtual and real obstacles similarly, avoiding both with equivalent distances, while a smaller group (~13%) kept a significantly smaller distance from virtual then

physical obtacles, including in some cases walking right through them. This was reflected also in their subjective reports, with most partcipants explicitly reporting treating them the same and a minority rating the physical obstacles as less of an obstacle. *Conclusion*: Our system offers an intuitive setup for testing multisensory interaction with visual-only vs. physical targets. It holds potential for the basic-science of spatial-interaction and multisensory-interaction, and practical potential for rehabilitation and for designing mixed reality interfaces. Finally, they demonstrate the importance of individual differences in user reactions to augmented content.

TALKS: Submission 6

Enhancing Spatial Abilities through Playing Racket Sports

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Spatial ability consists of small-scale and large-scale dimensions, each vital for navigating and interacting with the surrounding environment. The acquisition and refinement of motor skills, mainly through activities demanding high levels of spatial awareness and agility, are believed to influence the development of these abilities. Among such activities, racket sports require continuous engagement with spatial orientation. This study aimed to delve into the effects of long-term participation in racket sports on spatial abilities. Racket sports professionals (including badminton, squash, tennis, and ping pong players) with a minimum of ten years of experience (n = 30, M = 27.87, SD = 6.62) and non-movement experts (n = 30, M = 27.01, SD = 6.19) were required. All individuals did a battery of small-scale spatial tests (spatial perception test, Revised Purdue Spatial Visualization Test (PSVT: R), Revised Minnesota Paper Form Board (RMPFB), and three-dimensional computer-based test) and large-scale spatial tests (triangle completion test (TCT) and a Navigation test designed in Unity). The results of the one-way analysis of variance (ANOVA) showed that racket players, compared to non-movement experts, answered more questions in the spatial perception test (p-value = 0.021) and mental rotation test (p-value = 0.019) and showed less distance error in TCT (p-value = 0.002) and higher navigation score (p-value = 0.014). This result suggested that specific aspects of spatial abilities, such as spatial perception, mental rotation, path integration, and navigation, are enhanced by racket sports. It likely generalizes to broader cognitive improvements and underscores the value of professional sports in promoting spatial abilities.

TALKS: Submission 11

Sense of direction: What relationship does it have with injury-related behavior?

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Background: Sense of direction, a self-reported navigation ability, is essential in everyday movements. It tends to remain stable in the adult lifespan, but it is subject to individual differences, especially spatial-related inclinations and abilities. Other individual aspects can be related to sense of direction, such as accident proneness, as shown by some evidence. *Aims*: The aim is to investigate the relationship between self-reported sense of direction and nonfatal injury-related behaviors in daily life. This is examined in relation to gender, age and cognitive measures. *Methods*: A total of 412 participants, from 20 to 86 years of age, filled in two questionnaires: one for sense of direction and the other for injury-related behavior, assessing propensity for errors, risky behaviors and prediction of potential dangers. They also completed cognitive (Cattel and Mental rotation) tasks. *Results*: The regression models showed that significant predictors of sense of direction are gender (males having higher ratings), the Cattel test (associated with greater sense of direction), injury-related behavior in terms of errors (a higher score is associated with poorer sense of direction) and risk (a higher score is associated with greater sense of direction). Rotation abilities correlated with sense of direction. *Conclusions*: The study confirms that sense of direction remains stable across age and is related to gender and cognitive abilities. Moreover, it shares a relation with individual-related aspects, in this case injury-related behaviors, showing a positive association with risk proneness and a negative one with error proneness, at any age.

TALKS: Submission 18

Determining human navigation behaviours in the wilderness for spatial modelling

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Many people enjoy spending time in nature, hiking, and moving in the wilderness. With so many people spending time in the wilderness, it is important to understand and model how they move to ensure their safety and the protection of the wilderness environment. This research aims to fill a gap in current research that incorporates real-life human navigation behaviours replicable in spatial models that can be applied in a wilderness setting. Data and GPS tracks from 108 study participants were analysed to find commonalities that could reflect human navigation in a wilderness environment. The analysis shows the potential variances in how people of differing experiences, demographics and typologies navigate and how their decisions in the wilderness reflect their overall goals. Preliminary results of this project reveal experience in the wilderness and sense of direction correlate with the likelihood of navigation behaviour such as short-cutting and travelling off formed trails. This indicates that segmentation and binding may differ in a person with a higher experience of wilderness environments and a better sense of direction. It is anticipated that this data can inform future spatial models to provide more accurate spatial models of human movement in the wilderness that reflect real-life human navigation and add to the current research on segmentation and binding in spatial cognition. This research can benefit the safety of people who spend time in the wilderness and the protection of wilderness areas by better understanding how people move within wilderness environments.

TALKS: Submission 20

Event segmentation of dynamic maps: Expectations and saliency impact parsing of spatiotemporal data

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Dynamic thematic maps, while offering valuable insights into spatiotemporal phenomena shaping our world, pose a significant cognitive challenge due to the dense information presentation. Yet,

our understanding of how individuals process this information remains limited. Event Segmentation describes how people parse their complex and continuous experiences into discrete events, facilitating further processing. People generally agree when observing everyday scenes at which points in time they perceive boundaries between event units. A pilot experiment revealed significant segmentation agreement for dynamic maps, affirming the suitability of event segmentation for studying the processing of more abstract stimuli such as dynamic maps. The segmentation process has been shown to depend on both conceptual (e.g., knowledge structures, inference of actor's goals) and perceptual (e.g., motion, salience) stimuli features. We investigate if these conceptual and perceptual influences on segmentation generalize to depictions of spatiotemporal data on dynamic maps. In two within-subjects experiments, participants (N = 125, 176) segmented 32 maps displaying insect population densities over time, each with an overall trend and added Gaussian noise. We manipulated participants' expectations of the trend in population density and the saliency of the direction of the trend. We hypothesized higher agreement when the trend matched the expectation, especially in the high salience condition. The results support our hypothesis, both when saliency was manipulated through the map's color scale and through the spatial pattern of the change. Our research examined interindiviudally shared processing of dynamic map data, extending key event segmentation findings to the field of spatial cognition.

TALKS: Submission 26

Elementary Students' Problem-Solving with Graphical Representations: The role of Spatial Reasoning and Perception

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Scientific and geospatial representations in elementary school are strongly connected to their context, as indicated by the relevant learning content. This approach often overlooks the importance of spatial reasoning in utilizing graphical representations. Spatial reasoning plays a crucial role in younger learners' ability to understand and interpret such representations, contrasting with analytical reasoning, which becomes more significant as domain-specific expertise develops. Our study aims to explore broader categories of problem-solving approaches employed by elementary students when utilizing geospatial and scientific representations, along with the underlying perceptual processes. To investigate this categorization, we developed an online graphical representation problem-solving instrument using 18 different types of geospatial and scientific problems based on relevant graphical representations. Prior to solving each problem, we identified the level of complexity students perceived in the relevant representation. Data were collected from 633 5th and 6th grade students in the Metropolitan Area of Thessaloniki. Hierarchical clustering analysis was employed that grouped the geospatial and scientific problems into three distinct clusters. A chi-square test was applied to examine the correlation between the perceived complexity level of the representations and the student's effectiveness in problem-solving. The test revealed characteristic relationships for problems belonging to two of the three clusters identified in the hierarchical analysis. In one case perceptual accuracy was correlated with successful problem solving. In the other case increased perceived complexity was correlated with less successful problem-solving. These results, and the cluster interpretation can provide insights into the underlying mechanisms in problem-solving using graphical representations among elementary students.

TALKS: Submission 30

Differences in Gaze Transition Frequencies Across Spatial Gist Boundaries

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Background: Eye movements can play an important role in understanding what environmental information is used to guide spatial cognition, specifically wayfinding and learning. Until recently, most eye tracking studies only examined eye movements using 2D stimuli. Current methods for collecting and analyzing eye tracking data in 3D are less developed. *Aims:* In this study, we developed methods for collecting and analyzing eye tracking data while participants locomoted through an urban four-kilometer virtual reality environment. These methods allowed us to examine changes in eye movement behavior as participants searched for and identified the boundaries between thematically distinct areas. *Methods:* The test environment consisted of a linear urban street of forty 100m long blocks that varied in architectural style and two building size categories. Participants virtually locomoted down the street while wearing a head worndisplay equipped with eye tracking. In the analysis, gaze data were clustered using a velocity-based algorithm and analyzed using spatial hotspot and gaze transition entropy methods. *Results:* Analysis of first order gaze metrics found that mean fixation rates 10m before transition boundaries [BC1] were the lowest of any 10m section while sections 10m after transition boundaries received some of the highest fixation rates. The gaze transition entropy analysis found that participants' gaze oscillated between new, upcoming locations and the familiar, closer environment with increasing frequency as they approached transition boundaries. *Conclusion:* These methods and findings invite further exploration of gaze behavior in 3D and offer new ways to understand human visual interaction with dynamic environments.

TALKS: Submission 31

Dichotomic Characteristics of Horizontal Spatial Representation on Acute Deterioration Risk

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Background: The possibility that risks interact with spatial information such like the SNARC effect has been explored. However, the perception of risks in each situation is generally susceptive to an individual experience. Risks are also subjective representations without unit. Further investigations including a methodological development are needed to clarify the association between risks and space. *Aims:* The present study focused on medical-related risks and aimed to clarify the horizontal spatial characteristics of the representation concerning patients' acute deterioration risk. *Methods:* Eighteen registered nurses and 24 general students have completed a risk comparison task. The visually presented strings of 20 illness names serving as risk information were randomly presented on a computer screen. Participants were instructed to judge, by pressing one of the left or right response buttons, whether the risk of the given target was higher or lower compared to that of the standard stimulus. The condition of the response mapping was experimentally manipulated. The mixed-design ANOVA was performed on reaction times to

the target. *Results:* No significant interaction between the risk level and the response side was observed in the comprehensive analysis. However, further inspection on the individuals revealed that approximately half of the participants had a left-to-right representation and the other half had the reverse representation. *Conclusion:* These findings suggest that the magnitude representation of acute deterioration risk may be spatially aligned, but the horizontal orientation of the spatial representation is likely to be dichotomous across individuals.

TALKS: Submission 35

Space, memory and the future: Studies in Korsakoff patients

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Aims. Boundary extension (BE) is the remarkable phenomenon that when reconstructing a previously studied visual scene from memory, participants tend to create a zoomed out display of the scene in which its boundaries are extended. This illustrates that their memories go beyond what was originally contained in the input and make a spatial prediction of the broader context. BE could be a forerunner for future thinking in which participants have to form a deliberate image of a potential situation. In the current research we examined BE and future thinking in amnestic patients (Korsakoff patients). *Method.* Twenty Korsakoff patients and matched controls studied scenes of 2 colored cubes against an in-depth grid background including a horizon. After a 10 second delay they had to reconstruct the scene by resetting the horizon and placing and scaling the cubes. In a second study 20 Korsakoff patients and 17 controls had to describe past and future events in relation to cue words (e.g., apple). *Results.* In the first study, controls scaled the cubes as smaller in their reconstructions than originally presented. Patients however did not show this effect. In the second study, patients provided significantly fewer episodic details than controls across both past and future conditions. *Discussion.* The absence of scaling effects suggests patients have limited BE. Also they gave poor descriptions of future situations. Conclusions. Korsakoff patients display deficits in both remembering the past and in projecting to the future. Automatic BE and deliberate future thinking mechanisms may be functionally related.

TALKS: Submission 38

Language learning and cognitive restructuring: bilinguals' motion event conceptualisation

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In the domain of motion events, research suggests that speakers of different languages not only encode motion differently (verb-framing vs. satellite-framing of Path) but also conceptualise spatial components in language-specific ways. Second language (L2) learners of a typologically-different language are expected to show either deep entrenchment of first-language (L1)-based patterns or progressive conceptual restructuring. This study tests to what extent L1 lexicalisation patterns influence L2 learners' production and categorisation choices. Twenty-eight German L1 speakers and 20 French learners of German described target motion events depicted in videos and decided which of a Manner-congruent or Path-congruent variant

resembled a target motion event most, in two tasks coupled with eye-tracking. Lower-proficiency learners manage to adopt the L2 pattern in production (lexicalising Manner in verbs and encoding Path in the periphery) – a performance that improves progressively with increasing proficiency. In categorisation, however, lower-proficiency learners are more heavily influenced by Path (focus of their L1), but with increasing proficiency, they focus more on Manner-congruence, thus progressively approximating the L2 pattern. Finally, learners' visual attention allocation displayed more variability, with high-proficiency learners focusing even more on Manner-relevant areas of interest than L1 speakers, suggesting potential over-compensation in this regard. The findings suggest that learners' verbalisations start to approach target patterns early in the learning process, while restructuring of conceptual categories requires further experience with the target language.

TALKS: Submission 41

Mental representation of space through 2D and 3D sketching: a scoping review protocol

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Background. Mental representations of space, often referred to as cognitive maps, are necessary to facilitate spatial behavior. Sketch maps serve as a mean to externalize and assess cognitive maps. The lack of ecological validity of two-dimensional (2D) sketching calls for developing tools enabling three-dimensional (3D) sketching. This advancement will help in understanding the cognitive processes involved in the acquisition, storage, and retrieval of 3D spatial knowledge. *Aims*: This scoping review aims to provide a comprehensive overview of the key concepts and knowledge gaps concerning the externalization of cognitive maps through 2D and 3D sketching and its underlying cognitive processes. *Methods*: Following the checklist of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for scoping reviews, a comprehensive search from five electronic databases (Pubmed, Web of Science Core Collection, Scopus, Dimensions, Embase) was performed with predefined combinations of keywords. We included all published articles that involved adults and were written in English. Only research comprising 2D and 3D sketching and involving environments categorized under the 'environmental' class of Montello's classification were considered. Results: Out of 945 initial studies, 25 met the eligibility criteria, and only two papers utilized a 3D sketching tool. *Conclusion.* This review emphasizes the scarcity of research protocols involving 3D sketching and calls for further investigation into the cognitive processes underlying 2D and 3D sketching, using physiological evidence such as neuroimaging data along with gaze behavior data. This paper offers an overview of the different technologies utilized in this field and their effectiveness in enhancing sketching.

TALKS: Submission 43

Statistical learning in allocentric space: Examining the role of peripheral environmental cues

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Background: Efficient environmental search is an important and adaptive everyday skill. A particular feature of theoretical interest is whether large-scale search is informed by the spatial statistics of an environment. Probability cueing is a robust effect in two-dimensional visual search tasks, but the few studies of large-scale three-dimensional search have generated equivocal findings, meaning that the precise factors that modulate sensitivity to spatial contingencies remain unclear. *Aims:* We examined whether sensitivity to a statistical cue specified within an allocentric reference frame was modulated by the presence and location of peripheral environmental landmarks. *Methods:* Participants explored fully-immersive virtual environments, wherein they were presented with an array of locations (columns) and were required to search them for a hidden target (i.e. the column that changed colour upon activation). A target was present on each trial, appearing within the cued hemispace on 80% of trials. In Experiment 1, the array was surrounded by a featureless circular wall. Subsequent experiments introduced a stable landmark into the environment and manipulated its location. *Results:* Participants failed to learn the statistical cue in Experiment 1. They reliably biased their search in response to the cue in the presence of a landmark, although only when it was placed along the axis orthogonal to the midline separating hemispaces. *Conclusion:* These findings suggest that the presence of a stable landmark facilitates the learning of spatial distribution when it is specified independently of the searcher's viewpoint, although this is dependent upon the spatial relationship between the landmark and the distribution itself.

TALKS: Submission 45

Neurocognitive predictors of exploratory impairment in older adults

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Exploratory behaviours are reliably affected by cognitive ageing, with older adults demonstrating less efficient search behaviour and suboptimal foraging strategies. These difficulties become particularly acute in neurodegenerative disorders, such as Alzheimer's disease, and it has been suggested that they can provide cognitive markers for atypical decline before more overt episodic memory impairments are noted. However, because our current understanding is mostly confined to simple desktop tasks, it is unclear how these behaviours interact with exploratory movements. It is also unclear how they relate to specific age-related changes in brain morphology. Younger (N = 45; 18-35 years) and older (N = 48; 65-93 years) participants engaged in a novel large-scale search task in immersive virtual reality, requiring search for targets defined either by a single visual feature (colour) or a conjunction of features (colour and shape). They also completed a battery of cognitive assessments and underwent a structural MRI scan. At a group level, older and younger adults did not differ in search or foraging performance, supporting recent arguments that age-related difficulty can be mitigated against by the adoption of alternative strategies. However, when participants were grouped according to atypical performance on cognitive tasks, older adults in the atypical group inspected significantly fewer cued items and made fewer exploratory decisions. Search success was predicted by tractography measures, where higher white matter connectivity between fronto-cortical and midbrain structures was associated with greater efficiency. These findings suggest that atypical age-related change to brain function is best predicted by a combination of behavioural and cognitive assays.

TALKS: Submission 49

Linking Spatial Cognition and Environmental Psychology: Path Description Learning, Biophilic Landmarks and Emotions

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Background: One issue of spatial cognition is understanding the role of individual and environment features in environment representation performance. Studies have shown that positive-laden landmarks are positively related to route learning (navigation) accuracy. Environmental psychology research in addition, suggests that biophilic elements (as material inspired by nature) are related to positive emotions. Can nature-based elements, functioning as landmarks, be related to positive emotions and path learning accuracy? *Aims:* The study aims to examine whether and how environment representation accuracy derived from path learning is related to nature-based or build-based landmarks and emotional state. *Methods:* A total of 163 participants (19-36 years) listened to three paths (route) descriptions (nature- vs. build- vs. function-based landmarks). Then they self-rated emotional (positive and negative) state, performed the map drawing task and self-rated the learning strategies used. Other individual measures were administered. *Results:* The regression models showed that the accuracy of map drawing was positively predicted by positive emotional state after path learning and map-based learning strategy; specifically, the accuracy was negatively predicted by build-based description and negative emotional state. The nature-based and build-based landmarks recall was consistent with the types of description learnt. *Conclusion:* Positive emotional states favor path learning accuracy even when reproduced with description (not only through navigation). However, landmarks made with built material (but not natural one) are negatively related to the goodness of environment representation. Overall, the type of landmark (natural or built) and emotional state may influence the spatial representation accuracy.

TALKS: Submission 53

Using 3D Point Cloud-Based VR-Landscapes to study the role of landscape elements on perception and physiology

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Simulating high-fidelity real-world environments can be challenging within virtual reality (VR). This work demonstrates how to re-create these scenes within game engines using accurately colored terrestrial laser scans (3D point clouds). When experienced through a head-mounted display, these virtual environments offer a more precise representation. In this study we demonstrate how these environments are used in tandem with physiological measure and 3D point cloud eye tracking. Few studies have shown that incorporating natural elements into virtual environments can positively influence physiological, psychological, and cognitive responses. Despite these advances, the physiological effects of specific elements remain largely unexplored. Our study aims to investigate how landscape elements relate to physiological responses (Heart Rate, Electrodermal Activity (EDA)) in three different landscape scenes: urban, agricultural and forest. The physiological measures are combined with eye-tracking data to analyse participants' spatial observation patterns and responses to different elements as they freely navigate the virtual landscapes. In urban environments, less mentally demanding

vegetation is typically less appealing to individuals as they stated in a questionnaire. Landmarks provoke stronger preferences, as indicated by phasic peaks in EDA and patterns in eye-tracking. The correlations between eye tracking and physiological arousal of individual landscape objects can contribute to our understanding of their recreational effects. These findings could guide interventions aimed at reducing stress, such as integrating them into VR based gait therapy for inpatients. Beyond enriching our understanding of human-environment interactions, our technical approach holds promise for facilitating studies where high fidelity environments are beneficial to cognition and navigation studies.

TALKS: Submission 54

Spatial Demonstratives and Perspective Taking in Japanese and English

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Spatial demonstratives exist in all languages, but there is much debate regarding the parameters that affect their use both between and within languages. In this work, we explore 'perspective taking' as a means of accounting for variation in demonstrative use both between and within languages. Analysing primary and secondary data, we test the effects of egocentric distance and addressee position on demonstrative production in speakers of two languages with two purportedly different demonstrative systems: English and Japanese. Based on individual differences between speakers, we propose a framework unifying different theoretical accounts of demonstrative systems in which demonstratives require a spatial reference frame to be chosen prior to the application of a range of routines to select the appropriate term in a given context.

TALKS: Submission 59

Egocentric and allocentric abilities share a common process in the acoustic modality, but not in the visual modality

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Background: Spatial representation is an essential cognitive process for human navigation and interaction with the environment. Two main spatial representations have been recognized in the human brain: egocentric and allocentric. Egocentric representations are those based on the observer's perspective. Allocentric representations are based instead on environmental landmarks. Allocentric reasoning is expected to be independent of the observer's perspective; however, this assumption is under debate as it has been shown that egocentric cues can interfere with allocentric judgments. However, how egocentric and allocentric representations overlap is still unclear. Aims: The present study aimed to investigate if egocentric and allocentric spatial abilities can be explained by a common process using body posture to manipulate egocentric reasoning experimentally. Methods: Visual and acoustic left-right discrimination and space-bisection tasks, implemented in virtual reality, quantified, respectively, egocentric and allocentric bias and precision in a pool of healthy adults. Each task was conducted twice: with the head turned 45° leftward and 45° rightward, to manipulate the egocentric biases. Then, the principal component analysis (PCA) searched for latent components explaining the interindividual variability in visual and acoustic spatial

abilities. Results: The PCA found a first significant component in the acoustic interindividual biases that originates from summing the four experimental conditions, and evidence for a second component differentiating left-right discrimination and space-bisection regardless of the head orientation. No significant component was found in visual biases or visual and acoustic precisions. Conclusion: Acoustic allocentric reasoning is linked to egocentric reasoning, and such a link seems modality-specific rather than supra-modal.

TALKS: Submission 62

Visual search for emotional targets in real-life, color-modified pictures: An exploration of visual attention properties

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Visual search is a task affected by multiple different characteristics of the task (Wolfe & Horowitz, 2004; 2017). In the present experiment we wanted to explore whether well known properties of the task influencing performance in visual search, namely emotionality of the target (Leclerc & Kensinger, 2008), color palette of the picture where the target is located (Pomplun, 2006) and type of background (Carrigan et al., 2019) would affect the performance when applied in different combinations, as well as whether they would interact in affecting the performance. We expected negative (threatening) targets to be located the most accurately and the fastest, we also expected the performance in the visual search to be most accurate and fastest on the background in natural colors (when compared to high-contrast or toned-down contrast conditions) and in plain, control backgrounds (when compared to natural pictures, such as house interior or forest). The results were mostly congruent with the stated hypotheses, however we observed a few unexpected results, e.g. the positive targets located faster than neutral or negative ones (while the negative ones were located the most accurately) or targets located most accurately in high-contrast conditions (while the response times for the natural color palette were the fastest). We also observed multiple interactions between factors for reaction times, among the most interesting ones is the interaction between target and color, where the emotionality of the target affected reaction times profoundly in the high contrast conditions, and was flattened in the natural or toned-down palette.

TALKS: Submission 63

Understanding the time course and spatial biases of natural scene segmentation

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Segmenting visual stimuli into distinct objects is central to visual function, but the timecourse of human perceptual segmentation of natural stimuli remains unclear. The dominant view is that perceptual grouping is time consuming due to recurrent interactions between visual-cortical neurons. This conceptual model predicts that judging if two regions of an image are grouped takes longer if they are more distant, because signals travel larger distances due to retinotopy in visual cortex. We test this prediction with our novel paradigm for perceptual segmentation of natural images (Vacher et al 2023). In 2AFC trials, participants report if two pixels are grouped or segmented. We probe several pixels across trials and estimate by maximum likelihood the segmentation map of the image. Surprisingly, spatial proximity does not predict the time-course of

segmentation: reaction times increase with distance when two regions are perceived in the same group but decrease with distance otherwise. We hypothesize that this reflects a preference to group items that are close in visual space (proximity bias), and that perceptual decisions take longer when visual inputs are incompatible with the bias. Although proximity biases are well established in traditional psychophysics, the evidence in natural vision is anecdotal. We provide the first characterization of spatial biases in perceptual grouping of natural images and develop dynamic Bayesian ideal observer models to test our hypothesis. Quantitative fits to reaction time data show that the interaction between spatial biases and dynamic evidence accumulation is necessary to explain our findings, with important implications for neural mechanisms.

TALKS: Submission 64

Reducing action capacity of the dominant arm extends peripersonal space around the head

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Background. The space immediately surrounding our bodies, called peripersonal space (PPS), is critical for our interactions with the external world. A network of multisensory neurons responds specifically to events occurring in that space near the body. PPS mechanisms are considered to have a protective function and to be closely linked to action. Previous studies have evidenced that PPS extent is flexible and that modifying action capacity of the arm modifies PPS around that same body part. Given the implication of upper-limbs actions in human defense behaviors, arm action capacity seems relevant for the protection of other parts of the body. *Aims*. We tested whether action reduction of the dominant upper-limb has an influence on PPS around the head. Methods. We used an audio-tactile interaction paradigm (Canzoneri et al., 2012; Hobeika et al., 2020) to measure PPS extent in healthy participants while their dominant arm was either partially immobilized or free of actions. The bodily representation of the arm was also examined with a line-reaching task (Apelian et al., 2022). *Results*. We show that reduction of the action capacity of the dominant arm leads to an enlarged PPS around the head while the arm is represented as shorter. *Conclusion*. This finding show an effect of action capacity reduction on PPS beyond the concerned body part. This suggests that PPS is part of a global interconnected defensive network around the body and might rely on bodily representations to flexibly reorganize itself.

TALKS: Submission 65

Students' Understandings of Static and Dynamic Spatiotemporal Data Visualizations

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Background & aims. Spatiotemporal (ST) visualizations like maps illustrate data across many disciplines (Yang et al., 2020), so it is crucial for students to develop ST data interpretation skills. However, the form of ST visualizations, such as whether they are static or dynamic, may affect students' understandings (Shipley et al., 2013). This study investigates whether students' visualization preferences and interpretations vary across static and dynamic maps. *Methods*. Nineteen high school students (67% female; 37% white, 21% Asian, 11% black, 11% Latine) described three types of ST data visualizations: a point map depicting tornados, thematic maps of presidential elections, and raster maps showing global rainfall. All three datasets were presented as static maps, then as dynamic videos. Students reported which visualizations were most and least useful, and their descriptions of the ST data were analyzed for spatial language use (Pennebaker et al., 2001). *Results*. The most common responses for most useful ST visualization were the rainfall video (32%) and the static election maps (32%), followed by the static tornado maps (26%). 37% of students said that the static tornado maps were least useful, followed by the static rainfall maps (26%) and the tornado videos (21%). Students used significantly more spatial language when describing video maps than static maps, Fs(1, 18) > 6.3, ps < .05. *Conclusions*. ST visualizations depicting continuous data may benefit from dynamic video presentation, but high school students prefer static maps when engaging with thematic and point data. Additional analyses will examine students' strategies when interpreting ST data.

TALKS: Submission 71

Mental representation as an intuitive geometric construct through a fusion of various strategies of visual perception

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Background: Studies on mental representations elucidate strategies humans adopt while interacting with environments around them. Broadly the strategies involve use of Elements and Principles of Architectural Design, Gestalt's Principles, and Geometry. Nevertheless, fusion of these strategies enables refined analytics in formation of mental representations. *Aims*: To expound the causal relationship of elements and principles of architectural design, Gestalt's principles of pattern perception and intuitive geometric constructs while experiencing spaces around for mental representation. *Methods*: Purpose of the experiment is circulated through Google form within the university campus for participation by students, and teaching staff. Information of locations and pathways they like and visit for different purposes is gathered. These spaces are captured using 3D Camera and the images are employed on desktop monitor and VR Headset to perform specific tasks. Tasks relate to strategic choice respondent makes between elements and principles of architectural design and Gestalt's principles of patterns. Corresponding eye-tracking data of visual gaze and area-of-interest are analyzed for patterns and shape formation for mental representation across demographic variables. *Results*: Mental representations of a spatial frame through intuitive geometric is a fusion of rudimentary elements and principles of architectural design and Gestalt's principles. *Conclusion*: Comprehending spaces is essential and the process initiates by any of the strategies and often keeps switching till they form a strong mental representation. Further studies are required to understand, at what different situations these strategies help in forming mental representation, how they complement each other to evolve a fusion of analytics for mental representation.

TALKS: Submission 74

Hide and Seek: Exploring the influence of other agents during search and concealment

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Background. Hide and seek is played by human and non-human species the world over, and it is considered a controlled context for refining essential survival skills. Studies suggest that search and concealment rely upon similar representations, although other theories posit that hiding requires additional social cognitive processes. *Aims.* We explored whether learning the statistical regularities of another agent was modulated by hiding and seeking roles, and whether this interacted with the perceived mental state of the opponent. *Methods.* Participants played a simple desktop game of hide and seek, assuming both roles in separate blocks. The other agent either hid, or searched in, one of two locations on 80% of trials. To examine the role of mentalising we also manipulated whether participants assumed the agent was artificial (Experiment 1) or controlled by a nearby participant (Experiment 2). Participants also completed a measure of perspective taking. *Results.* Participants developed sub-optimal strategies, although they tended to ensure greater payoff than the other agent. When seeking, participants showed more reliance on their own decision history, whereas hiding relied more on the other agent's decision history. When the opponent was presumed to be a computer, they tended to imitate using the previous trial, but when the opponent was presumed to be human, they relied on temporal trends. Behaviour was unrelated to perspective taking. *Conclusion.* Simple spatial statistics are not reliably learned when playing social games. Our results suggest that hiding is more influenced by the choices and presumed mentalising complexity of another agent than seeking.

TALKS: Submission 75

Neural basis of visual statistical learning during n-back working memory in cognitively healthy young and older adults

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Visual statistical learning involves the implicit association of temporally linked visual stimuli, which was often studied in the context of long-term memory. Using fMRI, we examined behavioral and neural correlates of visual statistical learning during working memory and their age-related differences. Twenty-seven young (mean age = 20.1 ± 8.3) and twenty older adults without cognitive impairment (mean age = 67.4 ± 8.1) performed 2-back working memory tasks with grey-scaled face and scene images. Each visual category was presented in block where face or scene images were either repeatedly followed by a predetermined face or scene image (STRONG-PAIR) or by different images in rotation (WEAK-PAIR). Additionally, other images were randomly selected with no pre-specified temporal association (RANDOM). Across the age groups, response time (RT) was faster for faces than scenes ($p < 0.001$), with significant differences across pairs ($p < 0.001$), having faster RT for WEAK-PAIR items than STRONG-PAIR and RANDOM items. Accuracy was higher for face than scene 2-back task performance ($p < 0.01$), with higher accuracy with WEAK-PAIR than STRONG-PAIR or RANDOM ($p < 0.05$). Overall, young subjects responded faster with higher accuracy than older adults ($p < 0.01$). Across the age groups, greater hippocampal activations were associated with STRONG-PAIR compared with WEAK-PAIR items for both face and scene conditions, with greater activations in the right inferior and middle frontal cortices for these comparisons. The present results suggest that visual statistical learning involving scenes and faces may interfere with working memory performance in both young and older adults by hampering the control of items in visual working memory with the learned associations between the items.

TALKS: Submission 77

The Impact of an Intervention for Improving Spatial Cognition Among Adolescents

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Background: Given the strong correlations between spatial cognition and success in STEM programs, there is a desire to improve spatial thinking among our students, particularly as they relate to mathematics. *Aim:* The aim of this study was to deliver and evaluate a spatial skills intervention aimed at 10th grade students in Ireland (∼ 15-16 years old). *Method:* Teachers were trained in the spatial skills intervention over three days at the beginning of the academic year. Students and teachers completed spatial skills testing at the beginning and were post-tested at the end of the intervention. The intervention consists of 6 modules on various topics in spatial visualization and includes software, video resources and workbooks for the completion of hand-sketching exercises. *Results:* Analysis of the data demonstrated that the spatial skills of all students improved compared to a control group. Spatial gains for students were higher when taught by teachers with higher levels of spatial skills. For the experimental group only, the spatial skills of girls in the pre-test behind behind those of the boys; however, at the post-test, girls were slightly better than boys. Similarly, for low socio-economic status (SES) students, they started out behind their more affluent peers; at the post-test they were ahead. For all students, the experimental group scored higher than control on a standardized test of mathematics. *Conclusions:* A spatial skills intervention can be successfully delivered to this age group with positive impacts in terms of closing gender and SES gaps in spatial skills and math performance.

TALKS: Submission 78

The Link Between Spatial Cognitive Skills and Problem-Solving Among Engineering Students

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Background: Spatial skills have been shown to be important to overall success in engineering. However, the mechanism for why they are important to engineering success is not well-understood.
Aim: The aim was to find common themes from two studies examining the relationship between spatial skills and problem-solving. *Method*: The role of spatial visualization (mental rotation, spatial relations) in problem-representation was examined in the first study (n = 115) and, in the second study (n = 24), its role in completing an open-ended design project was examined. Engineering students participated in both studies. *Results*: Success in problem-solving had a larger correlation with spatial ability than with mathematical ability; those with higher levels of spatial ability were more likely to form correct problem representations which led to correct solutions. In the design challenge, students with low spatial ability spent the bulk of their time repeatedly reading the problem statement and less time developing their design solution. The opposite was found for the students with high spatial skills. Further, high visualizers received better "quality" scores on their designs compared to low visualizers. *Conclusions*: Spatial ability plays an important role in representing or conceptualizing problems, both closed form and open-ended, and success in representation leads to success in problem-solving and design. Students can have the required core competencies for the task but still fail to provide a correct answer or create a satisfactory design

as they make errors or omissions or fail to understand the problem in the representation/conceptualization phase.

TALKS: Submission 79

Virtual Environments for Spatial learning in Primary Schools:A 3-Year Longitudinal Study on Spatial Cognition Development

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Background: Spatial abilities are known to be crucial for school and academic success. However, school curricula rarely include interventions specifically targeting these competencies, despite the large interindividual differences observed. In particular, sex differences in spatial cognition, often favouring males, typically emerge during childhood and continue to increase throughout development. Virtual Environments (VE), providing opportunities for controlled exploration and navigation in large-scale environments, may help to improve spatial abilities. *Aims:* This study explores the effect of VE-based interventions on spatial cognition in primary schools, focusing on sex differences. *Methods:* A virtual urban environment with embedded instructional activities was developed and used in a 3-year longitudinal study involving 2nd to 4th graders (7 to 10 years old). The experimental group (n = 64) received annual VE interventions, while controls (n = 30) followed the standard school curriculum. Assessments included spatial representation tasks (including landmark learning and relative distance estimation) and standard visuospatial ability tests (including perspective taking and mental rotation). *Results:* The experimental group got better performances in distance estimation and landmark learning compared to the control group. Regarding visuospatial abilities, the experimental group also showed better performances in perspective taking, but not in mental rotation. The sex performance gap increased over time, favouring boys over girls in the control group, but not in the experimental group, especially on the visuospatial ability scores. *Conclusion:* Integrating VE-based spatial learning activities into school curricula holds promise for enhancing spatial cognition, and promoting sex equity by reducing sex differences typically observed at this developmental stage.

TALKS: Submission 81

Space is a late heuristic of elapsing time: ERPs evidence from the STEARC effect

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Background: The STEARC effect consists of faster RTs to short temporal duration with left- vs right-hand responses and faster RTs to long-duration with right- vs left-hand. It was recently shown that the STEARC is only significant with slow, though not with fast RTs (Scozia et al., 2023a). The left-to-right time flow thus seems to be a late-heuristic of elapsing time, and fast decisions on temporal duration are made without spatial references. *Aims:* Here, we investigated the ERPs correlates of the RT distribution of the STEARC effect. *Methods:* EEG was recorded from 29 participants during the execution of a STEARC task in which a central visual dot was presented for 1 (Short; S) or 3 sec (Long; L). STEARC effect was assessed across four consecutive RT-Bins. *Results:* The STEARC was only found in bins 3-4. The CNV was enhanced with congruent (push left if S) rather than incongruent instructions, tough reduced at Bins 3-4. At

target offset, the N1-P2 evoked by S was enhanced at Bin 1-2 compared to Bin4; similarly, the P3 was progressively delayed from Bin1 to 4. Response-related LRP was negatively associated with the strength of the STEARC. *Conclusion:* These results show that the spatial representation of time succeeds when the preparation and implementation of instructed motor responses is defective or late. These results re-define the functional conditions that give rise to a spatial representation of time in tasks where spatial codes regulate response selection (see Scozia et al. 2023b for the crucial influence of spatial response codes).

TALKS: Submission 83

Sensorimotor mapping of emotive semantics in bilinguals

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Background: Existing research indicates involvement of brain systems underpinning spatial abilities in processing emotive semantics in L1: positive emotions are associated with the right part of space, negative ones with the left. Some suggest similar sensorimotor activations in L1 and L2. Others indicate attenuated processing of L2 emotional words. *Aims*: We investigated differences in sensorimotor biases in processing emotive semantics in L1 and L2. We controlled for the participants' degree of reduced emotional resonance (RER) in L2 as a factor influencing the strength of response to L2 stimuli. *Methods*: 85 native speakers of Russian with English L2 (55 women, average age 25 years, 80 right-handed) read Russian and English words and evaluated positive or negative emotional valence. We measured reaction times (RT) in congruent (positively valenced words + right key, negatively valenced words + left key) and incongruent conditions (positively valenced words + left key, negatively valenced words + right key), assessed L2 proficiency via LexTALE, Cambridge General English, LEAP-Q, and measured the degree of RER in L2 with RER-LX. *Results*: Using ANOVA, we found that positively valenced words were processed faster with the right hand than with the left hand in L2. The degree of RER positively correlated with RT. *Conclusion*: Our findings demonstrate differential activation in processing emotional semantics in L1 and L2 indicating significant differences in the nature of representations of L1 and L2 words that share common semantic storage. Our study examines features of sensorimotor mapping of emotional concepts at the level of individual differences.

TALKS: Submission 84

Age and physical activity modulate time perception

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Background. Processing of temporal concepts is accompanied by activation of spatial attention: reaction times (RT) are faster if participants classify past/future related words with left/right keys, respectively (STEARC effect; Bonato et al., 2012). Studies have also shown age-related changes in conceptual processes with senior participants more likely to map the future behind themselves than younger adults (Bylund et al., 2019). Moreover, physical activity also

has the potential to affect time perception (Behm & Carter, 2020). *Aims.* Here, we investigated whether access to past- and future-related words undergoes activity-related changes in younder and senior participants. *Methods.* 98 participants of varying age (19-80) read words (past/future/neutral) and classified them as related to time by pressing left/right response keys. RTs were recorded alongside the information regarding participants' age, physical and social activity, and education level. *Results.* Our analysis of the RT data registered a reliable interaction between Word Type and Age: Future/past related words were processed faster by younger/senior participants, with no difference for neutral words. Importantly, this age effect was modulated by physical activity: The higher participant's physical activity, the smaller the difference between temporal words. Furthermore, higher physical activity amplified the strength of the STEARC effect in senior participants. *Conclusion.* Results indicate that the individual's temporal concepts undergo life-long changes influenced by multiple proxy factors including age and physical activity. These preliminary finding suggest an integrative construct of conceptual age whereby the individual's embodied experiences lead to gradual changes in their conceptual space akin to cognitive reserve (Gallo, et al., 2020).

TALKS: Submission 88

Moving through architectural spaces involves spatial and aesthetic processing

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Background: Spatial cognition has taught us much about how spatial properties of environments inform how we understand space. However, what is overlooked is how these same spatial properties also impact affective and aesthetic experiences – how one feels about a place. Behaviour is deciphered through processing visual information, but also through affective experiences in aesthetic processing, and so we must better understand how emotional and spatial coding interact: how do neural correlates of aesthetic and affective experience relate to neural correlates of spatial cognition within architectural experience? *Aims*: To explore 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. *Methods*: In an fMRI scanner, participants watch a series of first-person-view videos that walk them through different built environments, and consider their valence or spatial layout complexity. We explore how perceived aesthetic and spatial properties of environments correlate, what brain regions they activate, and how they impact memorability. *Results*: As expected, key brain regions involved in valence processing activate with positively valenced spaces; key spatial regions activate with complex spatial layouts. Notably, regions usually considered to be involved in spatial processing are also involved in valence processing, suggesting that positive valence processing engages networks supporting both affective and spatial mapping. Simple layouts are also key drivers of memorability. *Conclusion*: This research extends the field of spatial cognition to include aesthetic and affective dimensions, demonstrating that these processes may in fact be deeply entwined within architectural experience.

TALKS: Submission 89

Increased attentional load leads to spatial processing asymmetries in brain damaged patients but not in healthy adults

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Background: Spatial processing allows us to deal with a continuous flow of visual information.
Increased attentional load has been described to modulate it, exacerbating contralesional spatial processing deficits in brain-damaged patients. More subtle and contradictory effects have been reported in healthy participants. *Aims:* Clarify whether load-induced spatial processing asymmetries can occur in the unimpaired cognitive system or if they are a specific feature of brain damage. *Methods:* We conducted three dual-task experiments. In Experiment 1 we tested a right-hemisphere damaged patient. We employed a spatial processing task combined with a concurrent categorization task, that allowed to manipulate attentional load. In Experiment 2 and 3 we tested about 200 healthy adults. To avoid ceiling effects, we developed more sensitive dual-tasks. Specifically, we employed an audiovisual integration task, which involved presenting stimuli capable of eliciting the Sound-Induced Flash Illusion (SIFI) on either the left or right space. Attentional load was manipulated by a concurrent working-memory task (Experiment 2) or visual discrimination task (Experiment 3). In the brain-damaged patient, we expected the emergence of contralesional spatial processing deficits under high attentional load, whereas in healthy participants, we expected a subtle disadvantage for the left hemispace under high attentional load. *Results:* In Experiment 1, the patient showed a significant number of contralesional omissions under high attentional load. In Experiment 2 and 3, SIFI increased under high attentional load but the effect was identical for left- and right-sided stimuli. *Conclusion:* Increased attentional load triggers spatial processing asymmetries in brain-damaged patients but not in healthy participants.

TALKS: Submission 90

Exploring the correlation between visuospatial inhibitory control and cognitive flexibility performance

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Spatial information processing plays a crucial role in enhancing executive functions like attention, working memory, and cognitive flexibility. When dealing with incongruent spatial information, inhibitory control becomes essential to suppress irrelevant or interfering information. Cognitive flexibility (CF) enables individuals to switch between tasks by temporarily inhibiting irrelevant information on the basis of instructed rules, in order to appropriately and alternatively resolve the conflict between relevant and irrelevant stimuli features. In the frame of a wider study on cognitive flexibility and perception, we were interested in exploring the reciprocal association between spatial inhibitory control and cognitive flexibility performances, assuming that Simon Task's (ST; where interference depends on spatial features) might correlate with a Task Switching Task (TST; where rules are defined by grid location). After performing Spearman correlations on N=46 participant's data (29 females), results revealed positive correlations between Simon test reaction times (RTs) and TST RTs ($rho_s = 0.489$, $p < .001$), while ST Inhibition Cost (IC) is

negatively correlated with TST accuracy (rho$_s$= − 0.473, p < .001). Regression models on ST RTs incorporating age, TST accuracy, RTs and Switching Cost explained 26% of the variance. These results may be due to a common inhibitory feature of both tasks, suggesting that an effective spatial inhibitory process may be related to improved task switching performance, and viceversa. Given CF's relevance in segmentation and organization of spatial information, further research could explore the extent and potential nature of the relationship between spatial information inhibition and cognitive flexibility.

TALKS: Submission 91

Anisotropy of the scintillating grid illusion in monocular vision

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The scintillating grid illusion is a visual phenomenon in which black spots are perceived in a white circle at a gray grid intersection. Previous studies have found that patch size, grid type, and background brightness affect the scintillating grid illusion. An illusory black spot of scintillating grid illusion occurs in the peripheral rather than the central vision. A previous study has shown that the illusory black spot in the scintillating grid illusion is wider horizontally than vertically in binocular viewing. However, it is unclear whether the fusion of binocular visual fields or a monocular induces anisotropy. This study investigated the anisotropy of the scintillating grid illusion in monocular viewing. Twenty-two participants observed the simplified figure of the scintillating grid illusion located at ten different horizontal (± 0.6, ± 3.0, ± 6.0, ± 9.0, and ± 12.0 degrees) and ten different vertical eccentricities (± 0.6, ± 3.0, ± 6.0, ± 9.0, and ± 12.0 degrees) They rated its illusory blackness using a 7-point Likert scale (0 = the absence of blackness, 6 = very strong blackness). Principal component analysis based on the coordinate points with the above mean of illusory blackness found that the scintillating phenomenon was 1.68 times wider in the horizontal direction than in the vertical direction in monocular viewing. The degree of anisotropy in monocular vision was similar to the experimental results of binocular vision in a previous study. The present result suggests that the scintillating phenomenon may be caused by a lower-order visual information processing mechanism than the stage of binocular fusion.

TALKS: Submission 92

Architectural experience modulates EEG responses during the observation of body expressions in virtual reality

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The built environment represents the surrounding stage of our everyday social interaction. However, little is known about the architecture's role in influencing our perception of others' affective states. To bridge this gap, we combined virtual reality (VR) and electroencephalography (EEG) and recreated a naturalistic paradigm in which participants observed avatars' body expressions at the end of a promenade in virtual architectures. They dynamically experienced high- and low-arousing architectures and then judged avatars' body expressions' arousal (low, middle, high). High-density EEG was continuously recorded to investigate how the dynamic architectural experience modulates neural responses. In line with previous findings, observing highly aroused avatars increased Late Positive Potentials (LPP). Importantly, we report an increase of P200 amplitude due to the experience of low-arousing architectures, reflecting early greater attention during the processing of body expressions 250ms before the

occurrence of the LPP. Source localization highlighted a contribution of the dorsal premotor cortex to both P200 and LPP. These results suggest the existence of an overlapping motor neural substrate devoted to spatial and social cognition, with the architectural space exerting an early and possibly adapting effect on social experiences.

TALKS: Submission 93

Assessment of navigation expertise and impairment: the Leiden Navigation Test and Wayfinding Questionnaire

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Background: The Leiden Navigation Test (LNT) has been developed to quickly capture all main domains of navigation ability: landmark, location, and path knowledge, from both an egocentric as well as an allocentric perspective. The Wayfinding Questionnaire (WQ) assesses subjective navigation ability and spatial anxiety. *Aims:* We aimed to assess LNT and WQ scores in two atypical samples in terms of navigation experience, to identify the link between these outcomes and real-world experiences. *Methods:* Individuals with Developmental Topographical Disorientation (DTD) (N = 14), represent lifelong navigation impairment and a sample of orienteering experts (army and civilian, N = 16) reflect extreme navigation expertise. Both groups performed the LNT and WQ, and performances were assessed at group level. Additional participants will soon be included. *Results:* Initial analyses show that the DTD shows above average landmark knowledge and impaired performance, specifically for allocentric location and route knowledge. The orienteering sample excels specifically in the allocentric location knowledge, not in the other domains. Additionally, in the WQ outcomes a mirrored image is found; the orienteering sample excels in navigation ability scores, which are very low in the DTD sample. Yet, spatial anxiety is rated equally in both samples. *Conclusion:* The navigation expertise and impairment are primarily centralized around allocentric location knowledge, which requires map use. Self-ratings of navigation ability strongly reflect the expertise level. Notably, individuals with DTD are not more anxious in spatial situations and have strong landmark memory skills, presumably as compensation. Both LNT and WQ appear effective to measure spatial performance in the respective samples.

TALKS: Submission 94

The role of spatial attention in visual short-term memory and visual consciousness: an ERP change detection study

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In the framework of visual consciousness theories, visual short-term memory has been divided in different stages with different characteristics in terms of capacity, duration of the trace, and dependency from attentional resources. To date, it is still debated which is the role

of attention in visual short-term memory, and which could be the electrophysiological activity related to visual consciousness. The present study had a twofold aim: to better understand the contribution of focused spatial attention on maintenance in short-term memory and trying to disentangle electrophysiological correlates related to attention, maintenance and visual consciousness. We tested 20 subjects during execution of a change detection task while recording EEG. Spatial attention was manipulated using an endogenous pre-cue which could predict (i.e., valid condition) or not (i.e., invalid condition) the side of appearance of the probe. An uninformative pre-cue was used as baseline (i.e., neutral condition). Behavioral results showed differences in accuracy between neutral and invalid conditions in all selected visual short-term memory intervals (150ms, 600ms, 1200ms), and between valid and neutral conditions for both 600ms and 1200ms intervals. The difference in accuracy between neutral and valid condition for 150ms interval was not significant. Electrophysiological results showed interesting attentional effects related to the retro-cue and probe appearance. Our findings suggest that focused spatial attention can affect maintenance of representations in visual short-term memory in a time dependent manner. Taken together with electrophysiological measures, our findings provide further insights on the role of attention in short-term memory maintenance and their implications in visual consciousness.

TALKS: Submission 95

Bonobo Spatial Exploration and Navigation in a Virtual Rainforest

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How do captive apes' spatial cognition, ability to explore and learn routes in complex environments, and spatial memory compare with wild apes who face challenges of competitors, seasonality, and food availability when navigating to foraging sites? What effect do captive environments have on the development of spatial cognitive abilities? We tested these questions with captive bonobos simulating their wild counterparts' real-world habitats. Navigation in a virtual "rainforest" presents a unique opportunity to assess bonobos' cognitive abilities to explore novel complex environments, attention to landmarks, and capacity to generate and encode novel routes. Captive bonobos explored a virtual "rainforest" comprising three regions: dense, moderate dense, and savannah-like area. Virtual fruits (mango, cherry, grape), region-specific, were associated with specific bird calls. Moving prey (rabbits, red river hogs, chickens) shifted between regions. Food rewards matched selected virtual food items. Three 12-minute trials/day presented daybreak to sundown. Individualized start locations began where each bonobo trial previously ended. Bonobos were highly attentive during virtual exploration. We discuss spatial memory over time for routes based on environmental features, landmarks, and goal-oriented navigation toward preferred fruits, in order of preference. Within trials, bonobos were observed to turn towards items previously seen but not presently visible, demonstrating object permanence of visual+directional memory within a virtual space. We compare results with wild chimpanzee navigation to foraging sites by route length, efficiency, re-use of routes, and goal-directed navigation to preferred foraging sites. We highlight novel use of virtual reality to compare species and populations with different experiential and developmental trajectories.

TALKS: Submission 98

The temporal transition zone: a gradual approach to a subjective set-point within the three-second time window

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Even though in physics 'time' is considered continuous, how the brain and mind deal with time is different. It has been proposed that in cognition, time windows provide logistic platforms for information processing, such as the low-frequency three-second time window. We did a series of behavioral experiments to show the dynamics within such a time window. Using a duration reproduction paradigm, we first replicated a pattern of reproduced duration in a previous single case study. Specifically, the reproduction increases as the pause between standard duration and reproduction increases, but only within the time window of some 3 seconds; when the pause goes beyond 4 seconds, the reproduction reaches a plateau of a subjective set-point. Three more experiments were done to show that such a transition zone can be observed with different standard durations (2s, 3s, and 4.5s); with auditory stimuli of different frequencies (300Hz for standard duration and 400Hz for reproduction). It appears only when the pause duration changes within some 3 seconds; when the shortest pause duration was 5 seconds, the transition zone was no longer observed. Corresponding fMRI and MEG experiments were carried out to investigate the neural correlation underlying the phenomena. Data analysis is in progress. Taken together, we suggest that the temporal transition zone indicates a pre-semantic logistic platform, and we expect to explore the neural components.

TALKS: Submission 99

Functional conjunctions between self-based and map-based components of spatial navigation and declarative memory

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Background: Neurocognitive structures and algorithms recruited to navigate the physical space are also recruited to navigate the mental space of conceptual knowledge (Milivojevic & Doeller 2013) and memory (Buszaki & Moser, 2013). For the latter, mechanisms supporting episodic and semantic memory would have evolved from self-based (i.e. egocentric) and map-based (i.e. allocentric) mechanisms of spatial navigation, respectively. Recent behavioral evidence supports this hypothesis (eg Committeri et al., 2020; Fragueiro et al., 2024) but neurofunctional evidence is lacking. *Aims*: To map functional conjunctions across the two domains (declarative memory and spatial navigation) by considering the organizational principles provided by self-based and map-based reference frames. *Methods*: We conducted an Activation Likelihood Estimation (ALE) meta-analysis including 109 task-evoked fMRI studies on spatial navigation (egocentric or allocentric) and declarative memory (episodic or semantic). Conjunctions were tested across-domains (navigation & memory), across self-based components (egocentric navigation & episodic memory) and across map-based components (allocentric navigation & semantic

memory). *Results*: Across-domains conjunctions were observed in the left retrosplenial/posterior cingulate cortex (RSC/PCC), left dorsal anterior cingulate area, left parahippocampal gyrus (PHG), right insula, and bilateral occipital place area (OPA). Self-based conjunction showed overlaps in the left RSC/PCC, left PHG and bilateral OPA, while map-based conjunction in the left RSC/PCC. *Conclusions*: Left RSC/PCC might act as a gateway between egocentric and allocentric representations not only for spatial navigation (Kravitz et al., 2011) but also for declarative memory (Renoult et al., 2019), thus sustaining the integration between reference frames across the two representational domains.

TALKS: Submission 100

Pathways' design can aid wayfinding by facilitating route navigational strategies

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We sought evidence-based findings for spatial designs that support wayfinding. While previous attempts to improve human wayfinding by architectural designs mainly focused on environmental cues that support landmark-based navigation, we asked whether wayfinding can be improved by strengthening route-learning navigational strategies. We hypothesized that formation and retrieval of route-target associations would be easier if each target is accessed via a selective route, rather than through several alternative paths. Accordingly, we predicted that in a star-shaped configuration of pathways, in which the center of the star serves as the origin of the routes and the arms of the star host the destinations, it would be easier to form route-target associations than in a grid-shaped design, wherein each target can be accessed via several paths. Moreover, as older adults show specific impairments in landmark-based navigation, and tend to over-rely on route-learning strategies, we hypothesized that star-shaped configurations will particularly aid navigation in aging. To test these hypotheses, young and older adults performed virtual-navigation tasks in either "grid" or "star" configuration of pathways. In Study-1, participants navigated on a computer desktop while in Study-2 participants navigated by naturally walking in a large-scale, immersive, virtual-reality setting. Findings in younger and older adults revealed superior wayfinding in the star-shaped condition compared to the grid-shaped design, suggesting that star-shaped configurations strengthen route-based navigation. The findings suggest that wayfinding can be improved by simple pathways' adjustments. To implement these findings, we develop analytical and transformative models to generate architectural designs that strengthen route-learning, and consequently, support wayfinding.

TALKS: Submission 103

Bubbles Revisited: A Computational Model for Binding Features, Objects and Locations

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Originally inspired by the hippocampal place cells, the *bubble model* or *bubble memory* was introduced as a visuospatial memory model for active and attentive robot vision systems. Subsequent work showed practical applications such as encoding visuospatial information via parameterization and using bubbles for place recognition. A *bubble* is a hypothetical deformable 3D surface around a robot, which is 'inflated' based on the strengths of features observed at attended targets while the robot is exploring its environment through successive saccades and fixations. Multiple bubbles are used to represent multiple features and different vantage points, thus forming a rich egocentric representation of the robot's perceptual experience. In this study, I revisit and update the bubble model according to recent findings on Transsaccadic Memory, Visual Short-Term Memory (VSTM), Object Files, and Long-Term Memory (LTM). In particular, the revised model can represent the retention of abstract features across saccades, identifying objects, subsequent consolidation of object representations, and the binding of features at the attended bubble coordinates. I discuss mechanisms of attention, memory formation, retrieval, time decay, and consolidation of old memories and new sensory experiences. Combined with metric cues from odometry and gaze direction, I show that the bubble representation can also support several features of spatial representations thought to be maintained in the Medial Temporal Lobe.

TALKS: Submission 107

Action verbs and demonstrative pronouns interactively affect volumetric affordance activation

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Affordances are automatic motor activations triggered by interactions between agents, object features and environment (Chemero, 2009), as evidenced by faster reactions for compatible stimulus-response pairings (stimulus-response compatibility effect - SRCE). Linguistic units can both activate (e.g., for nouns and verbs; Myachykov et al., 2013) and modulate (as shown in priming tasks with adjectives; Garofalo et al., 2021) affordance effects. Furthermore, affordance activation may be restricted to the agent's peripersonal space (Costantini et al., 2011). However, the interplay between linguistic and spatial contexts remains unexplored. This study examines the combined influence of linguistic and spatial cues on affordance activation using action/static verbs and proximal ('this') and distal ('that') demonstratives indicating object proximity (Coventry et al., 2023). 35 participants received auditory verbal primes (verbs 'take'/'look' and demonstratives 'this'/'that') and a target object words, e.g., 'take that pen'. They performed a semantic categorization task using a grip response device. ANOVA indicated that the presence of proximal demonstrative generally shortened reaction times (in comparison to distal ones; $p < 0.05$). Furthermore, a Verb X Demonstrative x Compatibility interaction ($p < 0.03$) was found: for the action verb ('take'), only the proximal demonstrative showed significant SRCE ($p < 0.05$), indicating a preference for actions in reachable space, whereas the static verb ('look at') produced an SRCE only with the distal demonstrative ($p < 0.05$). The latter may be due to interference between the manual response and the pointing gesture associated with 'look at that...'. These findings highlight the important role of language in shaping perception and action anticipation in the environment.

TALKS: Submission 111

Redundancy masking in segmented parts: How grouping determines the units of information compression in the visual system

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In redundancy masking (RM), the number of perceived items in repeating patterns is reduced. For example, when three identical items are presented in the visual periphery, observers often report perceiving only two items. RM has been shown to strongly depend on the spatial regularity of target arrangements: Regular patterns yielded stronger RM than irregular patterns. Here, we investigated RM with regular and irregular line arrays to shed light on the role of grouping and segmentation in the processing of redundant information in peripheral vision. Stimuli consisted of 3-5 lines, varying in color or contrast polarity. The line arrays were either uniform (all lines of the same color or contrast polarity; e.g., all lines black), or varied (subsets of lines of a different color or contrast polarity; e.g., black and white lines). The line arrays were briefly presented in the periphery. Observers reported the number of lines and indicated the feature values of each perceived line. Our results showed that there was RM in all conditions. Importantly, we found highly systematic RM patterns: The perception of stimulus edges and detecting the presence of the two feature values (e.g., black and white lines) was largely intact. Strong RM occurred in segmented subgroups of identical lines. These results suggest that regularity of the entire stimulus array is not mandatory for RM: RM occurred in stimulus parts that were segmented from other stimulus parts. We suggest that RM is a key mechanism that compresses redundant information following segmentation of visual stimuli.

TALKS: Submission 113

Peripheral cue modulation over spatial interference: attentional mechanisms triggered by gaze and arrows

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Recent studies employing the spatial interference paradigm have found qualitative differences between the congruency effects elicited by gaze and arrow targets. Typically, arrows elicit the standard congruency effect (SCE), where responses are faster when the direction of the target aligns with its location. In contrast, gaze targets often result in a reversed congruency effect (RCE), where responses are slower under a similar condition. It has been hypothesized that gaze cues trigger the same SCE as arrows, but also introduce an additional, opposite social component, resulting in the RCE. To test this, our study investigated whether the presence of a peripheral non-predictive cue, known to reduce the SCE in valid trials, would increase the RCE when using social stimuli. We also explored the role of placeholders, manipulating their presence vs absence between and within experimental blocks. The results showed that arrow targets consistently produced lower SCE in valid than in invalid trials, regardless of the presence of placeholders. In contrast, with eye-gaze targets, we observed a significant SCE in valid trials only when placeholders were absent in the between-block group. Furthermore, the interference effect disappeared under other conditions, showing a numerical but not significant SCE instead. These findings suggest that while gaze and arrows may share certain underlying mechanisms, others affect them differently. The relationship between SCE and RCE appears to be complex and non-additive, suggesting an intricate interplay between the two effects.

TALKS: Submission 114

Impacts of neurodegenerative impairments on perceptual organization

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Visuo-spatial processes are sensitive to early symptoms of neurodegenerative diseases. We present results from an eye-tracking experiment where perceptual organization (visual segmentation and grouping) is tested. In our study, we compared clinical group (n = 19, average age 62; early neurodegenerative cases of Parkinson's Disease) and control group (n = 29, average age 51). A set of geometric stimuli (n = 29) was used with the stimulus-driven segmentation, grouping, and accentuation tasks (a shape is presented with and without visual accent that induces changes in gaze pattern). The preliminary results show differences in gaze patterns in grouping: the gaze distribution in the clinical group has substantially smaller variation and fewer fixations that, in general, results in slower grouping. Also, in segmentation, the gaze distribution has a smaller variation in the clinical group, but the average number of fixations is higher. This might indicate problems of segmenting and shape discrimination. In the control group, the accent induces significantly different and pronounced gaze patterns according to the axial structure. This can be observed to a lesser degree in the clinical group. Also, in the accentuation stimuli, the average number of fixations is higher in the clinical group (indicating a fixational hypersensitivity, but at the same time, participants seem to miss a part of the figure). This study is unique in applying midlevel vision (measured by eye tracking) to the elaboration of early diagnostics of neurodegenerative impairments and is a part of broader research involving tests of spatial abilities, neurological tests, and MRI data.

TALKS: Submission 115

Manipulating decision trajectories by altering task topology: empirical mouse-tracking studies and dynamical system model

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Background: In most empirical studies involving human decisions, self-reports as well as indirect measures such as response times and mouse-tracking usually rely on the user taking a decision among a fixed set of responses (e.g., two-alternative forced choice tasks, Likert scales). The psychometric impact of spatial and sensorimotor

characteristics of the task are often neglected. *Aim:* Integrating conceptual and sensorimotor topologies in the modeling of decision-making, by estimating the influence of various factors that could alter such topologies and therefore response dynamics and distributions. *Methods:* Several empirical and computational studies were carried out to model decision-making processes reflected through mouse-tracking trajectories. The studies independently manipulated the spatial binding of responses on the computer screen by either grouping them (e.g., implicit association tasks), by manipulating target categories, or by allowing intermediate responses to prevent dichotomization in the decision process (e.g., continuous response scale). Other studies manipulated the sensorimotor cost to reach responses, relying on the dimensionality of the response space (2D vs. 1D) or biasing the movements of the mouse (e.g., speeding up movement towards an arbitrary response). *Results:* Manipulated factors influence not only decision-making dynamics (associated to indirect measures) but also final response distributions (direct measures). These factors and their effects were mirrored in a computational model of decision-making based on differential equations operating on topologies (spatial, sensorimotor or conceptual). *Conclusion:* Decision-making dynamics can be modelled as trajectories over a complex topology parametrized by the task design choices (e.g., type of response scale, target categories, their spatial configuration and accessibility).

TALKS: Submission 117

The remapping of peripersonal space after stroke, spinal cord injury and amputation: a systematic review

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Background: among the different body-centered space representations built by the brain, peripersonal space (PPS) is the sector within which interactions occur and objects can be reached. The boundary delimiting PPS is not fixed, but shaped by the ongoing experience: for instance, limb immobilization shrinks PPS, whereas tool-use enlarges it. Studies on subjects who suffered a stroke, spinal cord injury (SCI) and amputation, show that PPS is altered by the limited, or even lost, possibility of moving a body part; however, conflicting results make it hard to interpret the link between motor impairment and PPS remapping. *Objective*: to investigate whether specific etiologies (i.e., the brain damage rather than the CNS damage or the peripheral injury) alter PPS differently, and whether PPS is recalibrated using assistive devices. *Methods*: studies testing PPS following stroke, SCI, and amputation were included. The search was conducted utilizing Scopus, Web of Science and PubMed. *Results*: seventeen articles were included. Despite the wide variety of instruments employed, overall, the studies showed that motor impairment alters PPS. Specifically, a contraction of PPS around the affected limb was evident in SCI patients and amputees. In addition, assistive devices were able to restore PPS after a training, or even immediately in the case of prosthesis use. *Conclusions*: the results seem to resonate with the idea of an action-dependent PPS. As regards the assistive devices, their restorative effect on PPS is consistent with the literature showing that the brain can process a tool as a body part.

TALKS: Submission 118

A virtual- and mixed-reality platform to assess spatial neglect

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Background: Patient-friendly bedside screening assessment tests for spatial neglect are useful in clinical settings. In the baking tray task (BTT) the patient is asked to evenly distribute 16 cubes over a rectangular tray, as if they were buns to be cooked in an oven. The resulting spatial arrangement of the cubes is rightward-biased in case of spatial neglect. *Aim*: Here we describe a new, virtual- (VR) and mixed-reality (MR) version of the BTT using an all-in-one headset. Using mathematical indexes we have developed for a previous enhanced version of the BTT we were able to establish and analyze the 2D sequence of the final disposition. With the present device we can extract and analyze more complex 3D trajectories. *Methods*: The VMR-BTT has been developed, with the Unity real time development platform, for two headsets: Meta Quest 2 and 3. The first one is the cheapest (more affordable) but supports only VR applications while the second supports both VR and MR applications. *Results and conclusion*: Pilot results show that healthy individuals are comfortable using the two modalities, with a preference for the MR one.

TALKS: Submission 121

Individual differences in human spatial exploration

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Spatial exploration is a multifaceted activity. Although animal studies have defined a wide range of exploration measures, for human studies there has been a lack of comprehensive guidance on analyzing movement patterns in 3D exploration. Using metrics that are already commonly used in animal research we tested whether these metrics could also be used to investigate individual differences in spatial exploration in humans. A large sample (n = 409) of participants freely explored a virtual environment for 2.5 minutes. Using hierarchical clustering, we identified three key aspects of exploration—exploratory behavior, spatial orientation, and efficiency—that echo findings from animal research. Moreover, we validate our clustering approach by correlating movement patterns with the personality trait of novelty seeking, revealing a significant link between novelty seeking and the intensity of exploratory behavior. Interestingly, males and females exhibited different exploration patterns, with males showing more exploratory activity and a more complex shape of exploration, while females showed higher exploratory efficiency.

TALKS: Submission 122

Do Problem Gamblers see a Different Game? Segmentation, Binding, and the Illusion of Near-Wins

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Problem gamblers often hold cognitive distortions that shape their gambling behaviour. This talk proposes a new idea: through repeated gambling, problem gamblers develop a distorted cognitive map of slot machine outcomes. Segmentation and binding processes have warped this cognitive map, causing problem gamblers to overvalue gambling outcomes that merely resemble wins.

To investigate this idea, we used eye-tracking technology to study the attention patterns of 36 participants (non-gamblers, recreational gamblers, and those who gamble excessively) while they viewed images of slot machine results. These images showed wins, near-wins, and losses. As expected, images of wins drew the most attention across all groups. However, those who gamble excessively showed a unique pattern: they paid significantly more attention to near-wins than losses. This bias was absent in the other groups. These findings suggest that excessive gamblers have developed a flawed mental model of slot machine outcomes. This happens through two processes: segmentation, where gamblers overemphasise the importance of winning elements within outcomes that resemble wins, and binding, where gamblers link near-wins to the emotional payoff of real wins. This distorted cognitive map encourages persistent gambling by making near-wins a rewarding signal that a real win is just around the corner, even when it is not.

TALKS: Submission 130

Cognitive Semantics and Spatial Metaphors of "Li": Tracing Longitudinal Shifts in Chinese Residential Onomastics

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This study investigates the cognitive evolution of spatial metaphors associated with the Chinese locative term "Li", as reflected in the domain of residential place names. It interrogates how these spatial metaphors, through a diachronic lens, chronicle socio-cultural transformation, embodying the principles of spatial metaphor theory which posits that abstract socio-cultural concepts are understood through the concrete lens of space. By cataloging residential names over several decades and employing multidimensional scaling analysis (MDS) alongside profile-based distance metrics, the research renders a visual narrative of the metaphors' diachronic evolution. Chi-square analyses substantiate a significant linguistic shift correlated with socio-economic growth, urban evolution, and the changing lifestyle tapestry from 1971 to 2023. This progression illustrates a metaphorical shift from basic geographic locators to nuanced descriptors of communal well-being and aspirational life quality, indicative of deeper cognitive and perceptual changes. The study reveals the persistence of certain metaphor types like "state" and "scope," while others such as "activity" and "atmosphere" gain prominence in defined eras, aligning with spatial metaphor theory. These shifts not only mark a change in language but also signify a cognitive transition in spatial conceptualization and the collective social identity. Highlighting the significance of spatial metaphors in socio-cultural cognition, this research offers novel insights for urban planning, sociolinguistics, and policy-making. It emphasizes the critical role of linguistic analysis in deciphering the complex interplay between language, cognition, and social evolution, cementing the role of spatial metaphors as both mirrors and architects of cultural identity and societal perception.

TALKS: Submission 133

Metric and temporal relationships in collaborative map drawings

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Background: While many studies have focused on spatial or temporal memory individually, none have jointly examined these aspects in collaborative map drawings. This research extends initial distinctions between these memorization types, analyzing thirty collaborative drawings created after an urban exploration. *Objectives*: Our study investigates whether the relationships between metric and temporal distances in these drawings can distinguish between a group that interacted collectively during urban exploration and one that did not. *Methods*: We analyzed collective drawings after participants explored the Plaine Saint-Denis district in Paris, either individually or as a group. To this end, we first converted the unique six common landmarks to all collective drawings into 6-node graphs. We then video-recorded the sequence of their appearances in the drawing process, and finally compared these temporal sequences with metric distances measured in a GIS. *Results*: Significant differences were primarily found in the speed of landmark appearances. Spatial and temporal distance comparisons between graph nodes showed unclear results, with no strong relationships evident for either group. *Conclusion*: Differences in landmark appearance order suggest varying behaviors in biding nearest and far landmarks, especially among those who interacted collectively. Further research should focus on refining our understanding of spatial and temporal dynamics in collaborative map drawing.

TALKS: Submission 135

Gaze Patterns in Visual Search: Tracking Eye Movements in the Trail Making Test

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Background and Aims: We tested a new digital adaptation of the Trail Making Test (TMT) integrated with eye tracking. TMT involves participants connecting circles labeled with letters or numbers in ascending order, serving as a visual search task. *Methods*: Participants completed three TMT versions: 1. Control condition: lines connecting circles remain visible. 2. Trace-the-path condition: circles turn black upon connection, reducing interference of already explored items. 3. No-memory condition: all items change their position each time the participant reaches a target, making impossible for participants to memorize the positions of future targets. We systematically manipulated the spatial arrangement of subsequent targets according to criteria of Distance (new target can be near or far) and Continuity (participants need to follow either a continuous or a discontinuous path to reach the new target). All conditions were run with only numbers (1,2,3,4…) or alternating numbers and letters (1,A,2,B…) as visual search targets. Eye movements were monitored throughout the tasks. *Results*: Preliminary resulting (N = 12) indicate that: • Switching between letters and numbers increase processing time, saccades, and fixations. • The trace-the-path condition show no advantage over the control condition. Specific findings in the no-

memory condition include: 1. Fewer saccades and fixations were needed for nearby targets compared to distant ones; 2. Continuity in the path between targets had no impact on saccades and fixations. 3. A limited influence of the number-letter switch; *Conclusion*: Our computer-based TMT coupled with eye tracking allows for in-depth explorations of visual search, uncovering distinct eye movement patterns across conditions.

4. Abstracts of Posters

POSTERS: Submission 3

Neuroarchitecture study: Academic Spaces' Impact on Neurophysiological processes

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Background: The analysis of the relationships between space and neurophysiological processes represents a growing field of interest in neuroarchitecture applied to education and the academic setting. *Aims*: The study investigates the effect of four types of academic spaces (classroom, open space context, permanent exhibition space, and laboratory) on the neurophysiological correlates and cognitive restoration of a sample of healthy students. *Methods*: The study employed a qualitative-quantitative approach. An initial assessment evaluated resting neurophysiological states and mental environment representations. Neurophysiological data (Delta, Theta, Beta, and Gamma frequency bands) were recorded through a wearable electroencephalography system during space exploration. Subsequently, participants provided further mental representations and completed two psychometric scales (Building Wellbeing Scale and Perceived Restorativeness Scale) at the conclusion of the study. *Results*: The main findings suggest that environments dedicated to permanent exhibitions and educational activities entail higher levels of coherence compared to laboratory settings. Open spaces (such as atriums) have demonstrated greater social connectivity compared to traditional classrooms. Analyses of variance revealed a significant increase in activity within the temporo-parietal cortical regions as opposed to frontal cortical regions for the Delta, Theta, and Gamma bands. Furthermore, an increase in Beta band activation in the left hemisphere compared to the right was observed, implying involvement of positive emotions during exploration. *Conclusion*: This study highlights the importance of carefully considering the design of academic spaces to promote the psychological and cognitive well-being of students, using tangible evidence derived from neurophysiological analysis and a neuroscientific approach.

POSTERS: Submission 7

Mapping and Modelling of Landmark Modalities

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Background: Visual landmarks have been identified as crucial for navigation. However, sometimes visual information is not available. Then, landmarks from other modalities could be used in a complementary way. Studies are investigating which olfactory/auditory cues are most used (Koutsoklenis & Papadopoulos, 2011a, b, Hamburger & Nuhn, 2023). *Aims:* Maps showing where auditory or olfactory cues occur are needed to use these modalities for navigation. We investigate how this information can be systematically mapped and made available for further use (e.g., route descriptions) and for different groups (e.g., blind, elderly people). *Methods:* We use focus group interviews, online, and field studies to identify classes for three modalities (sound, smell, vision) in urban environments. We develop a taxonomy as a basis for field mapping of these modalities using geoinformation methods. *Results:* The results are maps with information about auditory, olfactory, and visual cues. These maps can be used for a variety of purposes, including navigation, urban planning, and design. *Conclusion:* This study is a step towards the integration of modalities other than vision in pedestrian navigation systems. This advances the adaptation of navigation systems to different users.

POSTERS: Submission 10

Perceptual biases and individual differences during a visual decision-making task

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In visual-perceptual processing, decision-making can be influenced by implicit bias (including perceptual bias) derived from individual-related factors and stimulus-related information. Notably, perceptual bias occurs when individuals' internal state alters the perception of external stimuli (i.e., colour or size) or the response to complex stimuli, such as human faces and everyday objects. Through a visual-perceptual paradigm, this study investigated the decision-making process, and possible biases, in two decision-maker groups (junior versus senior). Participants were exposed to a recognition "picture-picture" visual-perceptual decision-making task, based on congruent and incongruent conditions between primes and probes. The prime was always an animal, while the probe could be either six objects (incongruent condition) or five objects and an animal (congruent condition). Behavioural (accuracy – ACC, and reaction times - RTs) and self-report data (collected via the General Decision-Making Scale - GDMS) were gathered to explore their possible relation. Regardless of seniority, higher RTs in the incongruent condition and same level of ACC in both conditions were found. In senior decision-makers, the GDMS-dependent style had negative correlation with ACC and positive correlation with RTs, in the congruent condition. As pointed out by results, despite seniority, cognitive effort is necessary to overcome cognitive bias in an incongruent condition: indeed, the stimuli properties determine the ability to resist cognitive biases. Nevertheless, senior decision-makers with dependent style showed lower resistance to cognitive bias, particularly during simple decisions. In this perspective, having a dependent decision-making style may lead to lower behavioural performance and a reduced capacity for individual top-down executive control.

POSTERS: Submission 15

Mental rotation, strategy induction and sex differences: An eye-tracking analysis

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To solve mental rotation tasks, different strategies can be identified through the analysis of behavioral measures and eye movement measures, such as the holistic strategy (rotate the whole stimulus) or piecemeal strategy (rotate a part of the stimulus). The objective was to manipulate instructions that encourage solving a Mental Rotation Task with a holistic versus a piecemeal strategy. Both could be elicited and measured by eye movements and behavioral measures. Sex differences were also analyzed. A total of 86 participants (50% men) performed 140 MR trials in two phases across the experiment (each phase comprised 10 practice trials plus 60 experimental ones). In the first phase, participants solved the task in their own style, and in the second phase, half of the participants were encouraged to use the holistic strategy and the other half the piecemeal strategy. Reaction time, accuracy, number of fixations and saccades were analyzed through a mixed-design ANOVA. Both groups (holistic and piecemeal strategy) improved their accuracy in the second phase, but the holistic one decreased their reaction time. The number of fixations and saccades increased when a piecemeal strategy was induced and decreased with the holistic strategy. Sex differences only emerged in the accuracy rate, with men outperformed women. The results highlight the possibility of successfully inducing the strategy, being the holistic induction more efficient since, without affecting performance, the task was executed faster. The lack of sex differences in all measures except in accuracy rate emphasizes the need to explore these differences in other factors.

POSTERS: Submission 16

Emotional ambiguity and the effectiveness of the Visual Search task

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Background. How the emotional stimuli may influence our spatial cognition? Recently proposed theory introduced three different kinds of emotional ambiguity, i.e. the phenomenon of co-activation of opposite characteristics. Analogical to the ambivalence (dimensions of positivity, negativity), also the spaces of origin (automaticity, reflectiveness), and activation (arousal, subjective significance) were proved to be experienced as ambiguous and having their own characteristics. *Aims.* We wanted to compare how words ambiguous on different emotional spaces may influence the effectiveness of the visual search. We expected significantly longer reaction times and higher accuracy for the ambiguous stimuli rather than control group of words (unidimensional words). *Methods.* We conducted two experiments (behavioral and eye-tracking), asking our participants (Exp. 1: N = 56; Exp. 2: N = 50) to complete a Complex Visual Search (CVS) task, i.e. to find a target letter in a random display of letters. Before each trial of the CVS task, participants saw single word differing in the emotional load (ambiguous or from the control group). *Results.* The ambiguous words elicited significantly longer reaction times than control words. Furthermore, we found that the time until the first fixation on a target letter was significantly longer for ambiguous groups than control words. *Conclusion.* We show that the ambiguity in emotional load of word may influence how we conduct the visual search, elongating the reaction times and the time until the first fixation. This effect is probably caused by the change that emotions make in the cognitive functioning: perhaps the ambiguity facilitates more reflective processing.

POSTERS: Submission 22

Long-term retention of landmark and route knowledge acquired during a real-world map-aided navigation task.

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Background: Longitudinal studies assessing long-term spatial memory retention for real-world navigation tasks, aided by mobile maps enriched with landmark information, are scarce. Because the importance of landmarks for navigation and spatial learning has been well-established, landmark depiction on ubiquitous mobile maps has become popular to counter the negative influence mobile map aids have on short- and long-term spatial memory formation and retention. *Aims:* This longitudinal study assesses the long-term retention of landmark and route knowledge of participants who took part in a previous real-world map-aided navigation study. *Methods:* The initial study used a within-subject design with the landmark visualization style as the independent variable. Ten task-relevant landmarks were saliently depicted on the map as realistic or abstract 3D symbols. Forty-six participants were asked to navigate a 1 km real-world route with the map aid once. Of those, 25 participants returned for the present follow-up study (mean delay = 725.2 ± 15.77 days). We assessed their long-term retention of landmark and route knowledge about the route traversed in the initial study. *Results:* Returning participants performed above chance level on the landmark and route knowledge tests, showing long-term retention of spatial knowledge. Repeated-measure ANOVAs within the visualization condition and retention interval revealed that regardless of the visualization condition, landmark knowledge decreased over the retention period as expected, while, surprisingly, route knowledge was unaffected. *Conclusion:* These results contribute to a better understanding of spatial memory formation and long-term retention after a single route exposure aided by a mobile map enriched with salient landmarks.

POSTERS: Submission 23

Realistic landmark symbols on a map provide implicit, but not explicit, benefits during spatial navigation.

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Background: Featuring landmarks on navigation aids is one method proposed to improve wayfinding outcomes. However, there is little attention given to the how the depiction of specific features of landmarks on mobile-maps modulate attention and spatial learning during navigation.

Aims: In the present study, we aimed to assess how the provision of realistic landmark symbols on a mobile-map, compared to abstract symbols, affected the processing of relevant information during navigation, and the acquisition of spatial knowledge. *Methods:* Forty-six participants navigated a route in the real world prescribed via a mobile-map. The map featured 3D landmark symbols in either realistic or abstract formats. We recorded eye-movements and electroencephalography (EEG) throughout and administered post-navigation tests of spatial knowledge. *Results:* Subjects spent more time attending to the environment during portions of the route that had realistic landmark symbols on the map, although this effect was

modulated by self-reported spatial ability. Lower-ability subjects spent more time attending to task-relevant landmarks that had realistic symbols, whereas higher-ability subjects spent more time attending to the whole environment in general. Interestingly, this did not result in improved explicit spatial knowledge for the realistic landmarks. However, examination of EEG fixation-related-potentials revealed an enhanced P200 amplitude for realistically displayed landmarks, signifying improved implicit recognition and perceptual matching of real-world landmarks to their map symbol counterparts. *Conclusion:* Visualising landmarks as realistic compared to abstract symbols benefits the direction of visual attention towards, and implicit recognition of, important information during navigation. However, this does not result in improved explicit spatial knowledge.

POSTERS: Submission 47

Human sensitivity to the forced perspective illusion: A psychophysical study using virtual reality

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Background: In art and architecture, forced perspective describes an optical illusion: When looking at a non-rectangular or distorted space from a specific perspective, individuals perceive an illusion of altered depth or size, as exemplified by Borromini's corridor in Palazzo Spada in Rome. A similar phenomenon occurs in the Ames Room. *Aims:* We employ psychophysical methods to assess human's sensitivity to the illusion, i.e. how well distorted angles can be detected in architecture. *Methods:* We designed a virtual environment consisting of a corridor branching off an anteroom. The corridor was 3.5m wide, and either regular (i.e., walls of 90°) or distorted (i.e., conical, width and wall height was reduced in varying angles). 24 participants wearing a Meta Quest 2 head mounted display were virtually placed in the anteroom, viewing centrally into one corridor. Participants were moved in the virtual environment to one side along a fixed trajectory and had to indicate whether the corridor was regular or distorted. We measured participants' threshold for perceiving the perspective illusion by analysing error rates in identifying distorted corridors. *Results:* Participants' sensitivity for distorted angles for this particular corridor was very high, they detected deviations from the rectangular geometry of 2.9° and smaller (individual range 0.74° - 2.9°). *Conclusions:* Participants show individual differences but generally high sensitivity in detecting the forced perspective illusion. Ongoing work investigates participants' strategies and the influence of factors including participants' active visual behaviours, their viewpoint, and different hallway geometries.

POSTERS: Submission 48

Visual attention modulates perception of scenes more than faces: neural and behavioral evidence

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We are always within a spatial context (i.e., a scene) comprising inanimate features, like walls and furniture, that is usually static and predictable. Therefore, attentional modulation should be necessary to make such scene features salient. By contrast, baseline attention to

dynamic and unpredictable agents should be higher and thus less dependent on attentional mechanisms. We tested these predictions in two experiments. In a behavioral experiment, two-hundred participants viewed a rapid serial visual presentation of intermixed scene, human face, and object images. All participants were asked to remember how many scenes or faces were displayed. Half were told beforehand to attend to either scenes or faces. Detection of scenes and faces was well above chance when participants were told beforehand to attend to a specific category. However, as predicted, when not given instructions, scene detection fell to chance while face detection was unaffected. In a separate fMRI experiment, fifteen participants viewed images of scenes and faces while making three separate judgements: a category-specific judgment, one related to the central fixation cross, and another related to the outer edges of the image. As predicted, responses to scenes in the parahippocampal place area were significantly reduced when attention was diverted away from scene-specific features, and to a significantly greater degree than the minimal reduction in response to faces in the fusiform face area when attention was diverted away from the face-specific features. Taken together, these results provide behavioral and neural evidence that visual attention modulates perception of scenes more than faces.

POSTERS: Submission 51

Immersive Virtual Reality-Based Allocentric Spatial Cognitive Training on Improving ToM in Children with Autism

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Background: Is there any in common between understanding your friend's perspective and finding your way around the city? It seems there is an interconnection between these two functions in the brain. Understanding other's minds (Theory of Mind) is a vital factor in one's social interaction, however, ToM does not function efficiently in some mental disorders such as Autism. Moreover, the ASDs have difficulties in spatial frames of reference processing, especially the allocentric one (egocentric is intact). Other studies shown that allocentric frame of reference deficits in ASDs were not related to poor visual short-term memory or mental rotation. *Aim*: We intend to explore immersive virtual reality cognitive training to study the allocentric frame of reference of children with ASDs. By enhancing allocentric capabilities, we assume we observe a difference in ToM function among ASDs. *Methods*: We perform a pre-test intervention on ToM skills of children with ASD. Then, we propose an IVR training to 20 children with ASD (45 minutes a session, 3 days a week for 8 weeks) and conceive to improve their allocentric frame of reference skills through playing an interactive game. We will compare the ASD children's ToM in post-intervention. Results: We are currently in the starting phase of the experiment and will present the first results and a demo of the implemented VR game/application at the conference. *Conclusion*: We assume that our future results suggest that virtual reality training of allocentric frame of reference might be clinically beneficial to enhance ToM function of ASD children.

POSTERS: Submission 69

Individual differences in social attention: associations with sex, sex-role, social skills and academic background

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Numerous studies have demonstrated that eye gaze and arrow cues trigger quantitatively similar attentional orienting effects. Conversely, differences in the quality of attention elicited by these two types of stimuli have been observed when running specific experimental designs. For instance, it has been found that while arrows spread attention to a broader part of the environment, eye gaze directs attention specifically to the focus-at location. However, the question of whether this dissociation is related to individual differences in personal attributes related to social skills remains unclear. Therefore, the aim of the present study was to investigate whether the differences between eye gaze and arrow attentional orienting effects differed between individuals according to their sex, sex roles, social skills, or academic preferences. Results showed the expected dissociation between eye gaze and arrow, but no correlation between the dissociation and the participants' explored personal attributes was found. The outcome of this research argues against the idea that the qualitative differences between eye gaze and arrow orienting effects may be related to individual differences in social cognition.

POSTERS: Submission 70

A Fresh Take on Tool-Use Effect on Perceived Distance: Reexamining the Role of Intention

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Background: Studies suggested people perceive the distance to a target shorter when reaching with a stick rather than with their hand. However, this effect could come from hypothesis guessing and is difficult to replicate. Aims: Our study aimed to replicate this tool-use effect and reexamine the alleged role of intention while overcoming the main limitations of previous studies (i.e., response strategies, hypothesis guessing). Method: Participants learned to differentiate between long and short reference distances. Then, they judged as quickly and accurately as possible whether distances between targets and their dominant hand were rather short or long. Emphasizing speed decreases susceptibility to response strategies compared to common visual-matching tasks. Effector (tool vs. hand) and intention (reaching vs. waiting) varied within-subjects in a blockwise fashion. Reaching and waiting blocks were counterbalanced across participants and divided into tool and hand sub-blocks (randomly-ordered). In reaching blocks, participants reached to the target with their dominant hand either using a 40-cm-long stick (tool sub-block) or not (hand sub-block) after each distance categorization. In waiting blocks, they waited while passively holding the stick (tool sub-block) or not (hand sub-block). Finally, a post-experimental questionnaire assessed hypothesis guessing. Results: As expected, participants categorized the distances as shorter when they intended to reach the target with the stick compared to the other experimental conditions. Hypothesis guessing did not moderate this effect. Conclusion: According to previous studies and embodied theories, our findings provide more compelling evidence supporting the existence of tool-use effect on perceived distance and that intention is a prerequisite.

POSTERS: Submission 80

The occipital lobe as neural reference in an intercultural fMRI study

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Premises: When using non-reapeatable trials in fMRI, the dissimilarity of the stimuli often means there is too much noise for typical contrast analyses. We explore a between-subject series analysis method here and seek to see whether comparison of BOLD signal maginitude is meaningful in this case. Methods: Three groups of female participants (10 each) with mono-German, German-Turkish and German-Chinese cultural backgrounds were given descriptions of 10 scenarios in German language that would presumably invoke personal cultural identity conflicts; the task was to imagine these scenarios with closed eyes while the brain activity was recorded. Each scenario was repeated only once. Result: We performed a series analysis on multiple ROIs) where each scenario was treated as a unique condition. ROIs include left and right ACC, dmPFC, omPFC and insula; entirety of the culmen, the vermis and the occipital lobe. For each ROI, we extracted the average beta value for each scenario and each participant group, creating a 12 (ROIs) by 10 (scenarios) by 3 (participant groups) matrix, then performed Kendall's tau rank-order correlation between the three participant groups for each ROI. We found that occipital lobe showed the strongest and consistent overall correlation between all three groups like no other ROIs. Conclusion: This result indicates that despite differences in the mental imageries between the individuals in the groups, the change of scenarios created similar shifts in the mental imagery process of the groups. The occipital lobe can thus be deemed a pre-semantic reference in similar imagery tasks.

POSTERS: Submission 82

Implicit biological motion processing: a link between spatial attention and social cognition in Multiple Sclerosis

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Biological Motion (BM) perception plays a fundamental role in regulating social interactions with others. Essential aspects of BM can be extracted from a few light points which follow the movement of a human like figure (Point Light Walker Display, PLWD). Moreover, BM cues can induce an orienting of attentional response, following both from global cues involving the entire body and from local cue specific to the feet region. It has been suggested that patients with Multiple Sclerosis (MS) exhibit cognitive deficits also involving visuospatial attention processes as assessed by Posner paradigm-based tasks. In addition, MS neuroinflammatory processes mediated by the immune system has been traced back to an impaired social cognition. The present study is aimed to investigate, in MS patients, BM processing in the cognitive domain of visuospatial attention and within the broader domain of social cognition. With 24 MS patients and 15 matched healthy controls, we administered a Posner-like task with global (whole human body represented by dots arranged at joints) or local (two dots indicating the feet) PLWD configuration as central cue and a lateralized yellow square as target, to investigate

spatial attention orienting processes as expressed by different reaction times in response to the target stimulus which could appear or not in the spatially cued location. Compared to healthy controls, MS patients exhibit a different pattern of behavioural response. Such a different performance may be associated with lower social cognition abilities, that could be explained by impairment in the processing of BM cues.

POSTERS: Submission 96

Situation awareness and understanding: the effects of training and culture on perceiving and understanding the real world

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Making sense of the world around us is a complex and dynamic process, involving the full range of human cognitive abilities. Given extensive processing of the available information it is not surprising that different individuals may perceive, and react to, essentially the same situation in different ways. In essence situation awareness (SA) of any given situation may be constructed differently by different individuals. In this study we looked at the effect on situation awareness (and understanding) of two key influences on who we are – culture and training. Using a desktop simulation of a road traffic collision, we have collected data from nearly 1000 participants. We have examined firefighters' situation awareness (SA) and situation understanding (SU) of the situation they are in (SA). We have compared these findings across firefighters from different countries (to examine the effect of culture) and compared firefighters and non-firefighters (to examine the effect of training). We found cultural differences in the amount of information firefighters use when building SA but not in the amount of information considered relevant to their task (an indicator of SU). Similarly, we found differences between firefighters and non-firefighters in the amount of information they used when building, SA but not in the amount of information considered relevant to their task. The implication of our data is that culture and training may influence how individuals in the same situation may use different amounts of information in building awareness of that situation and so may perceive it in different ways.

POSTERS: Submission 97

A new approach detecting temporal regularities in time series of behavioral and electrophysiological data

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Many time series of biological processes have some periodic component(s), but often it is not clear what exactly the periods of these components are, especially (as is often the case in neuroimaging) when the time series contains a significant amount of noise and non-periodic components. A paper by Ernst Pöppel in 1970 first describes a non-parametric statistical method for analysing temporal regularities in data given by brain scans (fMRI, MEG, EEG etc). It is applied to more specific cases in a 1982 paper by Pöppel and Klaus J. Miescke, but between then and 2018 it has seldom been used. In 2018, Li et al created a different formulation of the method and demonstrated it on some simple waves with added noise. This method first uses a procedure loosely based on Kendall's tau test to 'smooth' the time series wave, after which a predicted range for the period to lie in is manually chosen and a further procedure finds any period within this range. The relevance of this method can be shown using results on data from both well-known historical experiments and present day psychological studies, which can be compared to some of the more commonly used statistical methods on the same sets of data. This manual method identifies some regularities that other methods struggle to find, and it has its own advantages and disadvantages which can be discussed.

POSTERS: Submission 106

The Relationship Between Restorativeness, Environment Quality Indicators, and Wellbeing: A Study in Northeast Italy

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Background: Residential satisfaction consists of pleasure derived from living in a place according to one's needs, expectations and outcomes and can have an impact on overall quality of life. *Aims*: The present research is part of iNEST project (Interconnected Nord-Est Innovation Ecosystem – spoke 4), aimed at examining the role of socio-demographic variables, environment quality indicators, and restorativeness in predicting i) mental wellbeing, ii) residential satisfaction, and iii) sense of communities in northeast Italy. *Methods*: A total of 100 inhabitants of cities in northeast of Italy (46 women - mean age = 31.14, SD = 9.66) took part in the study. They answered demographic questions and self-reported restorativeness, residential environment quality indicators, residential satisfaction, mental wellbeing, and sense of community. *Results*: After accounting for age, gender and income, results suggested that restorativeness positively contributes to mental wellbeing (B = .29; 95% CI [.07-.51], p = .009) and sense of community (B = .22, 95%CI [.04, .39], p = .01). Furthermore, place attachment emerged to play a positive role for residential satisfaction (B = .62, 95%CI [.45, .78], p < .001) and sense of community (B = .50, 95%CI [.31, .68], p < .001). Regarding environmental quality indicators, functional aspects contribute to residentialll satisfaction (B = .17, CI .02, .3) and sense of community (B = .17, 95%CI [.02, .32], p = .02) while architectural aspects contribute to residential satisfaction (B = .15, 95%CI [.01, .29], p = .03). *Conclusion*: The novelty of the study is to have found a link between perceived restorativeness and residential satisfaction and wellbeing giving some insight to professionals and policy to improve quality of life in the northeast of Italy.

POSTERS: Submission 119

The Beat Goes On: Exploring Interoception's Influence on Temporal Experience after Spinal Cord Injury

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The objective of this study is to examine how bodily interoceptive states influence the perception of duration in individuals with spinal cord injuries (SCI). Thirty-two participants with chronic SCI were

divided into two groups based on lesion level: 16 with higher lesions (C5-T4) and 16 with lower lesions (T8-T12). Interoceptive accuracy was measured through a heartbeat tracking task, where participants counted their perceived heartbeats, compared to actual counts obtained by an electrocardiography. Temporal abilities were assessed through time perception and expectation tasks. Briefly, a white circle was shown on a gray background, with a gray annulus superimposed acting as an occluding band. In each trial, a ball moved from the center of the display toward the periphery in a fixed direction and at a constant speed. To evaluate time expectation, for example, participants were then asked whether the ball re-emerged earlier or later than expected. The group with higher lesions demonstrated lower interoceptive accuracy compared to the other group ($p < 0.01$). Interoceptive accuracy correlated significantly with temporal difficulty ($r = 0.69$; $p < 0.002$) but not with control tasks ($p < 0.17$). These results suggest that diminished interoceptive accuracy influences subjective time perception. Patients with higher lesions are less accurate at perceiving their heartbeat and have more difficulty in temporal tasks. In summary, this study sheds light on the role of interoception in shaping our experience of time. Reduced ability to detect and process interoceptive signals may distort the perception of pulses from the internal clock "pacemaker."

5. List of Authors

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