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ABSTRACT

# Symposia

## (in alphabetical order, according to the first convenors' last names and, within each Symposium, according to the first authors' last names)

## THE PROMISE AND IMPACT OF TECHNOLOGY IN COGNITION AND SPATIAL NEGOTIATION

*Convenors: Cathy Bodine[1], Marcia J. Scherer[2]*
*[1]Departments of Physical Medicine and Rehabilitation and Pediatrics, University of Colorado, Denver, CO, USA*
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### A 5-year retrospective: lessons learned about technology and cognition

*Cathy Bodine*
*Departments of Physical Medicine and Rehabilitation and Pediatrics, University of Colorado, Denver, CO, USA*

The United States Department of Education, National Institute on Rehabilitation Research, funded the first US 5-year effort from 2004 to 2009 to research the benefits and effects of existing, emerging and new cognitive technologies. The RERC-ACT team also developed new approaches and technologies for persons with Traumatic Brain Injury, early-onset dementias and neurodevelopmental disabilities. Led by Dr. Cathy Bodine, the project is called the Rehabilitation Engineering Research Center for the Advancement of Cognitive Technologies (RERC-ACT). This talk will summarize the many projects incorporated into this effort. Topics to be covered include the design, implementation and deployment of context aware technologies for persons with cognitive disabilities residing in community living environments; a web-based tool called HealthQuest designed to improve health and well-being; initial stages of standards development for cognitive technologies; and the use of batteryless micropower sensors for context aware technologies. The RERC-ACT team also researched and developed a perceptive animated interface for workforce training and technology that provides environmentally appropriate behavioral cues for individuals with Traumatic Brain Injury. Dr. Bodine will also discuss what has been learned from a US-wide survey of needed and desired product design features, and projects focused on animated agents for vocational tasks, technology-delivered behavioral cueing and prompting devices, and the use of a social networking tool to connect elders with cognitive disabilities and their families at a distance.

### Orientation technology with direction cues or corrective feedback for indoor travel of persons with multiple disabilities

*Giulio Lancioni*
*University of Bari, Bari, Italy*

This presentation focuses on characteristics of indoor environments and how persons with blindness (or minimal residual vision) and other disabilities such as intellectual or intellectual and motor impairments may encounter serious orientation and mobility problems even inside their home and activity/work contexts. To curb these problems and their negative implications in terms of personal independence and activity engagement, different orientation technology systems have been developed. Those systems can be mainly divided into two types, depending on whether they rely on direction cues or corrective feedback. Orientation systems relying on direction (auditory or light) cues are intended to guide (direct) the person to the destination he or she has to reach. They do not require the person to have spatial/travel abilities or to take initiatives and make decisions except for those concerning the orientation to the sound sources. Orientation systems relying on corrective feedback (a) are designed for persons who have initiative in traveling to destinations and a relatively good notion of the space around them and (b) provide these persons ample opportunities of independence together with a reassurance of successful travel. In essence, if the person takes the correct direction and follows it appropriately, the system does not intervene, thus avoiding any interference with the person's independence. If the person takes the incorrect direction, the system provides feedback (e.g., a vibratory input). The feedback is due to last until the person has reacquired the correct direction. This presentation (a) provides an overview of studies using the aforementioned systems, (b) analyzes the results obtained, and (c) identifies relevant issues for new research.

### Measuring the impact of technology on spatial cognition: How, when and with whom

*Marcia J. Scherer*
*Institute for Matching Person and Technology, University of Rochester, Rochester, NY, USA*

This presentation discusses ways to enhance the measurement of technology's impact and ways to define desired technology features. Many times devices are developed that do not achieve consumer use or satisfaction with use. This typically occurs because end-user preferences were not considered in the product design and device selection stage. It is also the case that data regarding product usage is not obtained. Selecting the most appropriate measures and measurement designs is a key to getting good information from consumers, but the large number of options available makes this frequently confusing to clinicians and even researchers. It is also unclear when the best time is to measure outcomes and whether it should be in a laboratory setting or under situations of actual use in natural settings. The presenter will discuss ways to most productively engage consumers in device design and selection gain their help in finding other consumers willing to test products as well as provide support and training in how to maximize use, and procedures and measures available to assess the outcomes of product use. This presentation shares experiences from many research

projects with children and adults with a variety of disabilities and it will cover national surveys to one-on-one assessment.

### Enhancing learning through spatial cognition and awareness

*Susan Treichler*
*Arvada Public School, Arvada, CO, USA*

Ms. Treichler is a Special Education teacher working in a public school in Arvada, Colorado. Her focus is on the use of instructional and assistive technology for children with significant cognitive impairments. She will focus on the learning environment, particularly the classroom, and ways learning, cognition, and literacy can be enhanced through environmental management and spatial cognition and awareness. Special emphasis will be placed on arranging and managing the classroom for optimal teaching and learning enhancement; the use of assistive technologies to expand learning opportunities including alternative keyboards and learning softwares, along with specific interventions focused on increasing/enhancing spatial awareness. She has direct experience working students who have multiple disabilities and the confluence of technology and significant disabilities will be highlighted. Historically, educators have focused on teaching functional daily living skills rather than developing reading skills; particularly for children with significant cognitive impairments. Recently, special educators have begun to emphasize that students with significant cognitive disabilities require intensive instruction in order to learn to read. Classroom strategies to enhance visual spatial cognition and visual spatial memory for children with reading impairments will be described with emphasis on specific teaching strategies including analyzing content; developing repetitive cuing; adapting activities and the environment, and supporting the development of appropriate behavioral, communication and learning activities will be stressed.

## SPATIAL AND COGNITIVE AWARENESS IN HUMAN-SENSORS ENVIRONMENTS

*Convenors: Tiziana Catarci[1], Massimo Mecella[1], Marco Aiello[2]*
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General abstract:

Current ICT technologies, as sensor networks and service architectures, allow the development of complex collaborative environments in which humans and sensors/actuators/devices/etc. interact in order to support various tasks. In such environments, the spatial and cognitive awareness in critical, as in next-generation domotic environments. The symposium will address the issues of aging and spatial cognition, assistive technologies for every-day life, disability and rehabilitation with a specific multidisciplinary focus merging psychology, engineering and computer science research areas.

### Brain-computer interfaces (BCIs) for next-generation immersive applications

*Febo Cincotti*
*Santa Lucia Foundation, Rome, Italy*

The European project SM4All—Smart hoMes for All—aims at investigating a novel service oriented architecture in which humans interacts with sensors and devices through Brain Computer Interfaces (BCIs) used to trigger automatic composition tasks. In this context, various cognitive issues should be addressed and resolved, such as the spatial awareness of the user (quite critical in the case of disabled persons) and the one that the automatic domotic system has about the user himself, etc. In this talk a general introduction to the SM4All project will be given, and then the speaker will go into details of BCIs, of how they can support spatial awareness of the users, of how the system can manage the spatial awareness of the user it needs to have, etc.

### Interaction between navigation systems and human users in spatial environments

*Christian Freksa*
*University of Bremen, Bremen, Germany*

Car navigation systems encode precise knowledge about spatial environments and they have suitable natural language expression capabilities to convey route instructions to human drivers. Nevertheless, there are numerous reports about incidents in which cars are misled and do not arrive at their destination as intended. What is the problem? The System under consideration consists of three partly independent entities: (i) the spatial environment in which a human car driver seeks a destination; (ii) the navigation system that represents knowledge about the spatial environment and conveys instructions to the human driver; (iii) the human driver who interprets the instructions and controls the car. The alignment between (i) and (ii) has become surprisingly good, in recent years; similarly, the alignment between (ii) and (iii) is quite good, i.e. the spatial knowledge represented in the navigation system is expressed in correct natural language expressions; however, the relation between (iii) and (i) still is not yet sufficiently understood. We will look at two types of problems that can occur in this setting: (1) the human driver interprets the instructions in the context of his or her (local and global) knowledge and perceptual interpretation of the spatial environment; or (2) the driver blindly trusts that the instructor actually guides the driver to the intended location. In this talk, I will look at the relations between the three entities from a representation-theoretic point of view and I will discuss possible approaches to cure these problems.

### Novel techniques for voice-based spatial awareness in domotic environments

*Maurizio Omologo*
*ITC-IRST, Trento, Italy*

In the workspace of the future, ambient intelligence will be implemented via widespread use of various sensors, among which microphones connected to computers that are unobtrusive to their human users. Towards this end of ubiquitous computing, technological advances in multi-channel acoustic analysis are needed. The long-term goal is the ability to monitor speakers and noise sources in a reverberant environment, without any constraint in the number and distribution of microphones in the space nor in the number of sound sources active at the same time. Moreover, the targeted techniques will enable acoustic systems to become aware of their own characteristics and geometry and those of the environment that they operate in, and will eventually enable advanced space-time processing solutions to take advantage of the additional information provided by the environment's acoustic response. These problems are extremely difficult to tackle, given that

the signals collected by a set of far microphones are severely degraded by both background noise and reverberation, and given other variabilities that can be found in an uncontrolled "real usage" context. In a large variety of application contexts, in fact, it is also crucially important to provide interfaces that allow natural and easy-to-use control of devices, systems, and services, to any category of possible users. The aim of this presentation is to describe some basic problems and related solutions recently developed along this direction of research, with particular reference to the so-called "acoustic scene analysis" task. Problems as speaker localization and tracking, acoustic event detection and classification, and distant-talking speech recognition will be addressed. Experimental results will be reported based on the use of data collected in real-world situations. Finally, some examples of real-time prototypes will be shown as, for instance, one enabling a user to interact by voice with a TV and with the related devices, which can be considered for next-generation domotic environments.

## Cognitive vision of objects

*Arnold W. M. Smeulders, Sennay Ghebreab*
*University of Amsterdam, Amsterdam, The Netherlands*

The question how does the brain see the world has inspired many. How is it possible the brain is capable of seeing and understanding so many things? Object, scenes, moods, events? It is fact that we still know little about it, and it is fact that presumably computers whenever they perform cognitive tasks do so quite different. Recently, however, it was found there are regularities in the pdf of gradients in most pictures in the sense that they adhere to a three parameter family of distributions: the Weibull family. This is ultimately surprising as one would think there is no regularity to be expected in the gradients of a random scene. EEGs analysis with Steven Scholte and Victor Lamme of the Department of Psychology of the University has shown that these natural image statistics play an important role in the first 80 msecs of processing in the brain (that is very early in the human vision system). We will discuss results. At the same time, machine learning gave a big push forward to computer vision. By connecting good features to machine learning principles, objects may be recognized from examples as long as they have a predictable repertoire of shapes and appearances. We argue that for any system ñ man or machine alike—it is important to build a representation of objects by an array of features ranging from a set of features holding the basic spectral values, to sets of invariants, to regional, textural and contextual features. The first set of features is ruled by the laws of image formation, the second set by the laws of object and texture reflection, the third one by spatial coherence, and the latter types are ruled by image statistics. We have built a video search engine and performed well in the TRECvid competitions and last year, in addition, in the PASCAL object recognition competition, with the same system that is. We will discuss the contributions on video search and object classification.

# SPATIAL LANGUAGE AND SPATIAL COGNITION

*Convenor: Dedre Gentner*
*Department of Psychology, Northwestern University, Evanston, IL, USA*

General abstract:

Does spatial language provide speakers with cognitive tools with which to think about space? This symposium presents developmental and computational work on how spatial language connects with spatial cognition. The papers explore the following questions:

- The Levine et al. paper traces early language use and asks whether children's very early use of spatial language predicts their later abilities on spatial tasks; and, if so, which kinds of spatial language are most predictive.
- The Gentner et al. paper asks whether overt spatial language can help children perform a difficult spatial task; and if so, whether the effect is a transitory attentional effect, or whether instead spatial language induces a lasting representation of the spatial situation.
- The Goldin-Meadow et al. paper examines deaf children who have not acquired spoken language and have not been exposed to sign language. While these children invent homesign systems to communicate, their systems lack signs for many of the notions central to understanding spatial relations. The research tests whether these children are disadvantaged on non-linguistic tasks involving these relations.
- The Forbus et al. paper explores computational models combining spatial, linguistic and conceptual knowledge. A sketch-understanding system is used to model conceptual segmentation of spatial scenes and to model analogical learning of spatial prepositions from examples.

## Effects of spatial language on spatial cognition during development

*Dedre Gentner[1], Jeffrey Loewenstein[2], Stella Christie[1]*
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Spatial language may influence spatial learning and development by making spatial relations more salient. Four studies tested the claim that learning and using spatial language can foster children's spatial representation and reasoning (Loewenstein and Gentner 2005). Preschool children saw a "winner card" hidden in a three-tiered box and then had to search for the matching winner in the corresponding relative location in a similar test box-a difficult task for preschool children. Exposure to spatial language describing the boxes, such as "top, middle, bottom" or "in, on, under" greatly improved children's performance on the task. Further, children who had heard spatial language continued to show superior performance 2 days later, even without further use of the terms-suggesting that language influenced the children's spatial representation. These results suggest that spatial language induces a more precise encoding of spatial relations, thereby facilitates spatial mapping ability.

## Spatial language supports spatial cognition: evidence from deaf homesigners

*Susan Goldin-Meadow[1], Dedre Gentner[2], Asle Ozyürek[3], Ozge Gurcanli[4]*
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We tested the hypothesis that spatial language is instrumental in spatial cognition by testing children who lack spatial language. Our

participants were a group of 13 deaf children (mean age 5½ years) in Istanbul, Turkey, whose hearing losses had prevented them from acquiring a spoken language and who had not been exposed to a conventional sign language. Each of these children had invented a homesign gesture system to communicate, but prior observation suggested that none had invented gestures for spatial relations. We confirmed this observation by asking the deaf children and a group of 13 matched Turkish hearing children to retell events shown in short videos (in gesture for the deaf, in speech for the hearing). The deaf and hearing children produced about the same number of assertions and action verbs/gestures; but deaf children produced far fewer spatial terms. To test whether this lack of spatial language would hamper the deaf children on a cognitive spatial task, we gave both the deaf and hearing children the Loewenstein and Gentner (2005) spatial mapping task. We found that the homesigners performed significantly worse on the box task-both on the neutral (easier) version and on the more difficult cross-mapped version-than the hearing children. These findings suggest that spatial relational language provides representational tools that support spatial reasoning.

## Computational modeling at the intersection of spatial, linguistic, and conceptual knowledge

*Kenneth D. Forbus, Kate Lockwood*
*Northwestern University, Evanston, IL, USA*

Progress in AI has reached the point where computational models can be built that combine psychologically motivated models of spatial, linguistic, and conceptual knowledge. We use sketch understanding as a laboratory for conducting such experiments, since human sketch understanding seems to rely on all three forms of knowledge. This talk will summarize two such investigations. The first is a model of learning spatial prepositions. Spatial prepositions, such as 'on' and 'in' in English, or 'in', 'op', 'aan', and 'om' in Dutch, involve both spatial and conceptual properties. We show that these prepositions can be learned via an analogical generalization process from sketched versions of stimuli used in a psychological experiment. The second investigation concerns conceptual segmentation, an important problem in diagram understanding. When someone draws a solar system, for example, we understand that the region inside a circle representing the sun is part of the sun, whereas the region inside an ellipse representing an orbit is not part of the orbit. We show that a combination of conceptual and linguistic information can be combined with spatial reasoning to correctly decompose entities in a variety of diagrams in human-like ways.

## The relation between spatial language and spatial thinking

*Susan C. Levine, Shannon M. Pruden, Janellen Huttenlocher*
*University of Chicago, Chicago, IL, USA*

Existing research indicates that spatial language promotes the development of spatial thinking (e.g., Casasola 2005; Loewenstein and Gentner 2005). Building on these findings, we ask whether individual differences in spatial language knowledge predict performance on tasks such as mental rotation, typically used to assess individual differences in children's spatial skill. Sixty parent-child dyads were observed every 4 months for 90 min at nine time points between 14 and 46 months. Parents were asked to interact with their children as they normally would. Spatial language was coded and three categories are the focus of this study: Dimensional adjectives (e.g., big, little); Shapes (e.g., circle, triangle); Features/properties (e.g., bent, curvy). Three nonverbal spatial tasks were given to children at 54 months: (1) Mental rotation, in which the child selects the shape that two pieces would make if they were put together; (2) Block Design, from the WPPSI-3, in which the child uses blocks to recreate configurations shown with block models or pictorially; (3) Spatial Analogies, in which the child is asked to select the one picture among four that is like the target picture. Regression analyses show that children's cumulative spatial tokens (production of dimension terms, shape terms, and features/properties terms) from 14 to 46 months predicts their performance on the spatial tasks at 54 months, accounting for about 20 to 25% of the variance in children's performance on each. Moreover, these relations hold even if we control for children's overall speech tokens.

# SPATIAL MODELS MEET SPATIAL LANGUAGE: COMPUTATIONAL AND FORMAL MODELS FOR LINGUISTIC AND SPATIAL REPRESENTATIONS

*Convenors: Joana Hois, Yohei Kurata*
*Spatial Cognition SFB/TR8 Collaborative Research Center, University of Bremen, Germany*

General abstract:

How do people describe spatial scenes and motions? How can formal and computational models represent and interpret such description? Both linguists and computer scientists have tackled these questions for years now. This symposium endeavors to bridge the gap between both approaches by bringing together (1) linguistic research of spatial language and (2) formal and computational models of space. While both areas have been investigated in detail with respect to linguistic foundations (e.g., Talmy 1982, 2000; Herskovitz 1986; Langacker 1987; Bloom 1996; Levinson 2003; Tenbrink 2007) and spatial foundations (e.g., Cohn and Hazarika 2001; Aiello et al. 2007; Weld and De Kleer 1990; Faltings and Struss 1992; Hernandez 1994; Varzi 1996), their connection is still an open and active field of research (e.g., Coventry et al. 2005; Bateman et al. 2007, Levit and Roy 2007). Theoretical and computational models of representations of space and language, and particularly the connections between space and language are the main focus of this symposium. It brings together researchers working in the field of language and space from different disciplines and viewpoints, involving spatial cognition, linguistics, computer science, psychology, and related interdisciplinary fields. The symposium presents recent work on defining relationships and interpretations between models of space and spatial language. It emphasizes the inference between spatial situations and linguistic descriptions, the modelling of contextual information in spatial-linguistic representations, possible categorizations of spatial linguistic and abstract characteristics, ways of dealing with ambiguities and vagueness in natural language, and cognitive aspects in general about the way people conceptualize and talk about space. The symposium presents current research on the topics of these aspects of space and language. It is also intended as a forum for discussing and exchanging results from different research fields. Its focus on interdisciplinary approaches provides a benefit to stimulation of debate and prospective directions for future research.

## Spatial cognition through the lens of spatial language

*Michele I. Feist*
*Institute of Cognitive Science, University of Louisiana, Louisiana, LA, USA*

Language has been called a "window into the mind"; yet what can we learn about spatial cognition from spatial language? Research into the meanings of locative spatial terms indicates that they are semantically quite complex (e.g., Coventry and Garrod 2004; Feist 2008; Levinson, Meira, and the Language and Cognition Group, 2003), suggesting that similar complexity may underlie spatial cognition more generally. In this talk, I will explore the view of spatial cognition through the language used to describe static spatial scenes. Based on experimental evidence about the use of topological prepositions in English (in and on) and on crosslinguistic evidence about the factors important to related terms in 24 languages, I will argue that spatial cognition may, like spatial language, be influenced by three types of information about a spatial scene and the objects in it: geometric, functional, and qualitative physical.

## Translating between spatial representations and spatial language using a vaguefield model

*Mark M. Hall*
*School of Computer Science, Cardiff University, Wales, UK*

Natural language is one of the primary means of communicating spatial information, but existing geographic information system (GIS) facilities are weak in this respect. One of the major challenges for the automated interpretation of spatial natural language is how to model the regions described by spatial expressions. Current GIS tend to have a view of the world based on points, lines and polygons, which is sufficient for most GIS tasks, but insufficient for modelling the vague nature of spatial language. We have developed a field-based model for representing the vague regions defined by spatial prepositions and more complex spatial expressions. For spatial prepositions the fields can be derived from various sources, either by mining existing spatial language data sources, or via direct acquisition from people. The basic spatial preposition fields are then combined to model more complex spatial language expressions. To make it actually possible to translate between the vague spatial language and the GIS view of the world, a mixed qualitative quantitative spatial reasoner has been developed. A given spatial language expression is transformed into a qualitative model describing the spatial configuration of the expression and then, using the spatial preposition fields, enriched with quantitative information, resulting in a continuous field representation of the area that the spatial language expression describes. The reasoner can also take a point location, and based on knowledge of which places are around the location and the spatial preposition fields, generate a human style natural language expression describing the location.

## Description of movement from a topological viewpoint

*Yohei Kurata*
*Spatial Cognition SFB/TR8 Collaborative Research Center, University of Bremen, Bremen, Germany*

People often describe a spatial movement with such spatial predicates as "go into", "come out", and "pass through", from a viewpoint of how the moving entity transfers its location with respect to the inside, outside, and border of the area of interest. Geometrically, such transition of a moving entity is represented by a topological relation between a directed line segment and a region. In this presentation, we introduce a formal model of topological relations, called the 9+ intersection, which distinguishes 26 relations between a directed line and a region in a 2D space and 19 more relations in a 3D space. These relations are expected to have a strong correspondence with spatial predicates describing spatial movements. This correspondence is figured out on the analogy of the mapping between lineregion relations and spatial predicates in the previous studies, since this mapping reveals that even lineregion configurations are often characterized by spatial predicates used for describing movements. Consideration of line's direction makes the mapping between lineregion relations and spatial predicates more specific and useful for, for instance, automated generation of qualitative descriptions of spatial movements. We then discuss a practical issue of such description generating process: how we should segment the trajectory of a moving entity in a meaningful way, if it is complicated, such that its movement is described as a sequence of spatial predicates. Five solutions are proposed and compared in an exploratory way.

## From 'location' to 'place', from 'path' to 'way': spatiophysical constellation, spatial language, and a lexicalsemantics model

*Matthias Weisgerber*
*Department of Linguistics, University of Konstanz, Konstanz, Germany*

The current paper deals with formally modelling the impact that spatial constellation has on linguistic representation, focusing on the step from localization calculus (referred to e.g. by prepositions) to event calculus: While in $x$ refers to possible positions, $x$ is in $y$ denotes a truth statement, depending on the physical and topological structure of $x$, on $y$ and on the force and support makeup of the world. In a spatiophysical calculus, locating of objects is then restricted to cases where the object finds the kind of (physical) support it needs to rest in a stable position. A formal model will be given along the following lines: Three conceptual competitors, (moving object, supportobject, and path), mutually contribute to situation modelling. If the moving object needs contact to the ground (a conceptual feature) and if the ground object provides this support, then the underdetermined path adapts to the ground object's shape yielding a more determined path representation. When finally motion takes place, one 'way' along the direction of the moving object's motion is chosen The model will be successively applied to linguistic examples (über/over, above; auf/on; entlang/along; klettern, steigen/climb, rise; fliegen/fly). One main new contribution of the framework is the fact that the determination process of the path is made explicit, and that 'force and support' reasoning is explicitly involved in modelling. The model, an interface between conceptual/semantic structure and the perceiver's conceptualization of the physical world, meets the conceptualsemantic Jackendoff paradigm, though being more algorithmically formal.

## ENVIRONMENTAL DETERMINANTS OF ORIENTATION AND NAVIGATION

*Convenors: Christoph Hölscher[1], Anna-Maria Nenci[2], Renato Troffa[3]*
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*[3]University of Cagliari, Cagliari, Italy*

General abstract:

The cognitive and behavioural determinants of human orientation movement in the built environment have been a subject of

investigation by environmental researchers, cognitive psychologists as well as architects and urban planners for several decades. Human orientation movement in the built environment can be highly faceted, depending on environmental factors and the task structure of the human agent. For example, researchers are looking at both wayfinding and free exploration of indoor as well as outdoor environments and their consequences for formation of spatial memory. Wayfinding can be defined as the process to navigate through a chosen route that connects an origin to a destination. It is a target-directed process that implies to determine and correctly place the starting position, identify the favourite or correct route, monitor this route during the way, and properly recognize the destination (Downs and Stea 1973). Travellers use various spatial, behavioural and cognitive abilities, and use several kinds of environmental cues, depending on the variety of the task, and/or on the characteristics of the navigation setting (e.g., city vs. building). For tasks with less clearly restricted goal characteristics, like free exploration of a new environment or trips in large-scale shopping malls the interplay of environmental, cognitive and motivational factors will vary. Environmental features have been categorized broadly into visual access, architectural differentiation, signage and layout complexity (Weisman 1981), and each of these classes of features poses its own challenges to experimental investigation. Studies in this field have approached differently the question of how people select and read environmental cues: e.g., they focus more on social or physical characteristics of the environment, use different kinds of instruments to approach the topic through field studies or laboratory experiments, and target more social or cognitive aspects of the performance. In this symposium, we will bring together expertise on orientation and navigation from different disciplines as architecture, urban planning, cognitive and environmental psychology. The symposium aims to show similarities and differences between disciplines involved for both their methodological approach and theoretical perspectives. We will have studies covering wayfinding in highly controlled task environments as well as self-selected travel itineraries in urban settings. Real life questions of emergency egress are covered as well as search for targets in VR environments. Furthermore, the investigation of behavioural patterns will be complemented by eye-tracking studies of visual attention in exploration as well as route learning tasks. All of the contributions will put special emphasis on detangling the relative impact of task characteristics and environmental features, ranging from landmarks to route networks and place geometry, in a systematic fashion.

## Location and task effects on route learning in a large-scale virtual environment

*Simon Büchner, Jan Wiener, Christoph Hölscher*
*University of Freiburg, Freiburg, Germany*

When exploring a maze, the strategy to pick one wall and follow it, is often considered as a successful option (Løvås 1998). The advantage of the strategy is that one can always easily find back to the starting point without having to memorize the path as one can simply turn around and walk back along the same wall. At the same time the strategy guarantees that one does not explore one branch of the maze twice. While the strategy is often quoted, it has—to the authors' knowledge—never been thoroughly investigated in a controlled setting. We will present a study testing whether people spontaneously choose this strategy and we will show how it affects navigation performance when searching for target objects positioned at different locations within the maze. In addition, we investigated how prior knowledge affects the search performance. We found that prior exposure to the environment modulates performance differently depending on the exact object location. The results show how the success of this particular search strategy is determined by the location of the target object. We also show that previously acquired knowledge about the test environment facilitates the learning process only when the location of the target object is not compatible with the strategy. The latter result suggests that prior knowledge allows for more flexible changes in search strategies.

## The influence of spatial structure and configuration on behaviour: sase study of a complex school environment

*Erica Calogero, Ruth Conroy Dalton*
*University College London, Bartlett School of Architecture, London UK*

This paper presents the study of a newly constructed secondary school ('academy') located in central England. The purpose was to determine whether or not a relationship exists between spatial configuration, movement and spaces for learning. This study consists of three distinct sections: first, a questionnaire and 'social probe', second, a series of student occupancy and movement observations using video and manual observation techniques and, third, spatial analyses conducted using space syntax methods. The study confirms that there is a relationship between movement, crowding, social encounters and potential for learning taking place within the primary circulation spaces of the school. Surprisingly, few classroom spaces were identified by pupils as good for learning. Some key, unstructured spaces in the school fulfilled a symbolic, social, circulatory and learning function. In contrast spaces restricted to circulation only were identified as merely crowded. These findings support the hypothesis that peer learning and movement through unstructured environments play an important role in aiding learning. This paper proposes a hypothetical model through which the configurational design of a school building may movement through unstructured environments play an important role in aiding learning. This paper proposes a hypothetical model through which the configurational design of a school building may influence learning success through a mechanism of probabilistic social encounter that is directly manipulable through space. We expect this relationship to remain independent though weak when compared with other factors that may influence an individual's learning.

## Synchronization of brain dynamics with navigation behaviors in full scale, stereoscopic 3D virtual reality architecture

*Eve A. Edelstein[1], Klaus Gramann[2], Jurgen Schulze[3], Andrey Vankov[2], Nima Bigdely[2], Elke Van Erp[2], Scott Makeig[2], Eduardo Macagno[1]*
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Wayfinding responses within full-scale architectural models have been studied in a stereoscopic virtual reality environment. Software has been developed to synchronize electroencephalographic (EEG)

responses from a 256 electrode array with subject movement through the 3D model projected in a high definition 360° immersive CAVE. The combination of these technologies makes it possible to measure quantitatively and objectively the human responses features of the built environment, in real time, and in behaving, mobile individuals. Subjects were studied as they navigated through increasingly complex architectural models toward a designated goal. Behavioral observations and post-study surveys revealed different cognitive strategies as users calculated the most efficient path toward their goal. Specific features of design were altered to create different experimental conditions, one rich in visual orientation cues, and the other devoid of such cues. Visual ambiguity was systematically controlled by varying the symmetry of the surrounding environment, lighting effects and shadows, or other visual cues that might serve orientation. Independent component analysis of brain regions was used to explore the changes in EEG frequency and amplitude generated within specific regions of the cortex at different stages of wayfinding behavior and in subjects using different strategies.

## Escape: Wayfinding strategies and emergency

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The present contribution approaches the role of environmental structure on wayfinding. There are several evidences, in literature, stressing the importance of the configuration of built spaces in influencing people's movement. In particular, this work bases on previous studies that stressed the importance of visibility—together with the angular incidence—in the process of orientation in unfamiliar environments, so a real-world experiment was carried out. $N = 30$ people (equally divided according their level of familiarity with the setting) were involved in the study. They had to complete an emergency escape task in two real built environments. When completing the task, participants could choose between two typologies of strategies: a shortest route strategy, represented by the shortest way to go out from the building, and a high visibility strategy, represented by the route characterised by the highest level of visibility. In order to distinguish the role of visibility and angular-incidence, one of the experimental settings included a third typology of strategy: a lowest angular-incidence route. A pre-test showed that the different settings and routes were homogeneous for as regards possible intervenient variables. The main hypothesis of the study is the following: (H1) The routes characterised at the same moment by the lowest angular incidence and by the highest visibility are more chosen than the shortest ones. A second order hypothesis regards the different effects of visibility and angular incidence, in the case they are distinguished. Currently, the study is in the phase of data-collection.

## How the geometry of space controls visual attention during wayfinding

*Jan Wiener, Lars Konieczny, Christoph Hölscher, Simon Büchner*
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We present two eyetracking experiments investigating the control of visual attention during spatial decision making. Participants were presented with screenshots taken at different choice points in a large complex virtual indoor environment. Each screenshot depicted two movement options. In Experiment 1, participants had to decide between them in order to search for an object that was hidden in the environment. In Experiment 2, participants were informed about which movement option to take as if following a guided route. They were required to memorize the route during an initial encoding phase. In the subsequent decoding phase they were presented with the same images in random order and had to indicate whether they turned left or right during first exposure. In Experiment 1, we demonstrate (1) that participants reliably chose the movement option that featured the longest line of sight, and (2) a robust gaze bias towards the eventually chosen movement option in frequency and duration. In Experiment 2, we show systematic differences in gaze bias towards the two movement options during encoding phase and during decoding phase. Finally we present a novel bottom up, stimulus-based description that captures aspects of the geometry of the sceneries and that allows predicting participants' fixation behavior in both experiments. Taken together, results from this study shed first light onto the control of visual attention during navigation and wayfinding.

## The relative importance of environmental factors on path choice

*John Zacharias*
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The burgeoning literature on environmental factors in path preference and path choice strongly suggests that such decision-making is multivariate—no single, isolable factor accounts for most of the variance in behaviours. Environmental factors as drivers of behaviour act differentially according to situational and contextual factors, such as trip purposes and timing. As these environmental factors in preference and behaviour are defined, it will also be necessary to relativize them, for the purposes of a general behavioural model. The research task involves two basic approaches: (1) multiple sites with control for multiple variables, and (2) a single site with multiple studies. The second approach is illustrated with the following quasi-experiment. In Zacharias (2001), exploratory path choices were recorded from a photo set of the historic core of Montpellier, France. Signs of human activity were added to the least preferred path choices and removed from the most preferred, such that a new set of participants tended to shift their preference according to signs of human activity. The photoset was then manipulated to alter aspect ratio: those views with highest preference had their aspect ratio increased. A new set of participants tended not to shift their preference as a result of the manipulation of aspect ratio, however. Although other research findings tend to support the thesis that people prefer more spacious and less confined settings, such preference was not detected in this study, undoubtedly because of the more powerful effect of human activity. Thus, it is important to relativize the previously published finding that people prefer spacious architectural settings-the attraction to human presence is stronger than the attraction to spacious architectural settings.

# MUSIC AND SPACE: A PHENOMENOLOGIC POINT OF VIEW

*Convenor: Michel Imberty*
*University of Paris X, Nanterre*

General abstract:

On a Conference on Cognitive Science and Neuroscience on Spatial cognition and action we aim to bring, regarding the spatial aspect of

music, a different point of view: The one of composers and musicologists confronting each other on the role of space in music perception and composition. In addition, in this symposium we are going to present a phenomenological point of view. Numerous composers staged a spatial representation of their works, particularly during the XIX and XX century. This representation uncovered or masked a cognitive or emotional process rooted both in cognition and unconscious, in physics and history, in culture and advances in technology. Some of those aspects are studied in this symposium: tied in painting and music, in architecture and in the acoustic of spaces where one listen and practice music (in particular singing) and its perception form listeners or its writing by the composer when he conceive his work to be played in a specific place, or again in the psychological and biological roots of certain sonorous structures reflects both time and space in occidental contemporary music. It is then necessary to take into account the meaning of space in relation to time in music, specifically the defined space for the senses of the listener or the composer and how the ambiguity of this notion is related to time.

## Music and space in the works of Maria Elena Vieira da Silva and Emmanuel Nunes

*Jean-Marc Chouvel*
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The interaction in between the painting of Maria Elena Vieira da Silva and the musical investigations of Emmanuel Nunes are not only due to their belonging to the same country. Of course, their relation to the light and color of Portugal is quite important. Both works propose a specific perception of the space. Furthermore, they give rise to a deep interrogation on what is our sensation, our feeling, our conception of space. Therefore, they meet with fundamental concerns of phenomenology, and especially contemporary phenomenology, related to the thinking of Husserl. This reflexion, impulsed by esthetic, echoes profoundly some recurrent concerns of psychology. That is what this paper would like to underline, within a precise comprehension of the works and their underlying techniques.

## Echo in music: from spatial figures to temporal figures

*Michel Imberty*
*University of Paris X, Nanterre, France*

In one of his remarkable books, the composer Salvatore Sciarrino starting from Beethoven analyses the importance of 'figures' in western music production. What strikes on a first instance, is that the concept of figure is ambivalent, it is on the edge of space and time, and that contemporary music, preceded by some relevant examples, keeps this distinction even though sometimes it does trespass it in a sense—from time to space, or another, from space to time. Putting himself from both the neurobiological and psychoanalytical perspectives, the author examines the founding figure of all the contemporary music tradition, the eco. Instrumental eco in the Baroque art, situated into a delimited space; but also eco in becoming, a transforming sound, eco opposite to mirror, or, more specifically, dynamic and temporal mirror based both on the brain functioning and the inter subjective human relations. The rationale is that the eco represents the most general and fundamental way of thinking: on a way the mirror thinking is the primarily image and cognitive representation; on the other inter subjectivity is organised by the dynamic of mirror neurons which are the basis for the comprehension of the other, his emotions and intentions. The eco in music is deep-rooted in this double origin. Several musical examples are going to be analysed from this point of view, from Monteverdi to Sciarrino through Berio, Nono and Boulez.

## The sound dimension of the painted Palaeolithic caves

*Iégor Reznikoff*
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Caves have natural properties of resonance: some parts sound very well, the sound lasts for some seconds or gives several echoes, some other parts have a dull resonance or no resonance at all. It is extremely interesting to compare in a given cave the map of the most resonant locations with the map of the locations of the paintings: are there correlations between resonance and paintings? Many Palaeolithic caves in France have been studied, and for them the answer was remarkably positive; stated shortly: the more resonant the location, the more paintings or signs are situated in this location. Some results are presented and special considerations on the acoustical aspects of such studies are given. The problem of the pictures/resonance relationship in open spaces with prehistoric painted rocks is briefly considered.

## How space sounds: an inner view of Space as a real compositional parameter

*Valerio Sannicandro*
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Which criteria affirm that a compositional element (space) has reached the status of a true musical parameter inside a musical work and, generally speaking, in the musical writing? To answer this question it is imperative to first identify those paths and possibilities where both musical research and technology might be useful to the composer and the influences that they could exercise on musical language. With this aim, we will see how the organisation of musical material can be structured starting from space/spatiality (seen not as a metaphor but as a true acoustic entity), an approach that will allow us to understand as well the aesthetic reasons that have been the background for this research. Finally, we will show in which way space, an essential element for the music of our time, can be considered from an "inner" point of view instead of in its merely topological or architectural nature. This perspective will lead our research into the domain of room acoustics (in particular to the resonance modes) and extend the exploration into a field of sensorial perception of timbres.

## Categorizing musical space

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Space has become a central category in music (in contemporary instrumental music, in electroacoustic music, in popular electronic music but also in the recordings of various music) and in related arts (sound installations, multimedia works, etc.). It is theorised in composition, musicologists question it, and listeners use it empirically. However, there is not a single definition of what could be a "musical

space". On the contrary, there are various ways of understanding this category, which sometimes do not have common points or which can even be in contradiction. For instance, what can be the common point between "tonal space", the impression of far and near in a recording, spatialization of sound through a loudspeaker system or space as place? One way of understanding this plurality is to use oppositions such as:

- metaphorical space versus physical space. Ex.: Varèse' "volumes" vs Varèse's "sound trajectories" (Philips' Pavilon);
- abstract (physical) space versus concrete space (place). Ex.: Stockhausen's Oktophonie vs Nono's Prometeo;
- virtual versus real space. Ex.: common recordings vs Agostino Di Scipio's Audible Ecosystemics (where music itself is produced in an interaction between a digital sound process, loudspeakers, the listeners and the room in which happens the performance);
- parametrical versus morphological space. Ex.: common use of reverberation vs Vaggione's use of phase decorrelation;
- immersive space versus space as distance. Ex.: Scelsi's mature music, Xenakis' polytopes or rave parties vs Nunes' music.

## EMOTION, MOTIVATION AND COGNITION IN HUMAN WAYFINDING BEHAVIOR

*Convenor: Francesca Pazzaglia*
*Department of General Psychology, University of Padua, Italy*

General abstract:

The topic of what cognitive variables are involved in navigation and wayfinding is still debated in the literature on spatial cognition. Moreover, in the last years also personality, motivation, and emotional variables have been investigated. The symposium will present a review of research on motivational, emotional, and cognitive factors implied in navigation and wayfinding behavior.

### Clinical and rehabilitation approach to navigation and spatial representation deficits: description of a patient with posterior cortical atrophy

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Posterior cortical atrophy (PCA) is a rare form of progressive degenerative dementia characterized by visual disabling impairment. This study investigated the cognitive and correlates of a patient with PCA, and aimed to evaluate a cognitive rehabilitation therapy. The patient (G.S., man, aged 70, education 18) underwent a built up ad-hoc neuropsychological battery and SPECT neuroimaging. The neuropsychological assessment showed visual-perceptual impairment, visuoconstructive apraxia, apperceptive visual agnosia, tactile, digital and environmental agnosia and mental imagery deficits. Spatial deficits were characterized by disorientation in familiar and unfamiliar places, impairment in map learning and spatial representation, spatial navigation and wayfinding. Comparing the SPECT scan of the patient with those of a group of healthy controls, results showed a decreased regional cerebral blood flow (rCBF) mainly in the right hemisphere, in the precentral, cingulate and middle temporal gyri, cuneus and precuneus, in the left superior temporal and lingual gyri, and in the parahippocampi. These data seem to evidence that visuo-spatial deficits might be related with the reduction of perfusion in occipito-parietal areas. In particular, the lower rCBF in parahippocampi and precuneus (involved, respectively, in spatial and imagery processing) might underline the inability of the patient to generate a mental map of the space. The damage in visuo-spatial representation is a typical feature of PCA, which might underline the inability in wayfinding and in orientation in familiar and unfamiliar places. The cognitive rehabilitation of PCA should focus on the enrichment of spatial representation of familiar environments and to increase the navigation ability in usual routes in order to increase the quality of life.

### Route-learning in young and older subjects in a virtual town

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A number of studies attest that spatial abilities decline with normal aging (e.g. Craik 2000). Despite how vital wayfinding situations are in every day life, it is though still unclear which particular aspects of spatial memory are affected by this decline in relation to route-learning. This experiment explored route-learning in young and older subjects when they are exposed to a virtual environment. 34 young women (mean age 20.8) and 30 older adults (mean age 56.2) were presented a virtual environment of a route in a fictitious town. They then had to perform a series of tasks intended to assess for the mental representation constructed. Older adults recognized images of the landmarks as well as young adults, and were as able to point to a target landmark from another one. In addition, older adults were as accurate in the verification of statements about direct spatial relationships between landmarks, but they were less accurate than young adults to verify statements describing indirect spatial relationships. In a map drawing task, older differed relative to younger as for the number of landmarks placed accurately on the map. They were as accurate as younger, however, when the order of the landmarks was considered. Working memory and self-evaluation on spatial orientation measures were also considered and taken together, results suggest that both the decline of storing and processing WM and self-evaluation reduction may affect or at least limit the easiness to construct an accurate representation of a route.

### A neural mechanism underlying successful wayfinding

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People spend a great deal of their time navigating through their environment. To be able to find our way home, we need to retrieve spatial information from memory. We investigate the underlying neural correlates of spatial representations and spatial wayfinding mechanisms. With different functional Magnetic Resonance Imaging (fMRI) studies we showed that the human brain automatically organises spatial information by dissociating between places carrying information necessary for wayfinding, and others. Objects occurring at navigationally relevant locations are stored in the parahippocampal gyrus, a region involved in coding object-place associations. The selective neural marking for navigationally relevant objects is rapidly

induced and long lasting. This automatic neural mechanism can provide the basis for successful wayfinding. In a present event-related fMRI experiment, we investigated how specifically such a mechanism adjusts to different environmental conditions. Therefore, we placed the same object twice in a labyrinth at places with the same and with a different navigational relevance. Consistent with our previous results, increased neural activity was observed in the parahippocampal gyrus for objects previously placed once at a relevant location as compared to objects placed at irrelevant locations only. Interestingly, when comparing objects placed twice at two different relevant locations with objects placed twice at irrelevant locations increased neural activity was observed in the right middle frontal gyrus, an area involved in executive functions like cognitive control. These results show a highly specific wayfinding mechanism that reacts especially sensible, if information at navigationally relevant locations is misleading.

### Anxiety dependent spatial navigation strategies in virtual and real space

*János Kállai*
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Acquisition of a mental map involves spatial knowledge as well as orientations, strategies, cues usage, and perceptuo-motor processes. A cognitive map is classically defined as a representation of a set of connected places systematically related to each other by a group of spatial transformation rules. Our results demonstrate how one part of this system, the anxiety dependent exploration strategies might be able to cooperate with the whole. Assessing the healthy human subject's way-finding and route-finding efficiency in real and computer generated virtual places, allocentric and egocentric reference frame dissociation was found. During the place learning process subjects with elevated fear score showed a delayed shift from egocentric frame using to allocentric one and as a consequence their cognitive map constriction become disorganised. These results will be completed by current fMRI data coming from our Spatial Orientation and Psychopathology Laboratory.

### Influence of motivation on wayfinding

*Samvith Srinivas, Stephen Hirtle*
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Human wayfinding tasks involve complex information processing and decision making that usually involves access to acquired or deduced spatial knowledge. Acquired knowledge is well-learned by multiple trips through a space, while deduced knowledge is inferred from acquired knowledge. Spatial knowledge directly determines a wayfinder's familiarity with the environment. While there are many instances where wayfinding tasks take place in a region that is completely familiar or unfamiliar, human wayfinding may also take place in a partially familiar environment that is composed of a familiar portion and an unfamiliar portion along a single route. Environment familiarity in turn determines the complexity of the wayfinding task. Complex wayfinding tasks are described as tasks that require more cognitive processing, such as wayfinding tasks that involve access to deduced knowledge, are performed in unfamiliar environments, or are performed in partially familiar environments. Given that recent studies have shown that emotion or affect influences human cognition, it is worth considering the influence of emotion on wayfinding. In particular, it is argued that the complex wayfinding tasks mentioned earlier will be more susceptible to affective states. Experimental evidence using a Virtual Reality (VR) theatre is described in which participants are asked to perform certain navigation tasks under either motivated or control conditions.

## ACTION AND COGNITION: THE ROLE OF GESTURE IN SYMBOLIC SPATIAL REASONING

*Convenor: Thomas F. Shipley*
*Temple University, Philadelphia*

General abstract:

Actions are generally thought to be the product of complex cognition, but not inherently symbolic. In this symposium, we present research on actions that are symbolic–the gestures that accompany speech. Gesture is important in the communication of spatial information. When people talk about spatial locations, they often use their hands to indicate movements along a route, point to distant locations, or even form a map-like representation with their hands. Adults use gesture in order to describe relational information. Gestures can play a significant role in the development of complex spatial reasoning. For example, gesturing about movement improves the gesturer's ability to visualize spatial transformations. In addition, gesturing offers a way to abstract from the details of a transformation and thus has the potential to facilitate symbolic reasoning about spatial transformations. Gesture can add action information to people's mental representations of a problem, which then changes how they think about the problem. Gestures also can be used to relieve limited spatial working memory resources perhaps converting a continuous code to a categorical, or symbolic, code. Generally, gestures can help spatialize mental models. Participants will present their recent work on spatial cognition and gesture. Each will be asked to frame their research presentations in the context of gesture as a symbolic action that can bootstrap spatial reasoning.

### Gesture changes thought by grounding it in action

*Susan Goldin-Meadow, Sian Beilock*
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Gestures communicate. People's gestures typically elaborate information conveyed in their speech, and gestures may represent ideas not explicitly part of a speaker's message. But gesture can do more. We show in this study that gesture can add action information to people's mental representations of a problem, which then changes how they think about the problem. Adults were asked to solve the Tower of Hanoi problem twice. A stack of disks, arranged from the largest on the bottom to the smallest on top, had to be moved from one of three pegs to another without placing a bigger disk on top of a smaller one and moving only one disk at a time. One group used a tower in which the heaviest disk was biggest on both trials (No Switch). Another group used a tower in which the heaviest disk was biggest on trial 1 but smallest on trial 2 (Switch). In between trials, adults explained how they solved the problem. The more the adults' gestures in the Switch condition incorporated weight information conflicting with the actual movements needed to solve the next

problem (i.e., the more they used a 1-handed gesture when referring to the smallest disk, which could not be lifted with one hand after the switch), the slower the adults were to solve the problem. Adults in the No Switch condition showed no differences in improvement as a function of the gestures they produced. The action components of our own gestures can influence how we solve problems, and not always for the good.

## Thinking with gestures

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Gestures are usually viewed as an accompaniment to speech. Yet, just as people talk to themselves, they also gesture to themselves, a phenomenon that is often unnoticed. Participants first attempted to solve six spatial reasoning problems; then they turned to a camera and explained the solutions so that someone else would understand them. Half the participants had paper and pencil, half did not. For problems with high spatial working memory demands, participants gestured, though alone in the room. Their gestures reflected the structure of the problems, but not the solutions. Those provided with pencil and paper sketched the structure of the same problems. When explaining the solutions to others, participants gestured far more, for all problems, for problem structure and well as for solution. Like diagrams, gestures can be used to relieve limited spatial working memory as well as to spatialize a mental model.

## Gesture training leads to improvement in children's mental rotation skill

*Susan C. Levine, Susan Goldin-Meadow, Stacy Ehrlich, Kimloan Tran*
*University of Chicago, Chicago, USA*

Our study examines whether mental rotation skill, a skill associated with STEM success improves when children are encouraged to gesture about movement. A sample of kindergarten children (82 boys, 76 girls) received a mental rotation test at pre-test and post-test that involved deciding which of four shapes can be made from two pieces that were translated or rotated with respect to each other. They were randomly assigned to one of four training conditions. In all conditions the experimenter said: "First look at these pieces. Now look at these shapes. If I move the pieces together, they will make this shape." In the Move–Move condition, the Experimenter gestured the movement that would bring the pieces together and then asked the child to do the same. In the Point-Move condition, the Experimenter pointed at the pieces and then asked the child to show with his hands how the pieces would move together. In the Move-Point condition, the Experimenter gestured the movement but then asked the child to point to the pieces, and in the Point–Point condition, both experimenter and child pointed at the pieces. Both boys and girls in the Move–Move condition and Point–Move conditions improved significantly, whereas neither boys or girls improved in the Point–Point or Move–Point conditions. Thus, producing movement gestures promoted mental rotation skill whereas producing pointing gestures did not, even when the experimenter modeled the movement gesture. These results raise questions about whether movement gestures are more effective than actually having children practice rotating through actions.

## Gesture lends a hand to spatial communication

*David Utta, Megan Sauter*
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Gesture is important in the communication of spatial information. When people talk about spatial locations, they often use their hands to indicate movements along a route, point to distant locations, or even form a map-like representation with their hands. However, previous research on the development of spatial communication has focused mainly on speech. Our goal here is to examine the role of gesture in spatial communication and its development. Children between the ages of 8 and 10 and adults first learned the locations of six toy animals that were each hidden in a large box in a room. We then asked the participants to explain the space to someone who had never seen the room. Their descriptions were videotaped and then coded with a focus on both speech and gesture. We found a difference in the types of information that adults and children communicate when asked to describe space. The 8-year-olds mostly provided information about the route taken through the space, with little emphasis on the relations among the animals. The adults provided structural information about the room layout, followed by the relations among the animals. However, gesture potentially leads the way for the development of spatial communication. When 8-year-olds did provide relational information, it was communicated entirely using gesture. Across development, speech increasingly accompanies gesture but does not replace it. The adults use gesture (with or without the redundant information in speech) in order to describe relational information. Taken together, the results indicate that gesture plays a critical role in the communication of spatial information, and that it may also play an important role in the development of both spatial cognition and spatial communication.

# SPATIOTEMPORAL MUSIC COGNITION

*Convenor: Petri Toiviainen*
*University of Jyväskylä*

General abstract:

Human music processing comprises a wide range of activities such as perception, cognition, emotion, learning, interaction, and enculturation. In most cultures, music performance is a multimodal form of expression that is often associated with activities such as dance and theatre. Despite this fact, research on human music processing has traditionally concentrated solely on the auditory domain, thereby dissociating perception and action and to a large extent ignoring multimodal interactions. Only recently have corporeality and multimodality of music processing become established topics of research. The embodied view of human cognition stresses the importance of an organism's sensorimotor capacities, body and environment in cognitive processes. According to this view, the interaction between these elements allows particular cognitive capacities to develop and determines the specific nature of those capacities. In opposition to traditional views of cognition that stress the importance of computation in cognitive processing, the embodied view emphasises the importance of goal-directed actions unfolding in real time. In musical activities, corporeality manifests in many aspects. First, dance is usually performed with music. Second, physical movement is often associated with the process of music listening. It is well known that periodic rhythmic structure tends to elicit accompanying movements. The elicited movements can be regarded as a means of facilitating the

parsing of the rhythmic structure of music. Third, physical movement plays an important role in musical interaction and communication, helping maintain synchronization musicians and convey expressive intentions. Finally, movement is an important ingredient in social interaction associated with music listening. The aim of this symposium is to illustrate recent advances in the research on spatiotemporal music cognition, with a particular focus on its various kinematic aspects. The symposium will consist of six presentations. The first two presentations focus on the kinematics of musical sequence production. Peter Keller investigates kinematic aspects of musical sequence production and shows how they are modulated by auditory feedback and even auditory imagery. The work by Giulio Tirinelli focuses on embodiments of musical beat. He studies the kinematics of body movement in tasks where participants have to reproduce rhythmic patterns with varying degrees of complexity. In the third presentation, Geoff Luck discusses expressive movements by conductors. In particular, he studies the perception of emotion in these movements using a continuous response paradigm. The last three presentations focus on music and dance. Jessica Phillips-Silver discusses the ability to produce and perceive beat through dance-like movements in various populations ranging from musical experts through ordinary listeners to persons with musical deficits. Petri Toiviainen's presentation focuses on the kinematics of spontaneous movement to music. More specifically, he investigates typical eigenmovements that embody the metrical structure of music. Finally, Marc Leman discusses how musical characteristics of different styles are reflected in dancers' movement patterns. He presents a novel method for analyzing and visualizing hidden rhythmic processes in dancers' movements.

## How movement timing and kinematics are shaped by spatial attributes of pitch during musical sequence production

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Previous research has shown that cross-modal correspondence between pitch contours and movement transitions on the 'height' dimension facilitates temporal precision in music-like sequential action. The current study investigated this phenomenon further by using a motion capture system to examine timing accuracy and kinematics during the production of action sequences with auditory effects. Musicians responded to metronomic pacing signals by producing three unpaced taps on three vertically aligned keys at the given tempo. Taps triggered tones in two out of three blocked feedback conditions, where key-to-tone mappings were compatible or incompatible in terms of spatial and pitch height. Results indicate that, while timing was most accurate without tones, movements were smaller in amplitude and less forceful (i.e., velocity and acceleration prior to impact were lowest) when tones were present. Moreover, timing was more accurate and movements were less forceful with compatible than incompatible auditory feedback. It may be the case that auditory information is weighted relatively strongly during the integration of feedback from different sensory modalities when pitch and movement transitions are compatible on the height dimension. This may reduce the reliance upon tactile feedback for timing control, thereby engendering a lighter, more 'buoyant' movement style. The fact that these effects were observed at the first tap (before tone onset) suggests that anticipatory auditory imagery modulates the temporal kinematics of regularly timed auditory action sequences, like those found in music. Such cross-modal ideo-motor processes may function to facilitate planning efficiency and biomechanical economy during music performance.

## Spatial cognition of Samba and Charleston

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Problem: from the perspective of embodied cognition, human dance can be seen as a corporeal expression of musical patterns, and therefore, as a mirroring of perceived audio patterns into enacted spatial patterns. Although the nature of this audio to space mirroring can be related to the mirror neuron system (roughly: the idea that brain areas for perception and action overlap), this mirror system does not give us an account of spatial representations, nor of the entrainment between the biomechanics of the body, learned choreographies, and perceived music. Such an account is needed to better understand how people experience music and how they interact with music, using technological mediators (Leman 2007). Focus: in this contribution, we consider the spatial and temporal representations that underlay music-driven dances. We assume that these representations are expressed through the human body, and therefore, that they can be studied by looking at how the human body moves in response to music. Method: We approach the audio-space mirroring system by extending a multi-modal analysis in which repetitive patterns in dance are analyzed from the viewpoint of musical meter (Naveda and Leman 2008a, b). The dances are recorded with a three-dimensional motion capture system (infra-red). The trajectories of the markers on the body of the dancers are post-processed and decomposed into non-orthogonal periodicities that fit with the periods of the musical meter. By using this method, periodic trajectories can be extracted and plotted in a 3d space and time-stamped with temporal marks that reveal hidden processes of the rhythmical engagement of the dancer's body. The combination of spatial representation with temporal specifications results in a map of dance forms that shed light over the mirroring process. Results: We introduce a new form of 3D-music-dance representation and show that the emerging space-time representations reveal the characteristics of the learned styles, in particular Charleston and Samba.

## Perception of expression in conductors' gestures: a continuous response study

*Geoff Luck, Petri Toiviainen*
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Background: Previous research has highlighted relationships between corporal behaviour and musical expression. It has been shown, for example, that the visual channel is more informative than the auditory channel in perceptual judgements of a performer's level of expression. This may be due to the fact that performers tend to increase their overall amount of movement when asked to perform with more expression. An alternative hypothesis, however, is that observers react to more detailed features of the performer's movements, i.e., the movement kinematics. It has been shown, for example, that observers are sensitive to the movement kinematics of temporal conducting gestures. In this study, we investigate relationships between the kinematics of a conductors' expressive gestures and ratings of perceived expression. Aim: To examine relationships between movement kinematics and perception of expression in conductors' gestures.

Method: The gestures of two professional conductors directing an ensemble were recorded with an optical motion-capture system. Point-light representations of these gestures (totalling 15 min) were presented to participants, who provided continuous ratings of perceived expression using a virtual slider interface. Perceived expression was rated according to the three-dimensional model of emotion, with *activity*, *valence*, and *power* being rated separately. Relationships between these ratings and 16 kinematic variables computationally extracted from the movement data were subsequently examined statistically. Results and conclusions: Data collection is underway, and detailed results and conclusions will be reported at the conference.

## Music embodied in dance: studies of dance-like movement in different populations

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Musical movement and dance are observable in almost every individual, regardless of age, culture or type of musical experience. Infants and children respond to music with spontaneous, dance-like motion, and demonstrate the perceptual foundations of musical structures, such as rhythm and metre, that mature with time and practice. Adults synchronize the movement of their bodies with music, and can judge whether others are moving in time. We will discuss the abilities to perceive and produce the beat in music through dance-like movement, in groups ranging from the general population to musical experts, to individuals with music-specific deficits. We will consider evidence from studies in neuroscience and neuropsychology, as well as methods of practice and pedagogy in music and dance.

## Features of body movements during the reproduction of rhythmic patterns: the influence of the events complexity

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Current Research focuses on different topic regarding the relationships between movement and the perception (and reproduction) of music and rhythmic patterns. Studies in this field have approached differently the question of the role of the human body in music-related activities, e.g. Wanderley Vines et al. (2005); Palmer et al. (2004); Eerola et al. (2006); Luck and Toiviainen (2006). Which kinematic and dynamic features are important in people performing musical rhythms? Is there an influence by the complexity of the rhythm structure? Are there differences between professional musicians and non-musicians performances? Our study represents a systematic investigation of body movement during the reproduction of auditory rhythmic patterns in a real-world setting particularly investigating if and how people use their body movements in relation to the beat during the reproduction of rhythmic patterns. Skilled drummers and nonmusicians subjects performed rhythm reproductions of auditory rhythmic patterns clapping their hands and hit a stick on a drum-pad. The different levels of rhythmic complexity have been evaluated crossing two indexes: PS-Measure (Povel and Shmulevich 2000) and Toolbox Pulse Clarity (Lartillot 2008), having ten levels of complexity for the first index and taking into consideration the simplest level of the second one. Spatiotemporal features of the movements and temporal features of the performances have been extracted by means of a motion capture system. The body representation of the beat seems to be tied to the complexity of the pattern to reproduce. The effects of different movement features on the reproduction of rhythm are analysed so as the systematic relationships between the temporal features of the rhythm complexity and the spatiotemporal characteristics rhythm reproductions in movements and timing.

## Embodied metre: Hierarchical eigenmodes in spontaneous movement to music

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Music often contains temporal periodicities that evoke a percept of regularly occurring pulses. The perceived pulses are often hierarchically organised, and consist of at least two simultaneous levels, whose periods have an integer ratio. This gives rise to a percept of regularly alternating strong and weak beats, a phenomenon referred to as metre. Listening to music is often associated with spontaneous body movements, frequently synchronized with its periodic structure. The notion of embodied cognition assumes that intelligent behavior does not emerge from mere passive perception, but requires goal-directed interactions between the organism and its environment. According to this view, one could postulate that we may use our bodily movements to help parse the metric structure of music. We studied how pulsations on different metrical levels manifest in spontaneous movement to music. Participants moving spontaneously to instrumental music were recorded with a high-quality optical motion capture system. Subsequently, methods of signal processing, dimensionality reduction, and clustering were applied to extract representative eigenmovements synchronized to different metrical levels. In a preliminary analysis we found eigenmovements synchronized to several metric levels of the musical stimulus. Moreover, we found differences between metric levels in terms of the prevalence of synchronized eigenmovements. For instance, mediolateral movements of arms were found to be frequently synchronized to the tactus level pulse, while rotation and lateral flexion of the upper torso were commonly found to exhibit periods of two and four beats, respectively. More detailed results will be presented at the symposium. The results imply that periodicities on several metric levels are simultaneously present in spontaneous movement of music. This could suggest that we embody the metric structure of music.

# THE NEUROCOGNITION OF CATEGORICAL AND COORDINATE SPATIAL RELATION PROCESSING

*Convenors: Ineke van der Ham and Albert Postma*
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General abstract:

A profound knowledge about the spatial relations between objects in our environment is vital to navigate through space and to communicate about our surroundings. These spatial relations can be processed in two different ways: co-ordinately (precise and metric) or categorically (more abstract and qualitatively) (Kosslyn 1987). It has been proposed that coordinate relations are mainly processed by the right hemisphere, and categorical relations are processed by the left hemisphere. Many studies have confirmed this double dissociation, yet some criticism has

also been put forward. Also, the number of studies within this field has expanded over the last few years. Therefore, an evaluation of the original hypothesis seems in order, incorporating the latest evidence. In this symposium, we intend to review recent studies on this topic, in order to allow for a discussion of the current theories on spatial relation processing. A new theme that will be considered is spatial relation processing within mental imagery, as opposed to visual perception, which has also shown the hypothesized hemispheric specialization. Other issues that will be addressed by the speakers are the role of working memory, the link between spatial relations and ego- and allocentric processing, and recent developments in TMS research.

## The relationship between egocentric/allocentric frames and categorical/coordinate information

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Categorical spatial information refers to positional relationships (such as left/right) either between objects or between objects and the self. Similarly, coordinate spatial information defines metric spatial distance either between objects or between objects and the self. Therefore, categorical and coordinate spatial information cannot be encoded without specifying an egocentric (dependent on body's position) or allocentric (centred on external objects) frame of reference. What is the relationship between the two spatial distinctions? Drawing from the perception/action theory (Milner and Goodale 1995), one might argue that egocentric frames of reference organizing coordinate information are important for immediate visual control of action, whereas allocentric frames of reference structuring categorical information are relevant for object recognition. Recent data showing prevalence of categorical allocentric processing in tasks requiring perceptual judgments of 2-D stimuli and of coordinate egocentric processing in tasks requiring verbal estimates of 3-D actual objects are discussed. As also shown by previous literature, characteristics of objects (2-D vs. 3-D), modes of response (verbal/spatial vs. visuo-motor) and study-test delays are all important in predicting specific effects. It is proposed that reported evidence might be consistent with a snowball mechanism according to which the control of functions serving adaptive purposes may influence the development in neighboring cerebral areas of other related functions (Kosslyn 1987). Instead of predicting dichotomies, this idea would support both specificity and flexibility of the two spatial distinctions under scrutiny.

## Processing coordinate and categorical spatial relations with different apertures of attention

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By use of a cueing procedure, spatial attention was manipulated so that the attention window would select regions of the visual field of differing. It was found an interactive relationship between the presumed size of the attention window and performance in two spatial perception tasks: When the attention window was large, "coordinate" spatial judgments were better than when relatively smaller and when the attention window was relatively smaller, "categorical" spatial judgments were better than when the window was relatively larger. These findings can be accounted for by a computational theory of spatial perception processing (Jacobs and Kosslyn 1994), which maintains that high-level spatial representations of distance between objects are more efficiently obtained by attending to neural units with large, overlapping, receptive fields, whereas high-level spatial representations of categorical relations between objects are more efficiently obtained by attending to neural units with small, non-overlapping, receptive fields.

## Is the cerebral processing of categorical and coordinate spatial relations based on different or identical but differentially activated functional networks?

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The fundamental hypothesis related to the distinction between categorical and coordinate processing has been that these two types of spatial relations coding are qualitatively different. Based on Kosslyn's initial hemispheric specialization theory, they also are hypothesized to rely on different functional networks in the brain which are supposed to have evolved in a way to take advantage of more fundamental hemispheric specializations in order to adapt these hemispheric strengths to the processing of the two different types of spatial relations. This initial theoretical framework was based on empirical evidence that came essentially from divided hemifield studies and subsequent cerebral imagery research has provided partly contradictory evidence for the hemispheric specialization theory. An alternative hypothesis might be to view the coding of categorical and coordinate spatial relations in a continuous way, which would mean that the two coding types rely essentially on the same neural network consisting of more general-purpose processes, such as visuo-spatial attention, but with a different weighting of these general processes depending on exact task requirements. We will present data that support this 'continuous spatial coding' hypothesis, showing that categorical and coordinate spatial relations rely on the same fronto-parieto-occipital neural network, but that the coding of coordinate spatial relations relies more heavily on attentional and executive processes, which could be at the origin of the hemispheric differences that were described in the literature on categorical-coordinate processing.

## Hemispheric contribution to categorical and coordinate representational processes: A study on brain-damaged patients

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According to Kosslyn, two types of spatial relations can be used to arrange parts in mental imagery, i.e., categorical spatial relations and coordinate spatial relations, which are processed, respectively, by the left and right hemispheres. To investigate this possible hemispheric specialization in the imagery domain, we tested 34 left or right brain-damaged patients using both a categorical and a coordinate mental imagery task. The results show that left brain-damaged patients were selectively impaired on processing categorical representations, while right brain-damaged patients were more impaired on the processing the coordinate ones, regardless of the presence of visuo-spatial neglect. These data partly support Kosslyn's theory and, despite data reported in previous studies of brain-damaged patients, also support the hypothesis of a possible bilateral neural representation of mental imagery, with the two hemispheres taking part in this process in different ways.

## rTMS study of categorical and coordinate processing

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In a previous study (Trojano et al. 2006), we investigated the issue of lateralization of coordinate and categorical processing in the spatial imagery domain by means of repetitive transcranical magnetic stimulation (rTMS). We observed that right parietal stimulation interfered with the execution of the coordinate task, while left parietal stimulation mainly affected the categorical task, but also reduced the learning effect on the coordinate task. In the present study, we again used rTMS to verify and extend our findings to the spatial perception domain. The experimental paradigm required subjects to emit categorical or coordinate judgements on perceptual stimuli composed by two circles (one within the other) and two dots; the subjects had to decide relative or absolute position of the dots with respects to the target circles. The judgements had to be completed during visual perception of stimuli (immediate condition), or 4 s after stimulus presentation (delayed condition). An off-line (low frequency, low intensity, 10-min stimulation) rTMS paradigm was applied, with stimulation sites over intraparietal sulcus in the left (P3) or the right (P4) hemisphere (as in Trojano et al. 2006), in two separate groups of normal subjects. A third, control group received ineffective (sham) rTMS. The experimental paradigm was performed by all subject groups three times: before and immediately after rTMS, and 10 min later. Results showed that rTMS over the right parietal lobe significantly interfered with development of practice effect for the coordinate task in the perceptual condition, particularly in women, whereas rTMS over the left parietal lobe had a mild effect on development of practice in both tasks. No difference was observed between the two stimulation sites in the delayed condition, in agreement with other recent studies (Van der Ham et al. 2007). In conclusion, the present rTMS study partially confirmed a different lateralization of categorical and coordinate spatial processing in the perception domain, but highlighted that interactions between the two hemispheres are highly dynamic.

## Spatial relation processing in perceived and remembered scenes

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*Experimental Psychology, Utrecht University, Utrecht, The Netherlands*

Rosielle et al. (2002) have shown that change detection in a scene is faster when the categorical relations of the moved object change with regard to the nearest object in the scene, compared to a change in which only coordinate relations are different. Categorical spatial relations concern abstract labels, such as left of, or below. This study aims at further investigating the role of categorical relations in scene perception and memory. In the first experiment, subjects were shown two computerized images of a room simultaneously and had to identify which object had changed position, when comparing both images. The position change was either categorically the same or categorically different. The results confirm the previous findings and show that categorical relations are of importance during scene perception, because when they change, subjects are better at detecting them, than when they remain the same. In the second experiment, we studied this categorical advantage in an object location memory design. Subjects studied computerized images of rooms filled with objects. In the testing phase the room was shown without six of the objects, and subjects were asked to choose one of three options as the correct location for each of the objects sequentially. During testing, the room was either shown from the original perspective or from a small or large angle change. Even for this relatively complex task we found the categorical advantage. Moreover, we found that only the performance on coordinate trials decreased when the viewing changed, while categorical performance remained stable.

# GAZE AND COGNITIVE CONTROL IN MOTOR PERFORMANCE

*Convenor: Joan N. Vickers*
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General abstract:

In the course of all motor behaviour, the brain is limited in how much information can be processed and enacted upon at a time. Actors must constantly decide where to look, what to attend to, and how to time fixated information with precisely controlled actions. Gaze is directed to only one area at a time and information central to success must be selected from spatially complex environments, often under severe time constraints. The co-ordination of these processes is explored in this symposium in a number of motor tasks, including soccer, police handgun shooting, basketball shooting, and ice hockey goaltending. What visual information underlies the ability to make decisions under these complex task conditions? What is the relationship between control of the gaze to task outcomes? What changes occur within the gaze control and cognitive systems when an actor first learns a motor skill to performing it at a high level? These are some of the questions that will be addressed by the presenters in this symposium on the control of the gaze, perception/cognition processes and motor performance. A. Mark Williams will lead off and present recent research on the constraints that underly visual search behaviour in a number of sports. This will be followed by Raoul Oudejans, who will present his research on police training and performance under pressure. Mark Wilson will then present a study in basketball shooting where he re-examines the role of the quiet eye and location-suppression hypothesis. Derek Panchuk follows and presents a series of studies in ice hockey goaltending, where he looks at the role of predictive and prospective motor control theories in explaining elite performance in rapid interceptive timing actions. Finally, Joan Vickers presents her research on the gaze control and shooting performance of elite and trainee police officers during a live force on force encounter.

## Police performing and training under pressure

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In this presentation, we will present our work with police officers. First, Oudejans (2008) found that reality based practice under pressure helps in preventing degradation of handgun shooting performance under pressure for police officers. The experimental group practiced handgun shooting under pressure evoked by an opponent who fired back using marking (coloured soap) cartridges. The control group practiced shooting on standard cardboard targets. While at the outset both groups performed worse in front of an opponent firing back compared to cardboard targets, after training,

shooting performance of the experimental group no longer deteriorated while performance of the control group was still equally harmed. These results indicate that training under pressure can acclimatize shooting performance of police officers to those high-pressure situations they may encounter during their work. Yet, this study does not provide insights into more detailed changes in behaviour that accompany or underlie changes in performance. Therefore, in a next (pilot) study we explored changes in shooting accuracy, movement times, head/body orientation, blink and gaze behavior of police officers shooting under pressure. Results again showed that with pressure, shooting accuracy decreased. Furthermore, participants acted faster, had a different head/body orientation, made more blinks, and seemed to have higher search rates and decreased durations of fixations on the targets. The pilot study is currently followed-up by a training study investigating the effects of training under pressure on the same variables. It is expected that the negative changes that were found under pressure will disappear.

## Quiet eye control strategies in interceptive timing actions

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Interceptive actions require an individual to time a motor response to coincide with an external event. There is no denying that in order to meet the tight spatial-temporal demands needed for successful performance a tight coupling and coordination between perceptual and motor processes is required. However, the control strategy that underlies successful performance is a matter of debate. On the one hand, a predictive control strategy would assume that advanced information is used for response selection and the movement is carried out faithfully without modification. Conversely, a prospective control strategy assumes that the movement response is continually specified through to the point of interception. Using the rapid interceptive task of ice hockey goaltending we explored the effects of progressively removing predictive information on the gaze behaviours and motor responses of elite goaltenders. Results showed that goaltenders generally used a predictive control strategy, however, a prospective control strategy was observed on a number of trials. Interestingly, the gaze behaviour that corresponded to either of these strategies was the quiet eye, which was the final fixation prior to the onset of the saving motion. Optimal location and duration of the quiet eye was an important factor for successful interception of the puck.

## Gaze and shooting performance of police officers in a force on force encounter

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Despite receiving extensive handgun training, police officers perform poorly when involved in force on force encounters against an armed attacker. One reason given is the action-reaction hypothesis where it is argued the attacker has a time advantage over the officer who is forced to react. Officers from an elite tactical unit and trainees from the same unit responded to a live simulation of an armed attack while wearing a light mobile eye tracker coupled with cameras that recorded the officer's and attacker's movements. Five trials were performed which required firing their weapon, plus two catch trials randomly assigned where a cell phone was brandished instead of a gun. Significant differences were found due to expertise in shooting accuracy (SWAT 70.8%; Trainees 52.4%) and errors during the catch trials (SWAT 18.2%; Trainees 61.5%). Rather than finding support for the action-reaction hypothesis, we found that on 28.6% of SWAT trials and 77.4% of trainee trials the officers lost sight of the attacker due to using a saccade back to the sight of their own gun during the final 700 ms of the attack. During this time they were unsuccessful in aiming their weapon but instead lost the sight picture, which in turn led to errors in accuracy and decision-making. In contrast, those officers who were successful maintained fixation on the attacker and aligned their weapon to a stable and uninterrupted line of sight. This gaze control and attention strategy contributed to higher levels of shooting accuracy and a reduction in decision errors.

## Mapping the constraints on visual search behaviour in sport

*A. Mark Williams*
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The ability to locate and identify relevant visual information is essential for skillful behavior in many dynamic sports. Performers are required to move the eyes around the display in an efficient manner and to extract critical information using the fovea, parafovea, and/or visual periphery. According to traditional cognitive perspectives, the visual search patterns employed by performers are thought to be prescribed in an almost a-priori manner by a symbolic code or knowledge map. In this presentation, an alternative theoretical framework is considered that views search behavior as an emergent phenomenon based on unique constraints that influence the visual system exist at any given moment. Research is presented to illustrate how visual search behaviors are shaped in a dynamic and evolving manner by the unique constraints imposed by the task, the environment, and the individual characteristics of the performer. Although empirical evidence is needed to clarify and support a constraints-based explanation of visual search behavior, the ideas are intuitively appealing, and may have significant implications for theory and practice.

## Visuo-motor control in far aiming tasks: re-examining the location suppression hypothesis

*Mark Wilson*
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In this study, we re-examined the predictions of the location suppression hypothesis (Vickers 1996) using the basketball free throw as a far aiming task. 14 male participants performed free throws whilst wearing an ASL Mobile Eye gaze registration system. Participants were classified as either better performers (BP) or poorer performers (PP) based on their shot accuracy. Quiet eye (QE) duration and onset were measured, and results showed that longer and earlier QE periods were indicative of superior performance. The different types of gaze behaviours used during the occlusion period, when the ball and arms block the target, were also measured, and a composite score of 'suppressed vision' calculated. Results showed that the occlusion period was significantly longer and occurred significantly earlier for BP than PP, and BP utilized an attentional strategy consisting of more

suppressed visual processing during the occlusion period than PP. A final exploratory aim was to further our understanding of the complex relationship between visual control, shooting action and performance. PP adopted a high-shooting style; lifting the ball quickly above their heads, where they paused to re-fixate on the target, before completing the shot. In comparison, BP adopted a low-shooting style complete with an early QE and late suppression of vision. We propose that visual control drives subsequent shooting action for the free-throw task and discuss the findings in relation to Vickers' (1996) location suppression hypothesis.