

## **Report: Spatial Representation and Multisensory Perception workshop Rethinking the Senses, Room 246, Senate House, 28th November 2014**

The motivation for this workshop was to make progress in providing a taxonomy or framework for understanding spatial multisensory interactions through structured discussion of a number of questions concerning the difference between spatial representation and spatial information, what reasons there are for thinking that there is a single representation of space common to all the modalities, or even within a modality, the distinction between perceptual and non-perceptual representations of space, and the kinds of interactions we think take place.

The aims of the workshop were to clarify and refine our philosophical questions about spatial multisensory interactions and move towards generating empirical work on the basis of those philosophical questions.

The meeting, organised by Matthew Nudds and Alisa Mandrigin, didn't include any talks. Instead, the day was spent in roundtable discussion, chaired by Matthew Nudds, of a series of questions circulated to participants beforehand.

### **Participants**

Elena Azañon – Birkbeck

Colin Blakemore – School of Advanced Study, University of London

Andy Bremner – Goldsmiths

Yi-Chuan Chen – University of Oxford

Ophelia Deroy – School of Advanced Study, University of London

Frances Egan – Rutgers

Naomi Eilan – University of Warwick

Merle Fairhurst – School of Advanced Study, University of London

Giandomenico Iannetti – UCL

Matt Longo – Birkbeck

Alisa Mandrigin – University of Warwick

Mohan Matthen – University of Toronto

Robert Matthews – Rutgers

Matthew Nudds – University of Warwick

Ian Phillips – University of Oxford

Jan Schnupp – University of Oxford

Frederique de Vignemont – Institut Jean-Nicod

Keith Wilson – University of Glasgow

Hong Yu Wong – University of Tübingen

Yuanyuan Zhao – School of Advanced Study, University of London

### ***Session 1: What do we mean by a representation of space?***

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Discussion in the first session revolved around the question of what distinguishes representations of space proper and the encoding of information about spatial location in the nervous system that falls short of what philosophers would think of as a representation. Underlying this was the issue of whether, in thinking about the integration of spatial information, we should always think that what is integrated is a representation, or whether there are cases of integration of spatial information.

The idea that representations of space are map-like featured prominently in the discussion, where a map is understood as something that represents places and all the distances between all the places that are represented such that for any two places represented, every place in between them is represented. The spatial isomorphism between the Cartesian coordinates of the external world and the Cartesian coordinates of certain structures in the brain such as the Superior Colliculus was suggested as a paradigm example of a map in the brain.

Doubts were raised both over the necessity and the sufficiency of something's having this kind of structural organisation for it to count as a spatial representation. It doesn't seem necessary because the same information is captured even though the coordinates in the world are represented in a scrambled, distributed system. We have an example of this with O'Keefe's cognitive map. Moreover, in thinking of representations of space as map-like, what matters is the *kind* of information that is represented, e.g., spatial relations between places being encoded, rather than the structure of the representation itself. What makes something a spatial representation is that it has the functional properties that maps have. Neither does having this kind of structural organisation seem to be sufficient, unless there is some way for the perceptual system to be able to extract information about the spatial relations between locations from the spatial relations between neurons in the structure in question.

A number of different requirements for something to count as a representation of space were suggested. These included the supporting of flexible behaviour, persistence over time, and increasing specificity/decreasing informational content. It was also pointed out that different capacities will require different kinds of spatial information, so it might be that we should think of there being different kinds of spatial representation, some capturing certain kinds of spatial information, others capturing other kinds of spatial information, depending on the nature of the task supported by the representation.

### ***Session 2: Is there a single representation of space common to all modalities?***

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The focus of the second session was that of the reasons we might have for thinking that there is a single representation of space common to all modalities. First, what reasons are there for thinking that there is a general sense or awareness of a single space? For example, are we perceptually aware of the spatial relations between what we see and what we hear? If there is an awareness of a single space, does this have to be explained in terms of representations in different sensory systems all feeding into a single, common representation of space; or, could the integration of spatial information be localized and task-specific? Do psychologists think of the functional organization of all the systems that extract and represent spatial information as feeding into a common spatial representation?

One of the key topics discussed was the relationship between frames of reference and representations of space. Intuitively, it seems that a difference in frame of reference should be understood as a difference in representation. Yet, this still allows for a number of ways of understanding what might be involved in our being aware of the spatial relations between the things we see, hear and touch, all of which might deserve the label of being a multimodal representation of space: spatial information might be mapped into a single representation of space; or, there might be distinct modality-specific representations of space that share a common frame of reference; or, we might have the capacity to map between distinct representations of space, each with their own frame of reference, as and when needed.

Our capacity to re-identify places as we move around and our capacity to act on a place that we perceive through more than one modality were suggested as reasons for thinking that there must be a single multimodal representation of space. Multisensory binding was also suggested as a reason we might give for thinking that there is this common representation, although this depends on our accepting the idea that space provides the common code for binding. This latter suggestion led to further discussion of whether spatial representation is required for the development of bi-modal neurons in areas such as the Superior Colliculus. It was also pointed out that, while a single space is being represented, this in itself places no requirements on there being a single representation of space.

### ***Session 3: Can we distinguish perceptual and non-perceptual representations of space?***

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In the third session there was a return to the question of whether and how sameness of places might be represented across modalities. Can we explain the tasks that we might think require a multimodal representation of space in terms of identifying a place perceived in one sense as the same as a place perceived in another sense? If so, how do we represent a place as the same?

A deflationary approach to the question of how sameness of place might be represented was suggested: all that would be required would be a shared coordinate system—allowing for switching between different modality-specific representations—and the capacity to make unconscious inferences about sameness of

location. One problem for this approach is that, at least for vision and touch, mappings would have to be highly flexible since parts of the body can move relative to the eyes. Also on the topic of the representation of sameness of place, the question of whether it is special when compared to representation of other kinds of spatial relations was raised with reference to experiments conducted on amputees with phantom limb experiences. These patients react to a threat approaching the location at which the phantom limb is felt, yet do not react when there is a book located at the same place as the phantom limb is felt to be located.

The idea that cognitive maps are multimodal, involving the integration of inputs from a number of modalities, was connected to the idea that our capacity to navigate by employing a cognitive map also draws on inputs from the sensory modalities. If this is right, then there must be translation rules not only between the modalities, but between the modalities and the cognitive map also. Taking the 'modality' of a map to be based on its coordinate system, the idea that cognitive maps are multimodal was queried: it might instead be 'visual'. According to the suggestion, the representation of space we use in navigation inherits its frame of reference from our dominant spatial sensory modality - in sighted humans, vision.

This led to the second set of questions for the third session: how do we draw the distinction between perceptual and non-perceptual representations of space? Do we think that there are such things as non-perceptual representations of space, can we think of them as nonetheless modality-specific, and what role do they play in multisensory experience? It was suggested that we might have non-perceptual but sensory spatial representations, i.e., representations of space that are built up from and dependent upon past perceptual experiences. For example, we can think about regions of space extending beyond the present limits of the visual field, and that capacity seems to depend on our past perceptual experiences and be closely connected to them, without those thoughts being perceptions of a region of space.

The discussion turned to the distinction between defensive and action-oriented peripersonal space (PPS), based on differences in their modulation. Tool use extends action-oriented PPS but not defensive PPS, while anxiety results in the expansion of defensive PPS and the contraction of action-oriented PPS. It was also pointed out that representations of defensive PPS have an evaluative component not found in other representations of space, and seem also to automatically activate an appropriate response. We might still query, though, whether the representation of peripersonal space is not integrated with representations of the space beyond it. If a dangerous object is approaching a subject, she needs to start getting ready to move before it is within close range. This suggests there must be some continuity between representations of peripersonal space and far space. What distinguishes the representation of PPS from the representation of far space may not be a difference in the way in which space is represented, but a difference in the kinds of response activated when objects are located within a region of space close to the body.

#### ***Session 4: Are there modality-specific representations of space?***

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The fourth session started with a discussion of the relationship between representation of the form of an object and the representation of space: are these entirely distinct processes or are they connected and interdependent? Are the spatial properties of objects represented entirely independently of their location or do spatial coordinates play a role in the representation of form?

The rest of the session focused on questions about modality-specific spatial representations. In particular, the question of whether there are reasons for thinking that the many different representations of space within each modality come together to form a single modality-specific representation was discussed.

In response to the first question, it was highlighted that neuroscience has identified a consistent set of structures and pathways that seem specific to processing either where an object is or what it is (e.g. ventral and dorsal stream of the visual system). So, *pace* Evans' (1985) view that shape information is derived in touch from the plotting of the locations of the edges or boundaries of an object, it seems unlikely that the perception of shape is dependent on the perception of location. It was suggested, however, that we might need to distinguish between more or less 'spatial' objects. For example, success in Shepherd & Metzler's (1971) mental rotation task seems to require some kinds of configural representation of the relation of the parts of the object to the whole in an object-centered frame of reference.

It was suggested that it is more intuitively plausible or natural to say that there are single representations

of shape across the modalities than that there is a single multimodal representation of space. This might be because when we explain the perception of a shape we invoke a notion like an object-centered representation that is not modality-specific, as opposed to a frame of reference that is centered on the eye or the hand. However, it seems equally open to us to say that objects are identified across modalities and this allows for the association of distinct representations of shape across modalities.

The second set of questions about spatial information being brought together into a single modality-specific spatial representation seems to assume everything gets into consciousness, but many people have a more sparse view. This response suggests the question is based on a false premise: there is no single conscious experience, so there is no reason to think that spatial information must be brought together. We should also be careful not simply to assume that there is any mapping from certain representations featuring in psychological accounts of vision or audition, to what we might call phenomenal representations.

Evidence from the body representation literature was used to expand on the question of whether spatial information must be integrated within each sensory system. There is evidence from healthy subjects that the body schema and body image interact with one another (for example, see Lucilla Cardinali's work), and that it is difficult to tease apart their individual contributions to our conscious experiences of our bodies. However, evidence of interactions is not evidence of integration, so we don't have a way to answer the question definitively.

### ***Session 5: Can we provide a catalogue of kinds of spatial interaction?***

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The final session started with the question of what we mean by interaction and integration. Can we come up with a catalogue of the kinds of interaction and integration that there are? Are there different processes or different mechanisms for combining or integrating spatial information?

Vignemont (2014) distinguishes *additive binding* (the combination of information about the same object but about different properties) from *integrative binding* (the integration of information about the same property of the same object). Integrative binding can be partial, which we see by looking at prismatic adaptation: over time felt and seen location merge, but at first the signals merely interact and the subject has access to the information from each modality. The question of how we should categorize the interaction underlying our awareness of the spatial relation between seen and heard events was raised. In this kind of case one is aware of a single spatial relation, but one is aware of the relation through different modalities (see also Bayne's example of comparing the size of coins, one that you feel one that you see). It seems to be more than a case of the unity of consciousness, but it's not clear whether the interaction should be considered to be integration or the mapping of an event into another frame of reference.

If we take integration to be only summing under a curve, then there is a question about how we explain what is going on in the McGurk Effect. It involves summing, but to describe it as a case of integration misses out the fact that it is a bimodal discrimination or categorization task. Moreover, if we think of integration as summing only, then we risk missing the fact that the signal(s) might have to be transformed for the two to be put together, and that prior knowledge and weighting may be required. Information might be lost in the operation so that we cannot retrieve the original percepts in each single modality. Two ways in which the system might retain this original information were suggested: the output of the process might carry information about modalities of the original signals; or the system might still have access to the original information from each modality as well as the output of the summation.

In relation to the discussion of kinds of spatial interactions, the impact of the presence or absence of early visual experience on temporal order judgments about tactile stimulation was raised. It seems that past visual experience has an impact on current tactile experiences. Is this enough for the current experience to qualify as multimodal? There seems to be some kind of calibrating or structuring of tactile information, but is this a kind of integration? In response, it was suggested that we can distinguish this kind of interaction from the mathematical summing involved in integration proper because it is part of the explanation of the difference in results across late-blind & sighted individuals on the one hand and congenitally-blind individuals on the other, that the mapping of the tactile stimulation into a visual frame of reference is part of the content of experience.

Bayesian accounts of multisensory integration have been popular in recent years and the question of how we should understand these accounts was raised. They allow us to make predictions of multisensory effects that have been successful when dealing with single stimuli in each modality. Since the predictions are right, it must be implemented in some way in the brain. However, it was suggested, there are different accounts of how Bayesian inferences can be implemented. Moreover, the account hasn't successfully been extended to explain integration when several stimuli are presented in each modality.

The importance of using 'multisensory' and 'multimodal' consistently was pointed out. We should use 'multisensory' to speak about sub-personal processing and multimodal to qualify conscious experience. Even when there is evidence of multisensory processing, that processing might not result in a multimodal experience.