2002 - January 3/4 University College London

LONDON MEETING 2002

A scientific meeting will be held at the Institute of Cognitive Neuroscience, University College London on 3/4 January, 2002. The local organiser will be Dr Steffan Kennett.

Symposia:

Thursday 3 January 2.00-4.30
The cognitive neuroscience of body representation
Organiser Patrick Haggard

Friday 4 January 2.15-5.00
Representation of Number
Organiser Professor Brian Butterworth

Presentations

Sessions will be held in the Wolfson Lecture Theatre, National Hospital and Seminar Room B10, Alexandra House. Both theatres have data projectors available for Powerpoint presentations. Presenters may provide their own laptops and dongles, or bring disks for the on-site computers. The Wolfson Lecture Theatre, National Hospital runs PowerPoint 97 on Windows NT 4.0 and Seminar Room B10, Alexandra House runs Windows 2000 and Powerpoint 2000. Any queries about facilities in the theatres should be sent to the local organiser, Dr Steffan Kennett (s.kennett@ucl.ac.uk)

Coffee will be served in the Old Board Room, National Hospital and Room 213 Second Floor Common Room, Alexandra House.

There will be a drinks reception on Thursday evening at 6pm in Seminar Room B10, Alexandra House . The conference dinner will be at 7.30 at Bertorelli's, 19-23 Charlotte Street, London WC1 – (020-7636 4174). A booking form is enclosed.

THURSDAY 3 JANUARY am

START OF PARALLEL SESSION

Session A

Wolfson Lecture Theatre, National Hospital

9.30 Rebecca G Thompson* and Martin A Conway (University of Bristol and University of Durham)
Memory collaboration in older adults: does 1+1 = 2.5?

10.00 Donna M Bayliss* and Steven Roodenrys* (University of Bristol) (Introduced by C Jarrold)
The influence of working memory load on negative priming and interference effects.

10.30 Robert Hughes* and Dylan M Jones (Cardiff University)
A negative order-repetition priming effect: Inhibition of order in unattended auditory sequences?

11.00 COFFEE (Old Board Room, National Hospital)

11.30 Anna Stone* and Tim Valentine (Goldsmiths College)
Non-conscious face recognition in neurologically intact participants: Valence but not familiarity affects responses.

12.00 R Henson, Y Goshen-Gottstein*, T Ganel*, A Quayle* and M Rugg (Institute of Cognitive Neuroscience, University College London and University of Tel-Aviv)
Behavioural, electrophysiological and haemodynamic effects of face perception, familiarity and repetition

12.30 K K W Kampe*, C D Frith and U Frith (Institute of Cognitive Neuroscience and Wellcome Department of Cognitive Neurology)
Modality independent activation of the medial prefrontal cortex and the temporal poles by ostensive communication

END OF PARALLEL SESSION

1-2 LUNCH

THURSDAY 3 JANUARY am

START OF PARALLEL SESSION

Session B

Seminar Room B10, Alexandra House

9.30 Jon Weaver* and Peter Walker (Lancaster University)
Naming familiar objects promotes viewpoint-invariance.

10.00 Toby J Lloyd-Jones and David J Vernon* (University of Kent and Imperial College)
Interference from object recognition on the generation of mental images of semantically related objects

10.30 David Crundall (University of Nottingham)
A kink in object-based attention: The disappearance of facilitation in angled objects

11.00 COFFEE (Room 213 Second Floor Common Room, Alexandra House)

11.30 T L Hodgson, C Golding*, M M Chamberlain*, M Husain* and C Kennard* (Imperial College of Science Technology and Medicine, London)
Self control and monitoring in patients with prefrontal cortex damage

12.00 Mel Kunar*, Glyn W Humphreys, Kelly Smith* and Derrick G Watson (University of Birmingham and University of Warwick)
When re-appearance is old news: Visual marking survives occlusion

12.30 Glyn W Humphreys, Srren Kyllingsbæk*, Derrick G Watson, Chris N L Olivers*, Ian Law* and Olaf Paulson* (Behavioural Brain Sciences, School of Psychology,University of Birmingham, Center for Visual Cognition, Department of Psychology, University of Copenhagen and Warwick University)
Parieto-occipital areas involved in efficient filtering in search: A time course analysis of visual marking using behavioral and functional imaging procedures.

END OF PARALLEL SESSION

1-2 LUNCH

THURSDAY 3 JANUARY pm

Wolfson Lecture Theatre, National Hospital

Symposium: The cognitive neuroscience of body representation
Organised by Patrick Haggard

2.00 Patrick Haggard (Institute of Cognitive Neuroscience, University College London)
Introduction
A Iriki* (Department of Maxillofacial Biology, Tokyo Medical and Dental University)
Plasticity and extensibility of body schema with tool use.

2.30 A S David, M Phillips, B Brierley*, P Shaw* and M Sierra-Siegert* (Institute of Psychiatry, King's College London)
Body representation: a cognitive neuropsychiatric approach.

3.00 A Sirigu* (Institute des Sciences Cognitives, Bron, France)
Body representation in normals and in brain damaged patients.

3.30 TEA (Old Board Room, National Hospital and Room 213 Second Floor Common Room, Alexandra House)

4.00 M S A Graziano* (Princeton University, USA)
Coding the location of the arm by sight.
End of Seminar

4.30 M G Edwards*, A M Wing, G W Humphreys and J Stevens* (Behavioural Brain Sciences Centre, University of Birmingham)
Knowing your nose better than your thumb: Directing hand actions to body parts.

5.00 M Jane Riddoch, Katie Ackroyd*, Glyn W Humphreys, Simon Nightingale* and Stella Townsend* (Behavioural Brain Sciences Centre, University of Birmingham and Departments of Neurology and Psychology, Royal Shrewsbury Hospital)
Widening the sphere of influence: Using a tool to extend extrapersonal visual space in a patient with severe neglect.

5.40 Annual General Meeting (Wolfson Lecture Theatre) (Members only)

6.00 DRINKS RECEPTION (Seminar Room B10, Alexandra House)

7.30 CONFERENCE DINNER, BERTORELLI'S

FRIDAY 4 JANUARY am

START OF PARALLEL SESSION

Session A

Wolfson Lecture Theatre, National Hospital

NB - *Session B* starts at 9.00

9.30 J R Hanley, J Masterson, D Evans* and L Spencer* (University of Essex and University of Wales, Bangor)
Orthographic consistency, reading development and phonological awareness; Evidence from children learning to read in Wales.

10.00 Chris Jarrold and Alan D Baddeley (University of Bristol)
Does verbal short-term memory drive vocabulary acquisition? Examining causal relationships among individuals with learning disability.

10.30 Elizabeth Jefferies*, Matthew A Lambon Ralph and Alan Baddeley (University of Bristol and University of Manchester)
Integration of working and long term memory in sentence span

11.00 COFFEE (Old Board Room, National Hospital)

11.30 Stuart Rosen*, Ruth Finn* and Andrew Faulkner (Department of Phonetics and Linguistics, University College London)
Plasticity in speech perception: Spectrally-rotated speech revisited

12.00 Sami Boudelaa* and William Marslen-Wilson (MRC Cognition and Brain Sciences Unit, Cambridge)
Differential time course of morphological, orthographic, and semantic activation: Incremental masked priming in Arabic

12.30 Emma Hayiou Thomas*, Dorothy Bishop and Kim Plunkett (University of Oxford)
Processing limitations in specific language impairment: Evidence from a grammaticality judgement task

END OF PARALLEL SESSION

1-2.15 LUNCH

FRIDAY 4 JANUARY am

START OF PARALLEL SESSION

Session B

Seminar Room B10, Alexandra House

9.00 Elizabeth Gilman* and Geoffrey Underwood (University of Nottingham)
Parafoveal preview during music sight-reading

9.30 Rebecca Kwok* (Department of Psychology and Institute of Ophthalmology, University College London) (Introduced by Professor O J Braddick)
The effect of delay on grasping two and three dimensional targets in the Titchener circles illusion

10.00 Patrick Haggard (Institute of Cognitive Neuroscience, University College London)
The feeling of what I made happen

10.30 Elisabeth Bacon, Jean-Marie Danion*, Eric Gokalsing*, Philippe Robert* and Marilyne Massin-Krauss* (INSERM U 405 Strasbourg and Psychiatric Clinic Nice)
Impaired strategic regulation of memory accuracy in schizophrenia

11.00 COFFEE (Room 213 Second Floor Common Room, Alexandra House)

11.30 Jonathan St B T Evans and John Clibbens* (Centre for Thinking and Language, University of Plymouth)
Explicit and implicit processes in multi-cue judgement

12.00 J H Wearden (Manchester University)

Travelling in time: A time-left analogue for humans supports a linear time scale

12.30 Anna Plodowski*, Rachel Swainson*, Ross Cunnington* and Stephen R Jackson (The University of Nottingham)

An ERP investigation of parity judgements to numbers in different visual formats

END OF PARALLEL SESSION

1-2.15 LUNCH

FRIDAY 4 JANUARY pm

Wolfson Lecture Theatre, National Hospital

Symposium: Representation of Number

Organised by Professor Brian Butterworth

2.15 Professor Brian Butterworth (Institute of Cognitive Neuroscience, University College London)

Introduction: Forms of representation

2.30 Stanislas Dehaene* (INSERM, Orsay, France)

Organization of number representations within the parietal lobe: Evidence from functional neuroimaging

3.00 Marc Brysbaert, Wim Fias* and Bert Reynvoet* (Royal Holloway and Ghent University, Belgium)

The issue of obligatory semantic mediation in number processing: Further evidence from the priming and the Stroop paradigm

3.30 TEA (Old Board Room, National Hospital and Room 213 Second Floor Common Room, Alexandra House)

4.00 Manuela Piazza* (Institute of Cognitive Neuroscience, University College London and INSERM, Orsay, France)

The quantifying brain: Cortical networks underlying numerosity estimation and counting.

4.30 Marco Zorzi* (University of Padova, Italy)

The numerosity model for the representation of numerical magnitude

5.00 Discussion

END OF MEETING

THURSDAY 3 JANUARY

Memory collaboration in older adults: does 1+1 = 2.5?

Rebecca G Thompson[1] and Martin A Conway[2]
1. University of Bristol
2. University of Durham

Collaborative memory literature has shown that collaborating groups of healthy young adults, fail to perform at a higher level than is predicted by the sum of two individual performances (nominal group). This counter intuitive pattern of performance has been termed collaborative inhibition. The aim of this experiment was to investigate collaborative memory processes in older adults on a famous face naming task.

Participants were tested twice over two separate sessions. In session one, participants were tested individually. In session two participants were divided into three groups: collaborating friend dyads, collaborating non-friend dyads and nominal dyads. The results revealed no difference in overall levels of performance between the three groups in both sessions one and two. Further analysis of 'new items' (items that were recalled in session two that were not recalled in session one) revealed higher levels produced by the collaborating dyads compared to the nominal dyads. No difference was found between the new items produced by collaborating friend and non-friend dyads. This result suggests that collaboration on memory tasks in older adults may act as a compensatory mechanism for normal age related decline in cognitive performance by promoting access to previously unavailable material. Furthermore the results highlight the importance of analyzing collaborative memory data using both qualitative and quantitative methods.

The influence of working memory load on negative priming and interference effects.

Donna M Bayliss and Steven Roodenrys
University of Bristol

Recent research has shown the negative priming effect to be sensitive to cognitive load and dependent upon individual differences in working memory capacity (Conway, Tuholski, Shisler & Engle, 1999). In the present set of experiments, the effect of increasing memory load on negative priming and interference effects was examined with a letter flanker task, which incorporated a concurrent memory load of increasing difficulty. In general, introducing a requirement to recall the named stimuli after each trial of 4 items did not affect the interference or negative priming effects. However, when the memory task required subjects to recall a different aspect of the stimuli to what was named, negative priming was eliminated and interference increased. These results are in contrast to previous findings and suggest that the effect of load on negative priming and interference effects may be due to the re-allocation of attention between tasks. The implication of these results for current theories of working memory will be discussed.

Conway, A. R. A., Tuholski, S. W., Shisler, R. J., & Engle, R. W. (1999). The effect of memory load on negative priming: An individual differences investigation. *Memory & Cognition*, 27, 1042-1050.

A negative order-repetition priming effect: Inhibition of order in unattended auditory sequences?

Robert Hughes and Dylan M Jones
Cardiff University

A novel negative priming effect is reported in which the order of events within an unattended auditory sequence, not their individual identities, negatively primed the subsequent serial recall of the same sequence presented visually. Recall accuracy for a sequence of visually presented digits was significantly poorer if those digits were in the same order as presented in a to-be-ignored auditory sequence of digits on the previous trial, relative to when the previous auditory digits were arranged in a different order (Experiment 1). Increasing the number of pre-exposures of a sub-set of the critical to-be-

remembered sequence did not promote a larger effect (Experiment 2), but the negative priming effect was nevertheless replicated. The findings suggest that the order of unattended auditory events is represented in short-term memory, and the negative direction of the priming effect further suggests that this order information may be associated with inhibition.

Non-conscious face recognition in neurologically intact participants: Valence but not familiarity affects responses.

Anna Stone and Tim Valentine
Goldsmiths College

Covert face recognition in neurologically intact participants was investigated using very brief stimulus presentation to prevent awareness of the stimulus. In Experiment 1 skin conductance response (SCR) was recorded to photographs of celebrity and unfamiliar faces displayed for 220ms and for 17ms in a within-participants design. SCR to faces presented for 220ms was larger and more likely to occur to familiar faces than to unfamiliar faces. Face familiarity did not affect the SCR to faces presented for 17ms. SCR was larger to faces of good than to faces of evil celebrities presented for 17ms but valence did not affect SCR to faces displayed for 220ms. Experiment 3 found that participants were able to differentiate evil and good faces presented without awareness in a two-alternative forced-choice decision. Experiments 4-6 presented faces in simultaneous pairs of one famous and one unfamiliar face. Participants who were at chance in discriminating famous from unfamiliar faces selected more faces of celebrities rated as good than rated as evil. Experiment 6 demonstrated perceptual defence in a similar task. These results provide no evidence of familiarity detection outside awareness in normal participants, but a response based on affective valence appears to be available from brief presentation.

Stone, A., Valentine, T. and Davis, R. (2001). Face recognition and emotional valence: Processing without awareness by neurologically intact participants does not simulate covert recognition in prosopagnosia. *Cognitive Affective and Behavioural Neuroscience*, 1, 183-191.

Behavioural, electrophysiological and haemodynamic effects of face perception, familiarity and repetition

R Henson[1], Y Goshen-Gottstein[2], T Ganel[2], A Quayle[1] and M Rugg[1]
1. Institute of Cognitive Neuroscience, University College London
2. University of Tel-Aviv

In two identical experiments, one using functional magnetic resonance imaging (fMRI) and one using event-related potentials (ERPs), we examined the effects of perception, familiarity and repetition of faces. In Phase 1, participants made symmetry judgments on intermixed face and nonface stimuli matched for low-level visual properties (the nonfaces being phase-scrambled versions of the faces). The grayscale faces were edited to remove hair, and one half were recognisable as famous people (the other half belonging to people unknown to participants). In the subsequent Phase 2, participants made gender-judgments on famous or unknown faces that either were or were not previously presented in Phase 1, reaction times for which allowed a behavioural

measure of repetition priming. There was some evidence that the face-specific haemodynamic responses in bilateral fusiform cortex are modulated by familiarity and repetition. These modulations are likely to reflect "re-entrant" effects, since there was no evidence for modulation of the earliest face-specific ERP (N170) by familiarity or repetition. These findings are discussed in relation to models of face processing and the relationship between haemodynamic and electrophysiological measures of brain activity.

Modality independent activation of the medial prefrontal cortex and the temporal poles by ostensive communication

K K W Kampe[1], C D Frith[2] and U Frith[1]
1. Institute of Cognitive Neuroscience
2. Wellcome Department of Cognitive Neurology

Theory of mind is thought to be a crucial factor in human ostensive communication. We used fMRI to investigate the neural substrates involved in the perception of two basic ostensive gestures: making eye contact and calling your name. We hypothesized that a previously identified neural system that underlies Theory of mind (mentalizing), is also activated early in the initiation of communication, independently of a particular modality or sensory input path. Faces were photographed with the subject looking either straight into the camera or at a point deviating horizontally by 30 degrees. As a visual baseline condition, scrambled, non-face control images were derived using a program which preserved brightness and spatial frequencies of the original faces. Voice recordings calling the subjects name or two other names twice (e.g. "John, hey John!") were made and cut to the length of 1.2 seconds to parallel the presentation time of the faces. As auditory baseline condition speech recordings of 10 subjects were made and superimposed. Every subject performed two sessions alternating the two stimulus types. During a session 153 gradient EPI T2*-weighted functional images (32 transverse slices; 3x3x3mm; TR 3.16sec) were acquired using a Siemens VISION system at 2T. Stimuli were presented in an event related design (fixed SOA of 3.5s, faces/voice recordings presented for 1.2s, remaining time scrambled face/unintelligible speech as baseline, 1/3 null events). Fixed and random effects analysis of the data was performed using SPM99b.
Comparing faces against the baseline (scrambled faces) showed bilateral activation of the fusiform gyrus. Hearing names, as compared to the baseline condition of unintelligible superimposed voices, activated the superior temporal gyrus and the superior temporal sulcus bilaterally. The conjunction of both ostensive acts, direct eye-gaze (as compared to averted gaze) and calling someone’s personal name (as compared to a different name) activated the anterior medial prefrontal cortex, specifically the paracingulate cortex and the temporal poles, areas consistently associated with Theory of mind.

Naming familiar objects promotes viewpoint-invariance.

Jon Weaver and Peter Walker
Lancaster University

Three experiments investigated the contribution that object naming makes to viewpoint-invariant matching. Using a primed matching paradigm Experiments 1 and 2 revealed

that the naming of familiar prime objects promotes viewpoint-invariance. When naming is precluded, recognition alone does not appear to represent a sufficient condition for viewpoint-invariant priming. Using a sequential matching paradigm Experiment 3 replicated the findings of Experiment 1, as well as providing evidence that even when participants name the prime objects, they perform the matching task on a visual rather than a verbal basis. We speculate that object naming promotes viewpoint-invariance because it facilitates the activation of viewpoint-invariant structural descriptions of basic-level categories.

Interference from object recognition on the generation of mental images of semantically related objects

Toby J Lloyd-Jones[1] and David J Vernon[2]
1. University of Kent
2. Imperial College

A new technique for examining the processes involved in visual image generation and inspection is reported. This technique, the 'image-picture interference' paradigm requires participants to generate and make a response to a mental image of a previously memorized object, whilst ignoring a simultaneously presented distracter picture. Responses in two imagery tasks (left/right higher spatial judgements and responding when a coherent image is formed) are longer when a simultaneous picture distracter is categorically related (e.g., image 'bicycle' distracter 'TRUCK') relative to unrelated and neutral conditions. In contrast, performance is not impaired in this way when the distracter is a related word, when a semantic categorization decision is made to the target, or when distracter and target are visually but not categorically related to one another. These findings suggest the locus of categorical interference is in the process of image generation.

A kink in object-based attention: The disappearance of facilitation in angled objects

David Crundall
University of Nottingham

Many studies have demonstrated the same-object bias where responses to targets are facilitated if one is required to move or deploy attention within an object rather than between objects. Recently, concerns have been raised that some previous key studies in this area may have contained a confound, as the objects used in these studies are made up of straight lines. These lines may act as vectors, explicitly directing shifts in attention, regardless of whether they are part of an object or not.
To overcome this confound a series of experiments were conducted in an attempt to demonstrate a bias for responding to targets within a single object that contained an internal angle. Initial attempts failed to produce object bias in the angled objects for detection and discrimination of two targets. Two later experiments compared target elements within and between objects, and additionally within straight lines. All targets in these conditions were separated by an equal Euclidean distance. Results revealed no difference in response times for within-object and between-object conditions, though responses to within-line targets were consistently faster. This suggests that previous

published findings that report object bias may have confounded linearity with objects.

Self control and monitoring in patients with prefrontal cortex damage

T L Hodgson, C Golding, M M Chamberlain, M Husain and C Kennard
Imperial College of Science Technology and Medicine, London

We report experiments in which subjects alternated between stimulus-response mappings within a single block of trials. Participants had to learn an arbitrary rule which linked the colour of a central cue with a saccade to either the left or the right. The rule could reverse several times during the course of the test. Feedback was given on each trial to indicate if the movement was correct. Rule changes were cued by unexpected errors.

Control subjects showed a response time cost as well as an increase in erroneous saccades after a rule switch. The majority of incorrect saccades were followed by short latency movements towards the correct location. A group of 8 patients with prefrontal lesions also performed the task. Analysis based on corrective behaviour revealed an interesting dissociation based on lesion site. Patients made more erroneous saccades after a rule change, but those with medial damage corrected the majority of these mistakes. In contrast, patients with damage to lateral prefrontal regions rarely made corrective eye movements and continued to base their decisions on the preceding rule mapping. These findings implicate medial prefrontal cortex in control over automatic stimulus-response couplings. Our data suggest that lateral prefrontal areas are more important for monitoring the validity of these associations, ensuring that the sensory and motor consequences of behaviour match predicted outcomes.

When re-appearance is old news: Visual marking survives occlusion.

Mel Kunar[1], Glyn W Humphreys[1], Kelly Smith[1] and Derrick G Watson[2]
1. University of Birmingham
2. University of Warwick

Visual search for color-form conjunctions can be made relatively easy if participants are given previews of distractors in one color set. This preview effect may in part be due to top-down inhibition of the old (previewed) items (Watson & Humphreys, 1997), plus onset capture by the new stimuli (Donk & Theeuwes, in press). The effect is abolished however, if the old items are briefly offset and then re-presented with the new stimuli. We examine whether this offset effect is modulated by occlusion relations between stimuli. A reliable preview effect was found when offsets were consistent with the old items being occluded but not otherwise. The data comply with the preview effect being caused by top-down inhibition, applied via a higher level process, causing object representations to remain "marked" even after occlusion. Marking is attenuated to some degree, however, by movement of the irrelevant stimuli in the displays.

Donk, M. & Theeuwes, J. (in press) Visual marking beside the mark: Prioritizing selection by abrupt onsets. *Perception & Psychophysics*.
Watson, D.G. & Humphreys, G.W. (1997) Visual marking: Prioritizing selection for new objects by top-down attentional inhibition of old objects. *Psychological Review*, 104, 90-122.

Parieto-occipital areas involved in efficient filtering in search: A time course

analysis of visual marking using behavioral and functional imaging procedures.

Glyn W Humphreys[1], Srren Kyllingsbæk[2], Derrick G Watson[3], Chris N L Olivers[1], Ian Law[2] and Olaf Paulson[2]

1. Behavioural Brain Sciences, School of Psychology, University of Birmingham
2. Center for Visual Cognition, Department of Psychology, University of Copenhagen
3. University of Warwick

Search for a color-form conjunction target can be facilitated by presenting one set of distractors prior to the second set of distractors and the target: the preview benefit. The early presentation of one set of distractors enables them to be efficiently filtered from search. We examined the time course of this filtering effect, using behavioral and functional imaging methods. In Experiment 1 we use a standard reaction time analysis to show that the benefit has a relatively slow time course; old items need to precede the new set by 500 ms or more in order to be fully filtered from search. In Experiment 2 we examined the neural locus of this filtering effect using PET. First we reveal a close overlap between the neural areas involved in preview search and in search for a standard color- form conjunction target, comparing performance in the search tasks with that in detection baselines for each type of display. We then selected as regions of interest the parieto-occipital areas selectively activated in preview search relative to its baseline, and show that these regions increase in activation as the preview interval increases (and search becomes easier). We argue that these regions modulate the efficient filtering of distractors from targets in spatial search.

Symposium: The cognitive neuroscience of body representation

Introduction

Patrick Haggard
Institute of Cognitive Neuroscience, University College London

The body is distinctive as both a physical and a psychological object. At the physical level, the body supports voluntary actions of infinite complexity, and tactile information about objects. The body thus provides our major interface with the external world.
At the psychological level, the body plays a special role in mental life for three clear reasons. First, the somatic sensory system provides rich information about body configuration and body events, coupled with a distinctive and sometimes vivid conscious experience. Second, the mental representation of the body seems to be of primary importance for self-consciousness, and for the coherence of the "I", as neurological and neuropsychiatric studies of conditions such as depersonalisation and anosognosia for hemiplegia show. Finally, recent studies have documented high levels of plasticity in neural representations of the body: as our bodies move during action, neural coding changes commensurately. This rapid remapping of body representation may play a fundamental role in attention and awareness and is likely to be a major area of research in the next decade.
Drawing on the classical tradition of the "body schema", there is now a resurgence of interest in body representation from several directions. This symposium will present converging electrophysiological, neuropsychological, clinical and behavioural data to show how modern cognitive neuroscience is beginning to understand the special

psychological role of the body representation.

Plasticity and extensibility of body schema with tool use.

A Iriki
Department of Maxillofacial Biology, Tokyo Medical and Dental University

When using a tool it becomes an extension of the hand both physically and perceptually - the tool is incorporated into our body schemata. We trained macaque monkeys to retrieve distant objects, beyond the limit of the reach of the innate arm, using a rake as a tool and neuronal activity was recorded in the anterior bank and the fundus of the intraparietal sulcus contralateral to the hand using a tool. There we found a large number of bimodal neurons which appeared to code the image of the hand by integrating somatosensory and visual information - these neurons have visual receptive fields which encompass their somatosensory receptive fields located at hand and forearm. During tool use, their visual receptive fields were altered to include the entire length of the rake. This use-dependent expansion occurred only when the monkeys held a tool and intended to use it as an extension of their hand. These findings may constitute the neural correlate for modification of the body schema as a basis of assimilation of the tool into our own body. Also, we found that these neurons can code the body-image projected onto the video monitor, perhaps corresponding to its "iconic" representation. When above described representations were further advanced, it would become totally free from physical constraints of the actual world to become a (pre-)symbolic one to represent evolutionary precursors of higher cognitive functions and might eventually lead to evolution of human language or to the metaphysical thoughts.

Body representation: A cognitive neuropsychiatric approach.

A S David, M Phillips, B Brierley, P Shaw and M Sierra-Siegert
Institute of Psychiatry, King's College London

Many insights into the neural substrates for body representation come from people with neurological disorders. For example, deficits and dissociations in awareness of body parts and illness, and from a cerebral localisation point of view, the primacy of the right cerebral hemisphere. Psychiatric disorders can provide similar insights albeit less directly, by extending the range of consistently observed distortions in the representation of the body. The cognitive neuropsychiatric approach entails detailed phenomenological description leading to the development of explanatory and testable cognitive models and finally, mapping the cognitive architecture onto the brain. Examples include lateralisation of somatic delusions in schizophrenia, body image distortion in anorexia nervosa, and depersonalisation disorder. The latter is of particular interest in the light of recent attempts to develop a neurobiology of social cognition and work highlighting the importance of structures such as the amygdala in mediating emotion, arousal and cognition. People with depersonalisation disorder feel cut off from their surroundings and their own feelings. We have shown that their physiological responses in the form of skin conductance to emotive stimuli are specifically blunted and, using functional magnetic resonance imaging, that this probably reflects excessive inhibition by ventral frontal systems on "limbic" and "paralimbic" structures. We suggest that the normal representation of bodily states and their emotional accompaniments, is the result of a

dynamic equilibrium between frontal and limbic systems.

Body representation in normals and in brain damaged patients.

A Sirigu
Institute des Sciences Cognitives, Bron, France

In my talk, I will focus on body schema representation in patients with cortical damage (mostly parietal) and in patients with peripheral injury. I will argue that multiple and independent levels of representation are involved in the organisation of body knowledge and that these may dissociate within the parietal regions. I will also show how peripheral injury affects body schema and how the utilisation of a prosthesis modifies patients' perception of the missing limb. Finally, I will discuss the dynamics of body schema reorganisation in motor cortex, in a patient, before and after bilateral hand transplantation, using functional magnetic resonance imaging (fMRI).

Coding the location of the arm by sight.

M S A Graziano
Princeton University, USA

How does the brain represent the relative positions of the limbs, head, and torso? Studies in humans show that the body schema is not simply a representation of joint angles, but a complex integration of vision, proprioception, touch and motor feedback. In monkeys, many neurons in parietal area 5 are sensitive to the position of the arm. Do these neurons encode arm position using somatosensory input, visual input, or both? We found that neurons in area 5 encode the position of the monkey's arm while it was covered from view. The same neurons also responded to the position of a visible, realistic false arm. The neurons were able to distinguish the image of a left arm from the image of a right arm, and were not sensitive to the sight of unrealistic substitutes for the arm. These neurons therefore appear to combine visual and somatosensory signals in order to monitor the configuration of the limbs. They could form the basis of the complex body schema that we constantly use to adjust posture and guide movement. (End of Symposium)

Knowing your nose better than your thumb: Directing hand actions to body parts.

M G Edwards, A M Wing, G W Humphreys and J Stevens
Behavioural Brain Sciences Centre, School of Psychology, University of Birmingham

Reaching for objects in the environment involves co-ordination of arm (transport) with opening of the hand (aperture). Previous research has documented the dependence of grasp aperture on the reliability of position information about the target. We report three experiments that assess the accuracy of actions made to different parts of the body. Participants had to reach and grasp either (i) their nose or mouth, (ii) their thumb or wrist, or (iii) two neutral (wooden) objects of comparable width to the body parts. In Experiment 1, the hand parts and the neutral objects were positioned on the table. The data showed that the usual tendency to extend the grasp aperture to be wider than the target object (peak grasp ^Ö object size) was reliably smaller for facial targets than for the hand and neutral-object targets. In Experiment 2, all of the objects were positioned in the same location as the nose. The data replicated those from Experiment 1. In addition, actions to facial stimuli were typically faster (with a reduced deceleration time) than

actions to the hand and neutral objects. There was no evidence that the reduced over-extension in grasp aperture, for face parts, was due to a speed-accuracy trade-off. There was also no evidence for the effect being due to whether grasps were made to facial rather than to other spatial regions: there was no difference in the over-extension effect for hand and neutral-object stimuli positioned on the table vs. near the face. The difference in the over- extension effect may reflect differences in the proprioceptive representation of face parts relative to other parts of the body.

Widening the sphere of influence: Using a tool to extend extrapersonal visual space in a patient with severe neglect.

M Jane Riddoch[1], Katie Ackroyd[2], Glyn W Humphreys[1], Simon Nightingale[2] and Stella Townsend[2]

1. Behavioural Brain Sciences, School of Psychology,University of Birmingham
2. Departments of Neurology and Psychology, Royal Shrewsbury Hospital

We report evidence that visual representations of space close to the body can be extended when a patient uses a tool to explore the environment. HB had severe neglect of left and far visual space, which was determined more by how locations were perceived visually than by how they were represented tactilely or through proprioception. His ability to detect visual targets in left and far space improved, however, when he held a tool. He also had limited tactile/proprioceptive knowledge about his hand. These data suggest that, by holding a tool, HB's more intact representation of near, visual space could be extended to include stimuli presented at a distance from his body. We discuss the implications of these results for understanding the nature of our internal representation of space.

FRIDAY 4 JANUARY

Orthographic consistency, reading development and phonological awareness; Evidence from children learning to read in Wales.

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Spencer and Hanley (in press) have recently reported the results of a study which showed that children learning to read Welsh (a transparent alphabetic orthography) performed much better on tests of single word reading and phonological awareness than children learning to read English (an opaque alphabetic orthography). Here we describe the findings from a follow-up study that examined the reading performance of the same groups of children approximately 3-4 years later. We also report preliminary results from a longitudinal study that has investigated the performance of a new cohort of children on tests of rhyme and phoneme awareness before formal reading instruction commenced and again a year later.

Spencer, L & Hanley, J.R. (in press). Effects of orthographic transparency on reading and phoneme awareness in children learning to read in Wales. *British Journal of Psychology*.

Does verbal short-term memory drive vocabulary acquisition? Examining causal

relationships among individuals with learning disability.

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Previous research has shown that children's performance on tests of verbal short-term memory is related to their vocabulary ability. One interpretation of this association is that verbal short-term memory plays a causal role in driving vocabulary acquisition (Baddeley, Gathercole, & Papagno, 1998). Alternatively, it is possible that an individual's level of vocabulary acts as a fundamental constraint on their verbal short-term memory performance. Two studies are presented which adopt a novel approach to separating these two opposing accounts. This involves examining whether verbal short-term memory performance is more closely related to the absolute level of individuals' vocabulary, or the rate at which this level of vocabulary has been attained. In a first study, level of vocabulary was a clear predictor of verbal short-term memory performance among individuals with learning disability functioning around the 8-year-old level of vocabulary development. However, a second study showed that in less developed individuals, rate of vocabulary development was a clear predictor of verbal short-term memory performance. This implies that early on in development verbal short-term memory does drive vocabulary acquisition, with the causal relationship between these domains shifting as vocabulary level increases. This suggestion is consistent with both previous research and theoretical accounts of the link between vocabulary knowledge and verbal short-term memory performance.

Baddeley, A., Gathercole, S. & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review*, 105, 158-173.

Integration of working and long term memory in sentence span

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A recent revision of the working memory model (Baddeley, 2000) suggests that information in long term memory can be integrated with information in working memory, in an ‘episodic buffer’. Integration is thought to be attention demanding, and should be impaired by a dual task. Sentence span may involve more integration of long-term memory representations than word span, allowing sentence span to be higher. Two experiments investigated these predictions by comparing repetition of sentences and unrelated words, with and without a secondary choice reaction time task. The lengths of both materials were linked to each participant’s span. A number of differences in performance were found for the two materials, suggesting a greater involvement of long term memory in the sentence span task. Sentences were learned more rapidly over repeated presentations and showed a less rapid decline in percentage recall as the amount to be remembered was increased. Critically, in both experiments, the secondary task was found to impair recall of sentences more than word lists. Reaction time data from the secondary task were found to be consistent with this pattern.

Baddeley, A. (2000). The episodic buffer: a new component of working memory? *Trends in Cognitive Sciences*, 4, 417-423.

Plasticity in speech perception: Spectrally-rotated speech revisited

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There is currently much interest in the extent to which listeners can learn to perceive speech under transformations that render it initially unintelligible. In spectrally-rotated speech the spectrum is rotated around a middle frequency (here 2 kHz). Thus, low frequencies become high, and high frequencies low. Intonation and speech rhythm remain relatively intact under spectral rotation, as do contrasts of periodicity vs. aperiodicity. Spectral shape and its dynamics, however are completely altered.
Four adults underwent 6 hours of interactive training with spectrally-rotated speech from a single female speaker using both audio-visual and audio presentation. In audio sentence tests with a different female speaker, performance increased from 5% words correct prior to training to 42% after training. Performance with a male speaker increased to a lesser degree, from 9% to 26%, suggesting that a part of the training may be specific to the sex of the training speaker. Four untrained controls showed no improvement over multiple test sessions. Assessments with other signal transformations suggest that the trained listeners did adapt to a significant degree to altered spectral dynamics. Hence, their improved performance cannot be ascribed solely to better use of cues that are relatively unchanged through spectral rotation.

Differential time course of morphological, orthographic, and semantic activation: Incremental masked priming in Arabic

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In Semitic languages like Arabic and Hebrew, surface word forms consist of two interleaved morphemes: a word pattern and a root. The word pattern conveys morphosyntactic information while the root conveys semantics. The Arabic surface form [xatam] "end", for example, is analyzed into the root {xtm}, and the word pattern {faÀal}, where the letters "f,À,l" act as place holders indicating where the first, second, and third consonant of the root are to be inserted. Previous investigation of Semitic morphology has shown these units to play a crucial role in the processing of Hebrew verbs (Frost, et al., 2000), and of Arabic verbs and deverbal nouns (Boudelaa & Marslen-Wilson, 2000). Here we report two masked priming experiments aimed at determining the time course of word pattern and root effects relative to each other and to form-based and meaning-based effects. We varied the morphological, orthographic and semantic relationship between primes and targets in four SOA conditions (32 ms, 48 ms, 64 ms, and 80 ms). Results show that early in the visual processing of Arabic deverbal nouns and verbs, the role played by morphological structure (word patterns and roots) is significantly different from that played by orthographic and semantic factors. Additionally, while word pattern effects are transient and appear only in the earlier stages of processing, root morpheme priming is robust at all SOA's. We interpret this as clear evidence for the separability of morphological from semantic and form effects, and as pointing to significant differences internal to the morphological system.

Processing limitations in specific language impairment: Evidence from a

grammaticality judgement task

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A central question in the study of Specific Language Impairment is whether the proximal cause is one of limited linguistic competence or performance. In the former case, underlying linguistic representations are assumed to be defective. The alternative is that impaired cognitive processing (e.g. domain specific phonological limitations, or more general limitations of processing speed) interferes with the acquisition and on-line processing of language.

Two studies are presented, both examining sensitivity to inflectional morphology, the results of which are broadly consistent with a processing-deficit account of SLI. In the first experiment, a group of school-aged children with SLI demonstrated very poor performance relative to age- and nonverbal ability-matched peers on a grammaticality judgement task involving the regular English past-tense inflection *-ed*. Importantly, accurate judgements were strongly correlated (r = .7) with phonological ability, as indexed by phonological discrimination and nonword reading tasks. This relationship is not obviously predicted by a purely linguistic account of SLI.

In the second experiment, the cognitive stress factors of speeded speaking-rate and increased memory-load were used to 'induce' SLI-like performance in children with typically-developing language. Both increased speed and memory load had the effect of reducing detection of omitted inflections in obligatory contexts, in a grammaticality judgement task. While 3rd person-singular *-s* and past-tense *-ed* were dramatically affected, plural *-s* remained relatively unaffected, which is precisely the pattern of difficulty widely reported in the literature for children with SLI. The finding that this pattern of difficulty can be demonstrated in a population with intact underlying linguistic representations supports the position that performance rather than competence limitations may underlie SLI.

Parafoveal preview during music sight-reading

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How much visual information do pianists process when sight-reading music? Two experiments were carried out to investigate the use of parafoveal information during sight-reading, using two alternative paradigms. The first experiment studied the effect of spreading music notation on eye-movements and sight-reading performance. Data will be presented that shows that, when notes are presented closer together, musicians require fewer, longer fixations than when notation is spread out, even though total viewing time remains constant. This suggests that in the former condition, musicians are processing more notation within one fixation, a result that has implications for musical score editors.

The second experiment used a gaze-contingent moving-window technique to investigate musicians' perceptual span during sight-reading. Bach chorales (arranged in 3-part harmony) were presented to musicians through 1-beat, 2-beat and 4-beat gaze-contingent displays. Eye-movements and sight-reading performance for each window

condition were compared with a control condition in which music was presented without a window. The results of this experiment revealed significant differences between the 2-beat and no-window condition, indicating that musicians' perceptual span extends to approximately 3 beats. Surprisingly, the perceptual span measured in this experiment is similar to that measured by Truitt et al (1997) while pianists read more simple single-line melodies. This lends support for claims that chords are read as units or 'chunks'. Neither experiment revealed an interaction between sight-reading skill and preview, and it is suggested that limits are placed on the perceptual span during sight-reading to avoid increasing demands on working memory.

The effect of delay on grasping two and three dimensional targets in the Titchener circles illusion

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Goodale and Milner's (1992) dual visual system hypothesis has been supported by findings that perceptual judgement is affected by pictorial illusions, while action is relatively unaffected (Aglioti et al 1995; Haffenden and Goodale 1998). It has been suggested that delayed action relies on ventral stream functioning, because of the decay or inappropriateness of a short-lived dorsal visuomotor representation (Goodale et al 1994).
Two- and three-dimensional stimuli were compared to discover whether a stimulus must be 'graspable' for the dorsal stream to dominate in guiding action. Delay was varied to help dissociate dorsal and ventral function. Subjects made a grasping action to a flat circle (2D) or one of 3mm thickness (3D) in the Titchener Circles illusion, immediately or after 3 second delay. Results confirmed previous findings (Gentilucci et al 1996): delayed action towards the 3D target showed the illusory bias, whereas immediate grasping did not. However, for 2D targets, the illusion affected both immediate and delayed grasping. These results suggest that action towards a 2D stimulus is fundamentally different than to a 3D stimulus, and may be more dependent on ventral function. It appears that goal directed action is not in itself sufficient for a grasping action to be driven by dorsal stream visual information.

Aglioti, S., DeSouza, J. and Goodale, M. (1995). Size-contrast illusions deceive the eye but not the hand, *Current Biology* 5: 679–685.
Gentilucci, M., Chieffi, S., Daprati, E., Saetti, M. and Toni, I. (1996). Visual illusion and action, *Neuropsychologia* 34: 367–376.
Goodale, M., Jakobson, L. and Keillor, J. (1994). Differences in the visual control of pantomimed and natural grasping movements., *Neuropsychologia* 32: 1159–1178.
Goodale, M. and Milner, A. (1992). Separate visual pathways for perception and action. *Trends in Neuroscience* 15: 20–25.
Haffenden, A. and Goodale, M. (1998). The effect of pictorial illusion on prehension and perception, *Journal of Cognitive Neuroscience* 10: 122–136.

The feeling of what I made happen

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An operant action occurs when a person makes a movement which produces a sensory consequence. The concept of operant action has been developed primarily within animal learning theory. That tradition has explained operant actions via rules governing the association between internal representations of actions and of consequences, but it has been largely silent about the conscious experience of operant action in humans.
Since the ability to perform intentional, goal-directed actions is fundamental to human psychology, we have attempted to redress this imbalance. We studied the time at which subjects perceive simple operant actions (button presses) to occur. We also studied the perceived time of the sensory consequences of those actions (a short beep 250 ms after the button press). We observed a reliable binding effect in the conscious experience of operant action, whereby the perceived time of the consequence shifts back in time towards the action that caused it, while the perceived time of the action shows a rather smaller shift forwards towards the consequence that it produces.
In further experiments, we have shown that the binding effect: (1) is strongest under conditions of strong association between action and consequence (2) does not occur between two stimuli or between two actions, or between an involuntary movement and a consequent sensory event (3) is abnormally strong in chronic schizophrenic patients.
We conclude that the brain constructs a specific conscious experience of operant action, with the purpose of creating a unified and coherent sense of our own agency. This may be a conscious counterpart to the learning of operant associations.

Impaired strategic regulation of memory accuracy in schizophrenia

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Behavior abnormalities of schizophrenic patients seem to be related to an impairment of conscious awareness. We used a theoretical and experimental framework that delineates the role of monitoring and control processes in the strategic regulation of memory accuracy. A general knowledge task with two incentive conditions was used in patients and normal subjects. We measured monitoring effectiveness (the extend to which confidence judgements adequately assess the correctness of responses), control sensitivity (the extend to which volunteering of answers is sensitive to confidence judgements), and response criterion setting (the confidence threshold set for volunteering a report). Memory accuracy was lower in patients than in control subjects despite their adoption of a higher response criterion. Patients were more confident in their incorrect responses than were normal subjects. Their monitoring effectiveness and control sensitivity were deficient. However, they increased their response criterion in keeping with the incentive to the same extent as normal subjects. Subsequently, schizophrenia impairs both monitoring and control processes underlying strategic control of memory accuracy, but not its modulation by incentives. The dissociation between conscious awareness and volunteering behavior is therefore also a critical determinant in schizophrenia.

Explicit and implicit processes in multi-cue judgement

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We report three experiments in which participants were asked to judge the effectiveness of a set of arbitrarily labelled tests for predicting job performance. The tasks were computer administered and designed in such a way that participants could learn to predict the criterion using outcome feedback. However, this feedback had added noise in line with the multi-cue probability learning (MCPL) paradigm. Performance was then assessed on a set of transfer trials, without feedback, using multiple linear regression. Problem complexity was manipulated by varying both the total number of cues, the proportion of cues that were relevant (predictive) and the presence of positive or negative predictors. Experiments 1 and 2 showed that increasing complexity not only reduced performance on the task, but also tended to reduce measures of self-insight, even though these measures were statistically independent of accuracy. People were less aware of which cues they were using, whether or not these cues were the right ones. Experiment 3 compared performance of participants instructed as to the relevant cues with that of participants who had acquired their knowledge though outcome feedback.

Travelling in time: A time-left analogue for humans supports a linear time scale

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The leading theory of animal timing, *scalar expectancy theory* (SET: Gibbon, Church, & Meck, 1984), proposes that subjective time grows linearly and accurately with growth in real time, although others have proposed power or logarithmic relations between the two. Distinguishing between linear and non-linear time growth is made difficult by the fact that a multi-process theory like SET can often easily reconcile non-linear relations between *behaviour* and real time with an underlying linear time scale. Can a critical test be devised? Gibbon and Church (1981) argue that results from their "time left" procedure, which essentially pits an elapsing time to food delivery against a fixed delay to food, resolve the issue definitively in favour of linear timing. Devising a time-left analogue for humans is very difficult, but the present paper reports one. People experience a series of short, imaginary, train journeys. In one condition, a "normal" train completes the trip in 8 s, whereas a "special" train takes only 4 s. On some trials these are the only events experienced. On other trials, the "special" train is offered at some time during the "normal" train journey. The "special" train can be accepted (in which case the journey takes another 4 s), or rejected (in which case the journey takes the "time left"). People are instructed to minimize journey time. How does preference change as a function of elapsed time on the choice trials, and what happens when the absolute value of the two train journeys is changed? Results strongly supported an underlying linear time scale for humans.

Gibbon, J., & Church, R.M. (1981). Time left: Linear versus logarithmic subjective time. *Journal of Experimental Psychology: Animal Behavior Processes*, *7*, 87-108.
Gibbon, J., Church, R.M., & Meck, W. (1984). Scalar timing in memory. In J. Gibbon and L. Allan (Eds.), *Timing and time perception* (pp. 52-77). New York: New York Academy

of Sciences.

An ERP investigation of parity judgements to numbers in different visual formats

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Dehaene's triple code model of number processing proposes separate processing modules for Arabic digits, verbal numerals and analog magnitudes. The present experiment used event-related EEG recording techniques to test this model. Subjects were required to make parity judgements (i.e., odd or even) to numerical stimuli in the range 1 to 8, which were presented in four different formats: English words, Arabic digits, dots (analog magnitudes] and Roman numerals. Both the numerical size and the format of the stimuli were pseudo-randomised across trials, with no consecutive repetitions of numerical size or format. Each configuration of dot stimuli was unique, consisting of a random distribution of dots around the fixation point. Planned contrasts indicated significant differences in amplitude of the P100 component of the VEP for Arabic digits only and of the N100 component for dots only. Analysis of the P300 component revealed significant amplitude differences between digits + dots compared to words + Roman numerals. The differences between digits and dots and between words and Roman numerals were not statistically significant. The implications of these findings for Dehaene's triple code model will be discussed.

Symposium: Representation of Number

Introduction: Forms of representation.

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Organization of number representations within the parietal lobe: Evidence from functional neuroimaging

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Does the parietal lobe contain a specific representation of numerical quantity, or is it merely involved in generic processes of visuo-spatial representation and manipulation? fMRI experiments indicated that (1) there is a systematic map of visuo-spatial, language, and calculation activations in the parietal lobe, amongs which an area in the middle intraparietal sulcus responds solely during calculation; (2) this area shows notation-independent quantity priming, suggesting that it encodes specific numerical quantities; and (3) It is part of a network whose activation correlates tightly with the semantic distance effect in numerical comparison. The results are compatible with a putative model according to which numerical tasks are implemented in the parietal lobe by both generic mechanisms of spatial attention/manipulation in the posterior parietal cortex and a more specific quantity code in the left and right intraparietal sulci.

The issue of obligatory semantic mediation in number processing: Further evidence from the priming and the Stroop paradigm

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A major distinction between models of visual word recognition and models of picture recognition is that it is generally accepted that words can be named without semantic mediation whereas pictures cannot. In the literature of numerical cognition, there is an ongoing debate as to whether Arabic numerals belong to the former category or to the latter, whether digit naming necessarily requires semantic mediation or not. We will review the evidence for both positions and present new data based on classical paradigms, such as picture-word interference (a variant of the Stroop task) and masked priming. On the basis of this evidence we will defend the position that Arabic digits are processed more like pictures than like words: Digit naming normally involves the semantic system, and if there is a non-semantic route, this is likely to be a slow route.

The quantifying brain : Cortical networks underlying numerosity estimation and counting

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Numbers, as properties of sets, are abstract. Threeness is not defined by particular sensory features – there can be three cows, three tones, or even three wishes. It has been suggested that we use two distinct kinds of numerical representation: approximate and exact, where the latter depends on possession of verbal or symbolic representations. In a fMRI experiment, we present carefully-matched stimuli in the visual and auditory modalities in two numerical tasks designed to explore estimation (without the involvement of words or numerals) and counting. Subtracting auditory and visual baselines, revealed a common network for estimation exclusively in the right hemisphere. For counting there is an additional active network in the left hemisphere also common to the two modalities. The implications of these findings for the representation of number are discussed.

The numerosity model for the representation of numerical magnitude

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Neural network simulations of basic numerical abilities (number comparison, single-digit addition) can be used to contrast different views about the nature of magnitude representations. I will show that "numerosity" representations (Zorzi & Butterworth, 1999) provide the best account of human performance. The main properties of the numerosity model are that i) the representation of numerical magnitude is linear; ii) compressive effects emerge from the non-linear interactions at the response level (e.g., in number comparison); iii) the problem size effect is a by-product of numerosity representations and it depends on pattern overlap rather than pattern frequency. Finally, I will presenting converging evidence from experimental studies that support the numerosity model.