

# The posterior parietal cortex and non-spatial cognition

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## Abstract

The primate posterior parietal cortex (PPC) processes information related to environmental physical space. The human PPC has apparently expanded not only in size but also in its functional range to encompass certain abstract and higher-order conceptual spaces. In this report, we review various forms of non-spatial representation in the PPC. These forms are presented roughly in order of the level of abstraction of the 'objects' and pseudo-spatial relations represented. Also, we consider mechanisms that could have enabled the hominid PPC to establish such representations. Lastly, we offer a general principle to unify the newer forms of representation with the original functions of the PPC.

## Introduction and context

*When asked to give an account of his creative process, Albert Einstein reported that language played virtually no role in his thought process. 'The psychological entities which seem to serve as elements in thought ... are, in my case, of visual and some of muscular type' [1]. When Einstein's brain was examined postmortem, it was noted that among other irregularities, the inferior parietal lobe was significantly larger than normal [2].*

The posterior parietal cortex (PPC) plays a central role in multisensory integration [3] and environmental-spatial cognition [4]. Many recent human imaging (and also some monkey neurophysiology) studies demonstrate that the PPC additionally supports various forms of high-order non-spatial cognition that are not necessarily directly related to physical space itself. For example, while the superior parietal lobule (SPL) tends to process spatial information in a conventional way, the inferior parietal lobule (IPL) is often credited with non-spatial cognition. Debate exists on the comparative anatomy of the primate PPC (Figure 1). The IPL is said to be evolutionarily new and uniquely expanded in humans and the monkey PPC is said to correspond to the human SPL [5,6], but there is another view that the monkey PPC possesses functional homologues of both regions [7,8].

If the latter view is correct, neuroscientists should be able to identify precursory mechanisms of non-spatial information processing in non-human primates. Indeed, when monkeys were trained to acquire tool use – a high-order behavior they rarely exhibit naturally – PPC expansion was observed at both microscopic [9] and macroscopic [10] scales.

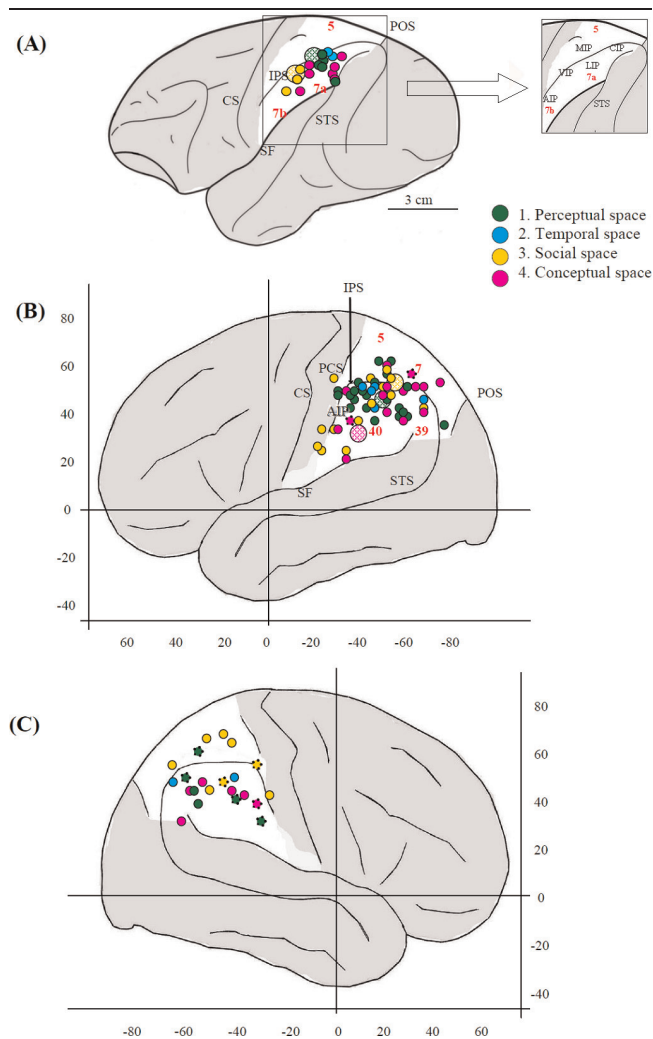
The following section reviews various recently reported forms of non-spatial representation in the PPC. They are ordered roughly in terms of the level of abstraction of the 'objects' and pseudo-spatial relations represented (Figure 2). The last section considers potential mechanisms that could have enabled the hominid PPC to establish such representations and hypothesizes a general principle to unify these newer forms of representation with the PPC's original functions.

## Major recent advances

### 1. Perceptual space

The PPC is implicated in three-dimensional (3D) object recognition, processing of number and quantity, attention, and memory. The intraparietal sulcus (IPS) and anterior intraparietal area are activated when concrete 3D objects are recognized, explored, imagined, and

**Figure 1. Comparison of substructures (unshaded) of monkey and human posterior parietal cortex (PPC)**



**(A)** monkey PPC; **(B)** human left PPC; **(C)** human right PPC. Results of meta-analysis (based on the references listed in Figure 2) of cortical areas responsible for non-spatial cognition are superimposed. Data points in monkeys are projected onto the left hemisphere (because no particular laterality has been claimed), whereas those in human subjects are illustrated independently for each hemisphere (being biased toward the left hemisphere). Large and dashed symbols indicate areas estimated from reviews and original papers, respectively, in which coordinates were not clearly specified. Arabic numerals indicate Brodmann areas (40: supramarginal gyrus; 39: angular gyrus). The subdivisions of the PPC were referred from the original sources. AIP, anterior intraparietal area; CIP, caudal intraparietal area; CS, central sulcus; IPS, intraparietal sulcus; LIP, lateral intraparietal area; MIP, medial intraparietal area; PCS, post central sulcus; POS, parieto-occipital sulcus; SF, sylvian fissure; STS, superior temporal sulcus; VIP, ventral intraparietal area.

constructed [11,12]. Discerning continuous quantity recruits the anterior IPS [13] while discrete number processing recruits the bilateral IPS [14-16], forming a mental number line [17] and mental arithmetic [18]. Sustained attention to spatial locations recruits the area between the right IPS and the IPL [19]. The lateral intraparietal area responds to various features of the stimulus shape [20-25]. Angular gyrus and temporo-parietal junction (TPJ) activity is related to stimulus saliency detection and control [26,27]. The left and right posterior TPJ are active while processing global and local information, respectively [28]. The bilateral IPS supports episodic and semantic memory [29]. The PPC may play a critical role in working memory [30-33], although this region can also be active during tasks requiring no working memory [34]. Thus, the PPC's apparent role in working memory may reflect a broader function, such as temporally transferring information from present to future (see 'Temporal space' section).

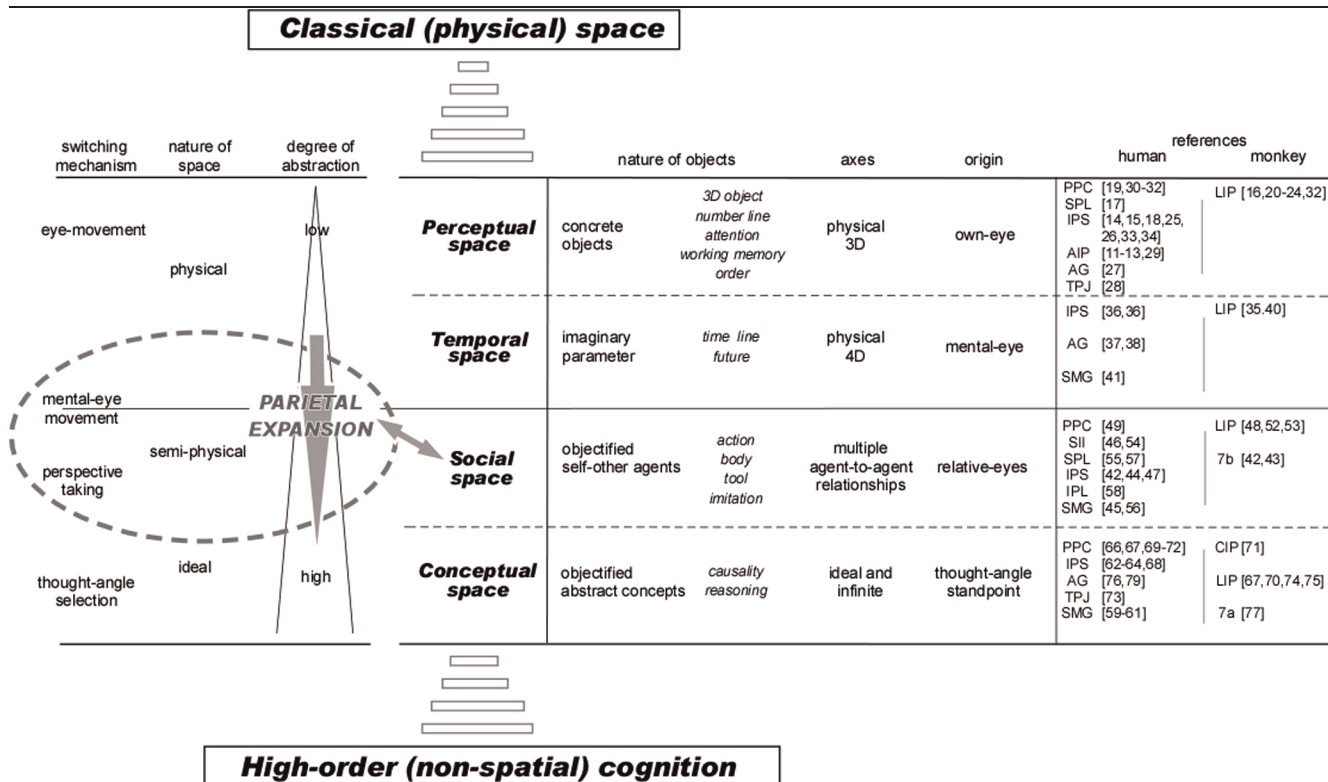
**2. Temporal space**

The PPC is implicated in temporal processing [35,36], time estimation, and future planning [37]. The TPJ plays a crucial role in temporal order judgment tasks [38] as well as in magnitude judgments about numbers [18]. The PPC supports time interval estimation and is active when estimating future object position [39,40]. In the PPC, events are processed in order and placed in a timeline [41].

**3. Social space**

The PPC processes some aspects of social space, including action understanding, tool use, and self-other relationships, thereby enabling imitation. The PPC is one of the brain areas showing mirror properties [42-44]. Gesture imitation activates the IPL and supramarginal gyrus (SMG) [45]. Imitation activates the left inferior parietal cortex more than observation does, regardless of first- or third-person perspective [46]. The human anterior IPS distinguishes between observed and executed movements [47], suggesting that PPC neurons have hierarchical properties for recognizing sameness or difference of kinematics, goals, and function of motion [48]. The PPC supports tool usage, an extension of the bodily self [49-52]. This faculty may require an implicit equivalence to be drawn between innate body parts and external objects. A proposed brain network subserving such body-part objectification includes the PPC [53]. The PPC supports the recognition and drawing of distinctions between agents [54,55]. Evaluations of physical

**Figure 2. Hypothetical mechanisms of non-spatial representations processed by posterior parietal cortex as a function of abstractness**



Left, hypothesized mechanism for increasing abstract levels of representations (see 'Future directions' section for details). Right, structure of various levels of abstract spaces (references for respective levels are listed in the far-right column). 3D, three-dimensional; 4D, four-dimensional; AG, angular gyrus; AIP, anterior intraparietal area; CIP, caudal intraparietal area; IPL, inferior parietal lobule; IPS, intraparietal sulcus; LIP, lateral intraparietal area; PPC, posterior parietal cortex; SII, secondary somatosensory cortex; SMG, supramarginal gyrus; SPL, superior parietal lobule; TPJ, temporo-parietal junction.

and social distance to others involve the superior and inferior PPC, respectively [56], in accordance with egocentric distance estimation by the parietal cortex [57]. Cooperative and competitive tasks recruit a common set of brain regions with competition activating the right inferior parietal lobe more strongly, reflecting the apparent contrast between self and others [58]. The PPC's facility with both concrete spatial cognition and self-other discrimination may have preadapted it to handle perspective transformation in social situations. This in turn could have laid the basis for further functional expansion into realms such as social categorization and, later in evolution, conceptual spaces [48].

**4. Conceptual space**

Finally, the PPC appears to play a role in causal reasoning, mental object manipulation, attention switching, set shifting, and dimensional abstraction. In addition to the role of the PPC in tool usage (see 'Social space' section), different PPC areas support broad concepts such as the causal ramifications of using tools [51, 59, 60] and the logical structures of the gestures

involved [50]. The SPL and SMG are differentially activated during rotations of visual and motor imagery, respectively [61]. Spatial scanning through mental imagery activated the precuneus, SPL, IPL, and IPS [62]. The PPC is responsible for mentally manipulating sequentially learned materials [63], whereas the mid-dorsolateral prefrontal cortex is responsible for monitoring the learned items [64]. PPC activation is also related to cognitive set shifting [65-70]. During a visual search with attention shifts, PPC neurons depend on a targeted dimension irrespective of the stimuli's spatial features [71]. PPC activation was diminished in elderly people in the solution-search phase of a set-shifting task [72]. Perspective taking [73] is one of the prominent qualitative distinctions between the attention-shifting abilities of humans and other primates [48]. PPC activity also correlates with abstract information at various levels and dimensions [74-77] and with modulation of the strength of the visual stimulus and motor planning [78]. The left parietal cortex is involved in the cortical rearranging of the relationship between semantic items in space [79].

## Future directions

As outlined above and illustrated in Figure 2 (right), various kinds of non-spatial cognition can be grouped and ordered based on the levels of abstraction of the 'objects' and ideally defined spaces represented. Assumed coordinate systems for such 'spaces' are summarized here.

The pseudo-spatial nature of the high-order cognition supported by the PPC may derive from the essential characteristics of the objects represented but alternatively may derive from the nature of the PPC's pre-existing information-processing mechanisms, namely as a hub for multisensory integration and representing physical environmental space. The meta-analysis in Figure 1 illustrates that the PPC areas responsible for these novel forms of cognition are not necessarily clearly segregated, either in monkeys or humans, but does suggest a trend of gradual expansion toward the IPL as the level of abstraction proceeds. Thus, it seems that the PPC gradually incorporated high-order cognition as it expanded during hominid evolution while preserving its original principles of operation.

What is the explanation for this expansion of function? Here is a hypothesis involving mechanisms for 'selecting' and 'switching' between objects among different represented spaces: (a) in classical (physical) space, spatial attention toward concrete objects was typically expressed as eye movement; (b) when such attention needed to be sustained or when the attending content needed to be memorized, invisible 'time' was 'visualized' in the mind's eye, becoming a new virtual dimension in the PPC's existing suite of spatial coordinate systems; (c) once the PPC could visualize an invisible virtual entity, a similar objectification process could be extended further, enabling intentional perspective switching (Figure 2, left).

Acquiring representations of social space might have accelerated this process. Through objectification processes [53] and the development of 'virtual eyes' [48,73], flexible and mutually integrated representations of the bodily self, the analogous selves of others, and tools as equivalents of body parts (and *vice versa*) might have served as a bridge between concrete physical and abstract conceptual spaces. As the PPC expanded in both physical volume and range of function [9,10] (Figure 2, dashed circle), a positive feedback process (arrow) could have been established to achieve further human-specific forms of non-spatial conceptual cognition.

Thus, crucial components of human intelligence derive their character from the precursorial spatial cognition

process of the PPC. Indeed, language is rife with spatial metaphors for abstract thoughts. Non-human primates possess the same precursorial parietal mechanisms as human ancestors; through training, their cognitive capacities can be artificially extended in the hominid/human direction. If correct, this hypothesis will be valuable in guiding the design of future experimental paradigms, in both animal and human studies, to elucidate the principles of parietal information processing.

## Abbreviations

3D, three-dimensional; IPL, inferior parietal lobule; IPS, intraparietal sulcus; PPC, posterior parietal cortex; SMG, supramarginal gyrus; SPL, superior parietal lobule; TPJ, temporo-parietal junction.

## Competing interests

The authors declare that they have no competing interests.

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## References

1. Hadamard J: *The Psychology of Invention in the Mathematical Field*. Mineola, NY: Dover Publications; 1954.
2. Witelson SF, Kigar DL, Harvey T: **The exceptional brain of Albert Einstein**. *Lancet* 1999, **353**:2149-53.
3. Duhamel JR, Colby CL, Goldberg ME: **Congruent representation of visual and somatosensory space in single neurons of monkey ventral intraparietal cortex area (area VIP)**. In *Brain and Space*. Edited by Paillard J. Oxford: Oxford University Press; 1991: 223-36.
4. Buneo CA, Jarvis MR, Batista AP, Andersen RA: **Direct visuomotor transformations for reaching**. *Nature* 2002, **416**:632-6.
5. Brodmann K: **Localisation in the cerebral cortex**. In *Ihren Prinzipien dargestellt auf Grund des Zellenbaues*. Leipzig: Johann Ambrosius Barth; 1909.
6. Geschwind N: **Disconnexion syndromes in animals and man. I**. *Brain* 1965, **88**:237-94.
7. von Bonin G, Bailey P: *The Neocortex of Macaca Mulatta*. Urbana: University of Illinois Press; 1974.
8. von Economo C: *The Cytoarchitectonics of the Human Cerebral Cortex*. London: Oxford University Press; 1929.
9. Hihara S, Notoya T, Tanaka M, Ichinose S, Ojima H, Obayashi S, Fujii N, Iriki A: **Extension of corticocortical afferents into the anterior bank of the intraparietal sulcus by tool-use training in adult monkeys**. *Neuropsychologia* 2006, **44**:2636-46.
10. Quallo MM, Price CJ, Ueno K, Asamizuya T, Cheng K, Lemon RN, Iriki A: **Gray and white matter changes associated with tool-use learning in macaque monkeys**. *Proc Natl Acad Sci USA* 2009, in press.
11. Jancke L, Kleinschmidt A, Mirzazade S, Shah NJ, Freund HJ: **The role of the inferior parietal cortex in linking the tactile perception and manual construction of object shapes**. *Cereb Cortex* 2001, **11**:114-21.
12. Durand JB, Peeters R, Norman JF, Todd JT, Orban GA: **Parietal regions processing visual 3D shape extracted from disparity**. *Neuroimage* 2009, **46**:1114-26.
13. Jacob SN, Nieder A: **Notation-independent representation of fractions in the human parietal cortex**. *J Neurosci* 2009, **29**: 4652-7.

14. Cappelletti M, Lee HL, Freeman ED, Price CJ: **The role of right and left parietal lobes in the conceptual processing of numbers.** *J Cogn Neurosci* 2009, [Epub ahead of print].
15. Castelli F, Glaser DE, Butterworth B: **Discrete and analogue quantity processing in the parietal lobe: a functional MRI study.** *Proc Natl Acad Sci U S A* 2006, **103**:4693-8.
16. Tudusciuc O, Nieder A: **Contributions of primate prefrontal and posterior parietal cortices to length and numerosity representation.** *J Neurophysiol* 2009, **101**:2984-94.
- F1000 Factor 3.0 Recommended  
Evaluated by Wolfram Schultz 07 Sep 2009
17. Knops A, Thirion B, Hubbard EM, Michel V, Dehaene S: **Recruitment of an area involved in eye movements during mental arithmetic.** *Science* 2009, **324**:1583-5.
18. Franklin MS, Jonides J: **Order and magnitude share a common representation in parietal cortex.** *J Cogn Neurosci* 2009, **21**:2114-20.
19. Malhotra P, Coulthard EJ, Husain M: **Role of right posterior parietal cortex in maintaining attention to spatial locations over time.** *Brain* 2009, **132**:645-60.
20. Balan PF, Gottlieb J: **Functional significance of nonspatial information in monkey lateral intraparietal area.** *J Neurosci* 2009, **29**:8166-76.
21. Oristaglio J, Schneider DM, Balan PF, Gottlieb J: **Integration of visuospatial and effector information during symbolically cued limb movements in monkey lateral intraparietal area.** *J Neurosci* 2006, **26**:8310-9.
- F1000 Factor 9.0 Exceptional  
Evaluated by Michael E Goldberg 22 Sep 2006
22. Sereno AB, Amador SC: **Attention and memory-related responses of neurons in the lateral intraparietal area during spatial and shape-delayed match-to-sample tasks.** *J Neurophysiol* 2006, **95**:1078-98.
23. Sereno AB, Maunsell JH: **Shape selectivity in primate lateral intraparietal cortex.** *Nature* 1998, **395**:500-3.
24. Gifford GW 3rd, Cohen YE: **Spatial and non-spatial auditory processing in the lateral intraparietal area.** *Exp Brain Res* 2005, **162**:509-12.
25. Medendorp WP, Goltz HC, Vilis T: **Remapping the remembered target location for anti-saccades in human posterior parietal cortex.** *J Neurophysiol* 2005, **94**:734-40.
- F1000 Factor 3.0 Recommended  
Evaluated by Kevin A Martin 13 Apr 2005
26. Hu S, Bu Y, Song Y, Zhen Z, Liu J: **Dissociation of attention and intention in human posterior parietal cortex: an fMRI study.** *Eur J Neurosci* 2009, **29**:2083-91.
27. Zenon A, Filali N, Duhamel JR, Olivier E: **Salience representation in the parietal and frontal cortex.** *J Cogn Neurosci* 2009, [Epub ahead of print].
28. Schendan HE, Amick MM, Cronin-Golomb A: **Role of a lateralized parietal-basal ganglia circuit in hierarchical pattern perception: evidence from Parkinson's disease.** *Behav Neurosci* 2009, **123**:125-36.
29. Phillips JS, Velanova K, Wolk DA, Wheeler ME: **Left posterior parietal cortex participates in both task preparation and episodic retrieval.** *Neuroimage* 2009, **46**:1209-21.
30. McNab F, Varrone A, Farde L, Jucaite A, Bystritsky P, Forssberg H, Klingberg T: **Changes in cortical dopamine D1 receptor binding associated with cognitive training.** *Science* 2009, **323**:800-2.
- F1000 Factor 3.0 Recommended  
Evaluated by Michael Frank 20 Feb 2009
31. Kawasaki M, Watanabe M, Okuda J, Sakagami M, Aihara K: **Human posterior parietal cortex maintains color, shape and motion in visual short-term memory.** *Brain Res* 2008, **1213**:91-7.
32. Rawley JB, Constantinidis C: **Neural correlates of learning and working memory in the primate posterior parietal cortex.** *Neurobiol Learn Mem* 2009, **91**:129-38.
33. Oztekin I, McElree B, Staresina BP, Davachi L: **Working memory retrieval: contributions of the left prefrontal cortex, the left posterior parietal cortex, and the hippocampus.** *J Cogn Neurosci* 2009, **21**:581-93.
34. Mitchell DJ, Cusack R: **Flexible, capacity-limited activity of posterior parietal cortex in perceptual as well as visual short-term memory tasks.** *Cereb Cortex* 2008, **18**:1788-98.
35. Leon MI, Shadlen MN: **Representation of time by neurons in the posterior parietal cortex of the macaque.** *Neuron* 2003, **38**:317-27.
- F1000 Factor 3.3 Recommended  
Evaluated by Michael E Goldberg 01 May 2003, Maurizio Corbetta 21 May 2003, Dora Angelaki 10 Jun 2003
36. Buetti D, Walsh V, Frith C, Rees G: **Different brain circuits underlie motor and perceptual representations of temporal intervals.** *J Cogn Neurosci* 2008, **20**:204-14.
37. Coull JT, Vidal F, Nazarian B, Macar F: **Functional anatomy of the attentional modulation of time estimation.** *Science* 2004, **303**:1506-8.
38. Davis B, Christie J, Rorden C: **Temporal order judgments activate temporal parietal junction.** *J Neurosci* 2009, **29**:3182-8.
39. Beudel M, Renken R, Leenders KL, de Jong BM: **Cerebral representations of space and time.** *Neuroimage* 2009, **44**:1032-40.
40. Calton JL, Dickinson AR, Snyder LH: **Non-spatial, motor-specific activation in posterior parietal cortex.** *Nat Neurosci* 2002, **5**:580-8.
41. Oliveri M, Koch G, Salerno S, Torriero S, Lo Gerfo E, Caltagirone C: **Representation of time intervals in the right posterior parietal cortex: implications for a mental time line.** *Neuroimage* 2009, **46**:1173-9.
42. Fogassi L, Ferrari PF, Gesierich B, Rozzi S, Chersi F, Rizzolatti G: **Parietal lobe: from action organization to intention understanding.** *Science* 2005, **308**:662-7.
43. Ishida H, Nakajima K, Inase M, Murata A: **Shared mapping of own and others' bodies in visuotactile bimodal area of monkey parietal cortex.** *J Cogn Neurosci* 2009, [Epub ahead of print].
44. Pelphrey KA, Morris JP, McCarthy G: **Grasping the intentions of others: the perceived intentionality of an action influences activity in the superior temporal sulcus during social perception.** *J Cogn Neurosci* 2004, **16**:1706-16.
- F1000 Factor 3.0 Recommended  
Evaluated by Aina Puce 18 Feb 2005
45. Mühlau M, Hermsdörfer J, Goldenberg G, Wohlschläger AM, Castrop F, Stahl R, Röttinger M, Erhard P, Haslinger B, Ceballos-Baumann AO, Conrad B, Boecker H: **Left inferior parietal dominance in gesture imitation: an fMRI study.** *Neuropsychologia* 2005, **43**:1086-98.
46. Jackson PL, Meltzoff AN, Decety J: **Neural circuits involved in imitation and perspective-taking.** *Neuroimage* 2006, **31**:429-39.
47. Dinstein I, Gardner JL, Jazayeri M, Heeger DJ: **Executed and observed movements have different distributed representations in human aIPS.** *J Neurosci* 2008, **28**:11231-9.
48. Yamazaki Y, Yokochi H, Tanaka M, Okanoya K, Iriki A: **Potential role of monkey inferior parietal neurons coding action semantic equivalences as precursors of parts of speech.** *Soc Neurosci* 2009, in press.
49. Culham JC, Valyear KF: **Human parietal cortex in action.** *Curr Opin Neurobiol* 2006, **16**:205-12.
50. Johnson-Frey SH, Newman-Norlund R, Grafton ST: **A distributed left hemisphere network active during planning of everyday tool use skills.** *Cereb Cortex* 2005, **15**:681-95.
51. Lewis JW: **Cortical networks related to human use of tools.** *Neuroscientist* 2006, **12**:211-31.

52. Obayashi S, Suhara T, Kawabe K, Okauchi T, Maeda J, Akine Y, Onoe H, Iriki A: **Functional brain mapping of monkey tool use.** *Neuroimage* 2001, **14**:853-61.
53. Iriki A: **The neural origins and implications of imitation, mirror neurons and tool use.** *Curr Opin Neurobiol* 2006, **16**:660-7.
54. Agnew Z, Wise RJ: **Separate areas for mirror responses and agency within the parietal operculum.** *J Neurosci* 2008, **28**:12268-73.
55. Shmuelof L, Zohary E: **Mirror-image representation of action in the anterior parietal cortex.** *Nat Neurosci* 2008, **11**:1267-9.
56. Yamakawa Y, Kanai R, Matsumura M, Naito E: **Social distance evaluation in human parietal cortex.** *PLoS ONE* 2009, **4**:e4360.
57. Neggers SF, Van der Lubbe RH, Ramsey NF, Postma A: **Interactions between ego- and allocentric neuronal representations of space.** *Neuroimage* 2006, **31**:320-31.
58. Decety J, Jackson PL, Sommerville JA, Chaminade T, Meltzoff AN: **The neural bases of cooperation and competition: an fMRI investigation.** *Neuroimage* 2004, **23**:744-51.
- F1000 Factor 3.0 *Recommended*  
Evaluated by Sarah-Jayne Blakemore 16 Mar 2005
59. Goldenberg G, Spatt J: **The neural basis of tool use.** *Brain* 2009, **132**:1645-55.
60. Lewis JW, Brefczynski JA, Phinney RE, Janik JJ, DeYoe EA: **Distinct cortical pathways for processing tool versus animal sounds.** *J Neurosci* 2005, **25**:5148-58.
61. Pelgrims B, Andres M, Olivier E: **Double dissociation between motor and visual imagery in the posterior parietal cortex.** *Cereb Cortex* 2009, **19**:2298-307.
62. Schicke T, Muckli L, Beer AL, Wibrall M, Singer W, Goebel R, Rosler F, Roder B: **Tight covariation of BOLD signal changes and slow ERPs in the parietal cortex in a parametric spatial imagery task with haptic acquisition.** *Eur J Neurosci* 2006, **23**:1910-8.
- F1000 Factor 6.0 *Must Read*  
Evaluated by Alan Palmer 25 Apr 2006
63. Zatorre RJ, Halpern AR, Bouffard M: **Mental reversal of imagined melodies: a role for the posterior parietal cortex.** *J Cogn Neurosci* 2009. [Epub ahead of print].
64. Champod AS, Petrides M: **Dissociable roles of the posterior parietal and the prefrontal cortex in manipulation and monitoring processes.** *Proc Natl Acad Sci U S A* 2007, **104**:14837-42.
65. Kamigaki T, Fukushima T, Miyashita Y: **Cognitive set reconfiguration signaled by macaque posterior parietal neurons.** *Neuron* 2009, **61**:941-51.
66. Liston C, Matalon S, Hare TA, Davidson MC, Casey BJ: **Anterior cingulate and posterior parietal cortices are sensitive to dissociable forms of conflict in a task-switching paradigm.** *Neuron* 2006, **50**:643-53.
67. Nakahara K, Hayashi T, Konishi S, Miyashita Y: **Functional MRI of macaque monkeys performing a cognitive set-shifting task.** *Science* 2002, **295**:1532-6.
- F1000 Factor 8.2 *Exceptional*  
Evaluated by John Duncan 27 Mar 2002, Earl Miller 30 Sep 2002, Mark D'Esposito 01 Aug 2003
68. Rossi AF, Pessoa L, Desimone R, Ungerleider LG: **The prefrontal cortex and the executive control of attention.** *Exp Brain Res* 2009, **192**:489-97.
69. Shomstein S, Yantis S: **Parietal cortex mediates voluntary control of spatial and nonspatial auditory attention.** *J Neurosci* 2006, **26**:435-9.
70. Stoet G, Snyder LH: **Single neurons in posterior parietal cortex of monkeys encode cognitive set.** *Neuron* 2004, **42**:1003-12.
- F1000 Factor 3.0 *Recommended*  
Evaluated by Susan Courtney 06 Jul 2004
71. Ogawa T, Komatsu H: **Condition-dependent and condition-independent target selection in the macaque posterior parietal cortex.** *J Neurophysiol* 2009, **101**:721-36.
72. Hampshire A, Gruszka A, Fallon SJ, Owen AM: **Inefficiency in self-organized attentional switching in the normal aging population is associated with decreased activity in the ventrolateral prefrontal cortex.** *J Cogn Neurosci* 2008, **20**:1670-86.
- F1000 Factor 3.0 *Recommended*  
Evaluated by Alunit Ishai 22 Aug 2008
73. Corradi-Dell'acqua C, Ueno K, Ogawa A, Cheng K, Rumiati RI, Iriki A: **Effects of shifting perspective of the self: an fMRI study.** *Neuroimage* 2008, **40**:1902-11.
74. Yang T, Shadlen MN: **Probabilistic reasoning by neurons.** *Nature* 2007, **447**:1075-80.
- F1000 Factor 9.0 *Exceptional*  
Evaluated by Dora Angelaki 03 Jul 2007
75. Freedman DJ, Assad JA: **Distinct encoding of spatial and nonspatial visual information in parietal cortex.** *J Neurosci* 2009, **29**:5671-80.
76. Hoenig K, Scheef L: **Neural correlates of semantic ambiguity processing during context verification.** *Neuroimage* 2009, **45**:1009-19.
77. Crowe DA, Chafee MV, Averbeck BB, Georgopoulos AP: **Participation of primary motor cortical neurons in a distributed network during maze solution: representation of spatial parameters and time-course comparison with parietal area 7a.** *Exp Brain Res* 2004, **158**:28-34.
- F1000 Factor 3.0 *Recommended*  
Evaluated by Peter F MacNeilage 25 May 2004
78. Tosoni A, Galati G, Romani GL, Corbetta M: **Sensory-motor mechanisms in human parietal cortex underlie arbitrary visual decisions.** *Nat Neurosci* 2008, **11**:1446-53.
79. Turriziani P, Oliveri M, Bonni S, Koch G, Smirni D, Cipolotti L: **Exploring the relationship between semantics and space.** *PLoS ONE* 2009, **4**:e5319.