

Schizophrenia and cognitive function

Gina Kuperberg* and Stephan Heckers†

Schizophrenia is often associated with cognitive deficits, particularly within the domains of memory and language. Specific cognitive deficits have recently been linked to psychotic phenomena, including verbal hallucinations and disorganized speech. Impairments of working and semantic memory are primarily due to dysfunction of the frontal cortex, temporal cortex, and hippocampus. Cognitive skills in schizophrenia predict social functioning and may serve as outcome measures in the development of effective treatment strategies.

Addresses

Massachusetts General Hospital, Department of Psychiatry, CNY-9, Building 149, Thirteenth Street, Charlestown, MA 02129, USA

*e-mail: kuperber@helix.mgh.harvard.edu

†e-mail: heckers@psych.mgh.harvard.edu

Current Opinion in Neurobiology 2000, 10:205–210

0959-4388/00/\$ – see front matter

© 2000 Elsevier Science Ltd. All rights reserved.

Abbreviations

DLPFC dorsolateral prefrontal cortex
fMRI functional magnetic resonance imaging
MT medial temporal area
PET positron emission tomography
WM working memory

Introduction

Schizophrenia is a severe mental disorder characterized by a variety of signs and symptoms. The clinical phenomena associated with schizophrenia can be grouped into positive and negative clusters. The positive cluster includes the phenomena that are not present in the normal individual: for example, hallucinations, delusions, disorganized speech or positive thought disorder. The negative cluster describes the absence of certain functions that are present in the normal individual: for

example, apathy, avolition, and poverty of speech. More recently, factor analytic studies have suggested that these phenomena cluster into three ‘syndromes’: psychomotor poverty (encompassing many of the negative symptoms), reality distortion (hallucinations and delusions), and disorganization (positive thought disorder and disorganized, non-goal-directed behavior). Since its earliest conception as ‘dementia praecox’ (i.e. early-onset dementia), impaired cognitive function has also been considered a core feature. Clear evidence to suggest that cognitive dysfunction is intrinsic to schizophrenia, however — rather than the result of chronic illness, institutionalization or medication — is only now emerging: cognitive deficits are present in adolescents at risk for schizophrenia and in untreated first-episode schizophrenic patients [1]. Moreover, cognitive performance does not deteriorate over the first few years of illness when patients are treated [2,3].

Research into cognition and schizophrenia over this past year has taken several different approaches. Here, we review behavioral studies of cognitive dysfunction, regional brain activation during task performance, the effect of cognitive impairment on social functioning, and the effect of psychotropic medication on cognition in schizophrenia (see Table 1).

Impaired cognitive function

Schizophrenic patients show deficits in a variety of cognitive domains including executive function, attention, memory and language. There is increasing evidence that such deficits are not global and generalized but rather they are specific and selective, manifest by distinct patterns of association and dissociation of performance across different cognitive tasks.

Table 1

Recent studies (reference number in brackets) of cognitive deficits in schizophrenia, their correlation with clinical features, and their neural mechanisms.

Deficits in	Clinical correlates	Neural mechanism
Working memory [4,5,7,8] Episodic memory [10**] Verbal learning		DLPFC [20,21,23,24**,25] Thalamus [27*] Striatum [28] CCTCC [29,30*] DLPFC [22*] Hippocampus [26**] Anterior cingulate [38*] Frontal-temporal-parietal [37*]
Semantic memory [6,9*]	Thought disorder [15]	
Semantic priming [17] Sentence processing [18**] Source monitoring [12,13] Speech perception [14]	Thought disorder [17] Thought disorder [18**] Auditory hallucination [11**] Auditory hallucination [14]	

CCTCC, cortical-cerebellar-thalamic-cortical circuit.

A distinct pattern of cognitive deficits in schizophrenia could theoretically reflect a single cognitive deficit. For example, the correlation of reaction-time facilitation and error interference on the Stroop task (a measure of selective attention) with performance on the Speaking Span test (a measure of working memory) could indicate a common cognitive disturbance [4]. Similarly, Cohen *et al.* [5] have demonstrated that schizophrenic patients show selective patterns of impairment on three different tasks (a version of the Continuous Performance Task, the Stroop test, and a lexical disambiguation task), with the poorest performance seen in experimental conditions that were most sensitive to context. Moreover, a significant cross-task correlation within these ‘context-sensitive’ conditions was taken to support the theory that schizophrenia is characterized by an impairment in using representations of context to govern appropriate behavior.

A dissociation in performance, either between two related tasks or between experimental conditions within the same task, is also consistent with the existence of selective deficits. For example, dissociations have been described between semantic as opposed to phonological fluency [6] and in verbal as opposed to non-verbal auditory working memory [7]. A deficit in the Stroop test but not in two other interference tasks [8] suggests that schizophrenic patients with the disorganized syndrome are impaired in their ability to suppress irrelevant verbal responses. In addition, selective deficits have also been described in the pattern of retrieval from both semantic and episodic memory. Semantic memory has been conceptualized as an associative network in which world knowledge and the meaning of words are stored. Following presentation of a series of words, the pattern of recall depends upon both the strength and the number of associative links with other words in the network. Schizophrenic patients recall fewer words than normal controls in a retrieval task. More interestingly, over and above this poor overall performance, patients show an abnormal pattern of word recall, suggesting a specific impairment in either the structure or modulation of this associative network [9•].

Schizophrenic patients are also impaired when asked to provide details of a previous episode, or when asked to identify the origins of an event. When schizophrenic patients performed or watched the pairing of objects, they showed an overall recognition deficit and were specifically impaired when asked to recall details of the pairing episode [10••]. This provides evidence that memory deficits in schizophrenia are associated with an inability to link the separate aspects of events into a cohesive, memorable, and distinctive whole.

Cognitive deficits are not necessarily found in all schizophrenic patients. This raises the issue of whether heterogeneity in cognitive performance reflects heterogeneity in symptomatology. Some of the paradigms used in studies describing specific qualitative differences between

normals and schizophrenics have face validity with particular symptoms of schizophrenia. For example, one might predict that patients with positive thought disorder (disorganized speech) may have specific deficits in semantic function, while those with auditory hallucinations may have particular problems with auditory source memory. This paves the way towards a ‘symptom-orientated approach’ to the study of cognitive deficits in schizophrenia. In such an approach, a particular symptom is taken as the point of reference; patients with and without this symptom are recruited, and the hypothesis posed relates to the theoretical link between the proposed cognitive deficit and this clinical phenomenon.

Verbal hallucinations might occur when internal thought (or ‘inner speech’) is misattributed as arising from external sources. Johns and McGuire [11••] report that hallucinators are particularly likely to make errors when articulating derogatory words — a finding consistent with the pattern of deficits revealed on a source monitoring task [12] and with the clinical observation that auditory hallucinations are often derogatory. Misattribution errors may arise from an abnormal attribution ‘bias’, as opposed to abnormal perceptual encoding [13]. A cognitive bias caused by the emotional content of the material may be influenced by top-down processes; for example, by one’s beliefs about one’s relationship with one’s surroundings, such as ‘metacognitions’ about controllability and danger [12]. An alternative hypothesis — that verbal hallucinations arise from abnormalities in speech perception — is supported by the finding that patients with, but not without, auditory hallucinations show deficits in speech tracking and sentence repetition [14].

It has been hypothesized that positive thought disorder reflects a specific deficit in processing meaning. At the level of individual words, this hypothesis has been explored using semantic priming paradigms [15]. Semantic priming is the decrease in the reaction time taken to make a lexical decision or to name a target word, if the word presented just before the target is semantically related. The results of semantic priming studies in schizophrenia have been mixed, showing both increased, normal and decreased priming effects. These contradictory results may reflect the psychometric parameters and paradigms used, and have been interpreted as consistent with abnormalities in semantic processing. For example, increased direct and indirect priming (where subjects are more likely to associate relatively weakly ‘linked’ words with one another) in healthy subjects with elevated scores for schizophrenic language disturbances [16] has been interpreted as evidence for an activated (or disinhibited) semantic associative network. On the other hand, reduced priming to medium or highly associated words in positively thought-disordered patients may reflect a deviant pattern of activation within the semantic network [17]. Clinically, positive thought disorder is characterized not just by abnormal word associations, but by phenomena such as

‘derailment’ and ‘tangentiality’, which suggest problems with whole themes. Kuperberg *et al.* [18**] aimed to bridge the gap between the clinical phenomenology of language abnormalities in schizophrenia and their underlying cognitive basis by using a task in which subjects monitored for words in auditorily-presented normal and linguistically-anomalous sentences. The results suggested a specific impairment in using linguistic context during ‘online’ language processing. All types of anomalous sentences were violated in meaning (pragmatics/semantics). Thus, these findings are consistent with the idea that thought disorder reflects a deficit in semantic processing. Intriguingly, the severity of thought disorder does not correlate with working memory and executive function [15] and reduced semantic priming fails to predict impaired performance on the Stroop test [19]. These findings suggest that deficits in semantic function can be dissociated from deficits in attention and working memory.

Mapping cognitive dysfunction in the brain

Studies involving functional neuroimaging during several different cognitive tasks suggest that schizophrenia is associated with a widespread dysfunction within a network of brain areas involving the frontal and temporal cortex, the hippocampus, and subcortical regions.

Impaired dorsolateral prefrontal cortex (DLPFC) function has been linked with impaired working memory (WM) — the internal representation, maintenance and updating of sensory information — in schizophrenia [20]. Several recent studies have given new insights into the precise relationships between DLPFC dysfunction and WM performance. DLPFC function may be dependent upon task ‘difficulty’: during tasks with a low WM load, DLPFC function lies within the normal range and only becomes abnormal when WM load increases and performance becomes less accurate [21,22*,23]. Although this finding reconciles the divergent results of some previous studies, discrepancies still remain: both decreased [21] and increased [23] recruitment of DLPFC have been described during high-load WM tasks, and both right [21] and left [23] DLPFC dysfunctions have been documented. Moreover, deficits on different WM tasks are associated with distinct patterns of dysfunction: for example, WM deficit for words but not tones [10**] is associated with an impaired recruitment of left inferior frontal cortex [24**].

Frontal dysfunction in schizophrenia may be associated with increased responses in distant yet highly connected areas such as the parietal cortex [22*,25] and the superior temporal gyrus [22*]. Moreover, a recent PET study revealed abnormally high levels of hippocampal blood flow in schizophrenia: patients failed to show a normal modulation of hippocampal activity during word retrieval [26**].

There is increasing evidence that three brain regions that make strong connections with the frontal lobe — the thalamus, the striatum and the cerebellum — are also

abnormal in schizophrenia. First, thalamic glucose metabolism during verbal learning is reduced in schizophrenic subjects, primarily in the region of the mediodorsal nucleus [27*]. Second, both treated and untreated patient groups show decreased striatal metabolic rates during a verbal learning task [28]. Third, studies of verbal learning and story recollection suggest that the cerebellum, via connections with both the DLPFC and the thalamus, is also part of the abnormal circuitry in schizophrenia [29,30*].

Recent studies of eye-tracking dysfunction in schizophrenia provide further evidence for the involvement of both frontal and temporal regions [31,32**,33,34,35*,36]. First, the observed pattern of impaired pursuit eye movements and intact catch-up saccades implicates the frontal eye fields or their efferent or afferent pathways [35*]. Second, a series of recent studies has described a motion perception deficit with impaired velocity discrimination, suggesting the involvement of the motion processing area MT (medial temporal area) in the temporal lobe [31,32**,33].

In summary, perturbations of brain activity in schizophrenia are not localized to one brain region but to neural networks, primarily involving the frontal and temporal lobes as well as subcortical regions. It has been proposed that the functional connections between these regions may be abnormal in schizophrenia. This hypothesis has been tested using novel statistical approaches. For example, structural equation modeling (path analysis) of a semantic processing study using PET showed differences between schizophrenia and control groups in the neural interactions amongst frontal regions, between frontal and temporal regions, and between the frontal lobe and anterior cingulate cortex [37*]. When PET data from a memory study were analyzed for the effects of one neuronal system over another (so-called effective connectivity analysis), the normal anterior cingulate modulation of frontal-temporal interaction was found to be disrupted in schizophrenia [38*].

Implications of cognitive dysfunction

Do cognitive deficits predict social functioning?

There has been a renewed interest [39] in predicting how the schizophrenic patient will function in the community, on the basis of both symptoms and cognitive deficits [40–43]. After reviewing studies that evaluated cognitive measures as predictors and correlates of functional outcome for schizophrenic patients, Green [39] suggested that deficits in verbal memory and vigilance are the best predictors for impaired social functioning in the community. Subsequent studies have provided further evidence that cognitive deficits contribute directly to impaired social functioning [40,41]. Cognitive dysfunction is not the only predictor for social functioning in schizophrenia. A recent prospective study, for example, linked community functioning to the degree of disorganization [43]. Cognitive dysfunction is a valuable measure in the study of schizophrenia however, as it allows for objective

and repeated assessments, can be linked directly with abnormalities in brain function (see above), and can serve as an outcome measure in the development of therapeutic drugs (see below).

The effect of medication on cognitive function

Psychotropic medication can, in theory, either impair or improve the cognitive skills of patients with schizophrenia. Moreover, some psychotropic medications may have selective beneficial effects on particular aspects of cognitive function. For example, there is preliminary evidence that several of the atypical antipsychotic drugs (such as risperidone and clozapine) improve cognitive skills more than typical antipsychotics (such as haloperidol) [44,45]. Indeed, cognition is emerging as a valuable outcome measure in the development of the new atypical antipsychotic medications. Specifically, risperidone has been associated with improved verbal WM and clozapine with improved verbal fluency and verbal learning [44,45]. The mechanism for the differential effects of psychotropic drugs is unclear [44], but could involve specific targets in the dopaminergic, noradrenergic, and cholinergic systems [46].

Neuroimaging studies provide an important link in the study of the neural mechanisms mediating the effects of antipsychotic medication on cognition: a recent fMRI study demonstrated that risperidone enhances brain activation during WM task performance in right prefrontal cortex, supplementary motor area, and posterior parietal cortex after substitution for typical antipsychotic drugs [47]. However, it is unclear how the differences in brain activation should be interpreted, because the task was sufficiently easy for the patients to perform at normal levels.

Conclusions

In recent years, we have seen the examination of cognitive function in many areas of schizophrenia research, perhaps reflecting our growing understanding of schizophrenia from a neurocognitive perspective. Cognitive dysfunction is a direct predictor of poor social functioning and can be ameliorated by certain psychotropic drugs. Deficits are found in many behavioral domains, and are mediated by widespread but distinct abnormalities in brain function. The existence of specific patterns of cognitive dysfunction — many linked with particular clinical phenomena — suggests several important avenues of future research. Are specific associations and dissociations of cognitive dysfunction reflected by parallel patterns of neuroanatomical dysfunction? Can these, in turn, be linked to individual symptoms of schizophrenia? Do different drugs have selective effects on symptoms and cognition? If so, what is their mechanism of action? Addressing such questions has direct implications for the prognosis and treatment of the individual patient: it will pave the way towards the development of more rational approaches to treatment, whereby specific symptoms and cognitive deficits can be targeted and remedied.

References and recommended reading

Papers of particular interest, published within the annual period of review, have been highlighted as:

- of special interest
 - of outstanding interest
1. Mohamed S, Paulsen JS, O'Leary D, Arndt S, Andreasen NC: **Generalized cognitive deficits in schizophrenia: a study of first-episode patients.** *Arch Gen Psychiatry* 1999, **56**:749-754.
 2. Gold S, Arndt S, Nopoulos P, O'Leary DS, Andreasen NC: **Longitudinal study of cognitive function in first-episode and recent-onset schizophrenia.** *Am J Psychiatry* 1999, **156**:1342-1348.
 3. Hoff AL, Sakuma M, Wieneke M, Horon R, Kushner M, DeLisi LE: **Longitudinal neuropsychological follow-up study of patients with first-episode schizophrenia.** *Am J Psychiatry* 1999, **156**:1336-1341.
 4. Barch DM, Carter CS: **Selective attention in schizophrenia: relationship to verbal working memory.** *Schizophr Res* 1998, **33**:53-61.
 5. Cohen JD, Barch DM, Carter C, Servan-Schreiber D: **Context-processing deficits in schizophrenia: converging evidence from three theoretically motivated cognitive tasks.** *J Abnorm Psychol* 1999, **108**:120-133.
 6. Feinstein A, Goldberg TE, Nowlin B, Weinberger DR: **Types and characteristics of remote memory impairment in schizophrenia.** *Schizophr Res* 1998, **30**:155-163.
 7. Wexler BE, Stevens AA, Bowers AA, Sernyak MJ, Goldman-Rakic PS: **Word and tone working memory deficits in schizophrenia.** *Arch Gen Psychiatry* 1998, **55**:1093-1096.
 8. Baxter RD, Liddle PF: **Neuropsychological deficits associated with schizophrenic syndromes.** *Schizophr Res* 1998, **30**:239-249.
 9. Nestor PG, Akdag SJ, O'Donnell BF, Niznikiewicz M, Law S, Shenton ME, McCarley RW: **Word recall in schizophrenia: a connectionist model.** *Am J Psychiatry* 1998, **155**:1685-1690.
- In normal subjects, recall of a particular word is dependent upon both its 'connectivity' with other words in a semantic network, as well as the number of associative links within this network; this study demonstrated that schizophrenic patients were impaired in recalling words of low connectivity, regardless of network size.
10. Danion JM, Rizzo L, Bruant A: **Functional mechanisms underlying impaired recognition memory and conscious awareness in patients with schizophrenia.** *Arch Gen Psychiatry* 1999, **56**:639-644.
- Subjects performed or watched the pairing of objects. They were then required to recognize pairs of objects, to recall who paired them (source recognition), and to distinguish between whether they 'remembered' details of the pairing episode (auto-noetic awareness) or just 'knew' that objects had been paired (noetic awareness). Schizophrenic patients recognized fewer pairs, were less able to recognize the source, and made significantly fewer 'remember' responses. This suggested that patients with schizophrenia were unable to link the separate aspects of events ('relational binding') and that the corollary of this deficit is a quantitative and qualitative impairment of auto-noetic awareness.
11. Johns LC, McGuire PK: **Verbal self-monitoring and auditory hallucinations in schizophrenia [letter].** *Lancet* 1999, **353**:469-470.
- This study extended previous studies of source memory in schizophrenia, by specifically linking the phenomenon of auditory hallucinations with an underlying cognitive deficit in source monitoring 'online'. The authors used an innovative paradigm in which subjects were required to distinguish the source of their own speech, which was distorted and instantaneously fed back. Even with minor distortions of pitch, hallucinators were particularly prone to conclude that their voice belonged to someone else (especially when articulating derogatory words).
12. Baker CA, Morrison AP: **Cognitive processes in auditory hallucinations: attributional biases and metacognition.** *Psychol Med* 1998, **28**:1199-1208.
 13. Brebion G, Smith MJ, Amador X, Malaspina D, Gorman JM: **Word recognition, discrimination accuracy, and decision bias in schizophrenia: association with positive symptomatology and depressive symptomatology.** *J Nerv Ment Dis* 1998, **186**:604-609.
 14. Hoffman RE, Rapaport J, Mazure CM, Quinlan DM: **Selective speech perception alterations in schizophrenic patients reporting hallucinated "voices".** *Am J Psychiatry* 1999, **156**:393-399.
 15. Goldberg TE, Aloia MS, Gourovitch ML, Missar D, Pickar D, Weinberger DR: **Cognitive substrates of thought disorder, I: the semantic system.** *Am J Psychiatry* 1998, **155**:1671-1676.

16. Moritz S, Andresen B, Domin F, Martin T, Probststein E, Kretschmer G, Krausz M, Naber D, Spitzer M: **Increased automatic spreading activation in healthy subjects with elevated scores in a scale assessing schizophrenic language disturbances.** *Psychol Med* 1999, **29**:161-170.
17. Aloia MS, Gourovitch ML, Missar D, Pickar D, Weinberger DR, Goldberg TE: **Cognitive substrates of thought disorder, II: specifying a candidate cognitive mechanism.** *Am J Psychiatry* 1998, **155**:1677-1684.
18. Kuperberg GR, McGuire PK, David AS: **Reduced sensitivity to linguistic context in schizophrenic thought disorder: evidence from on-line monitoring for words in linguistically anomalous sentences.** *J Abnorm Psychol* 1998, **107**:423-434.
- In this paradigm, subjects were asked to monitor spoken sentences for target nouns (e.g. 'guitar') in normal sentences (e.g. "... the young man grabbed the guitar..."), and for different types of pragmatically and semantically violated sentences (e.g. "...the young man drank the guitar..."). Healthy controls and non-thought-disordered schizophrenic patients took longer to recognize words that were linguistically-violated compared with words in normal sentences. Compared with both other groups, thought-disordered patients showed significantly *smaller* differences in reaction time, suggesting that they were relatively insensitive to all linguistic violations. In this study, syntactic violations (subcategorization violations) were also semantically violated. Thus, further studies are required to determine whether positive-thought-disordered patients are specifically impaired in processing semantics as opposed to syntax.
19. Barch DM, Carter CS, Perlstein W, Baird J, Cohen JD, Schooler N: **Increased stroop facilitation effects in schizophrenia are not due to increased automatic spreading activation.** *Schizophr Res* 1999, **39**:51-64.
20. Goldman-Rakic PS: **The physiological approach: functional architecture of working memory and disordered cognition in schizophrenia.** *Biol Psychiatry* 1999, **46**:650-661.
21. Carter CS, Perlstein W, Ganguli R, Brar J, Mintun M, Cohen JD: **Functional hypofrontality and working memory dysfunction in schizophrenia.** *Am J Psychiatry* 1998, **155**:1285-1287.
22. Fletcher PC, McKenna PJ, Frith CD, Grasby PM, Friston KJ, Dolan RJ: **Brain activations in schizophrenia during a graded memory task studied with functional neuroimaging.** *Arch Gen Psychiatry* 1998, **55**:1001-1008.
- This PET study demonstrated that DLPFC blood flow increased during learning and recalling words when the working memory load was low, but declined from the normal range with increased word list length. The DLPFC response was closely related to task performance in schizophrenia.
23. Manoach DS, Press DZ, Thangaraj V, Searl MM, Goff DC, Halpern E, Saper CB, Warach S: **Schizophrenic subjects activate dorsolateral prefrontal cortex during a working memory task, as measured by fMRI.** *Biol Psychiatry* 1999, **45**:1128-1137.
24. Stevens AA, Goldman-Rakic PS, Gore JC, Fulbright RK, Wexler BE: **Cortical dysfunction in schizophrenia during auditory word and tone working memory demonstrated by functional magnetic resonance imaging.** *Arch Gen Psychiatry* 1998, **55**:1097-1103.
- Using fMRI, the authors showed that verbal working memory deficits in schizophrenia are associated with an impaired activation of language-associated areas in the left inferior frontal gyrus (areas 6, 44 and 45).
25. Curtis VA, Bullmore ET, Morris RG, Brammer MJ, Williams SC, Simmons A, Sharma T, Murray RM, McGuire PK: **Attenuated frontal activation in schizophrenia may be task dependent.** *Schizophr Res* 1999, **37**:35-44.
26. Heckers S, Rauch SL, Goff D, Savage CR, Schacter DL, Fischman AJ, Alpert NM: **Impaired recruitment of the hippocampus during conscious recollection in schizophrenia.** *Nat Neurosci* 1998, **1**:318-323.
- This PET study reveals that schizophrenics lack the normal hippocampal blood-flow increases during conscious recollection but show widespread frontal lobe blood-flow increases and better than normal recall accuracy during effortful retrieval.
27. Hazlett EA, Buchsbaum MS, Byne W, Wei TC, Spiegel-Cohen J, Geneve C, Kinderlehrer R, Haznedar MM, Shihabuddin L, Siever LJ: **Three-dimensional analysis with MRI and PET of the size, shape, and function of the thalamus in the schizophrenia spectrum.** *Am J Psychiatry* 1999, **156**:1190-1199.
- This combined PET and structural magnetic resonance study found patients with schizophrenia and schizotypal personality disorder to have decreased thalamic glucose metabolism during verbal learning and an abnormal shape of the thalamus, but a normal total thalamic volume.
28. Shihabuddin L, Buchsbaum MS, Hazlett EA, Haznedar MM, Harvey PD, Newman A, Schnur DB, Spiegel-Cohen J, Wei T, Machac J *et al.*: **Dorsal striatal size, shape, and metabolic rate in never-medicated and previously medicated schizophrenics performing a verbal learning task.** *Arch Gen Psychiatry* 1998, **55**:235-243.
29. Crespo-Facorro B, Paradiso S, Andreasen NC, O'Leary DS, Watkins GL, Boles Ponto LL, Hichwa RD: **Recalling word lists reveals "cognitive dysmetria" in schizophrenia: a positron emission tomography study.** *Am J Psychiatry* 1999, **156**:386-392.
30. Andreasen NC, Nopoulos P, O'Leary DS, Miller DD, Wassink T, Flaum M: **Defining the phenotype of schizophrenia: cognitive dysmetria and its neural mechanisms.** *Biol Psychiatry* 1999, **46**:908-920.
- The authors summarize recent PET studies of a neural network including cortex, thalamus, and cerebellum during the performance of several memory tasks; in each of the studies, schizophrenia was associated with decreased blood flow in all or some of the three brain regions.
31. Chen Y, Nakayama K, Levy DL, Matthyse S, Holzman PS: **Psychophysical isolation of a motion-processing deficit in schizophrenics and their relatives and its association with impaired smooth pursuit.** *Proc Natl Acad Sci USA* 1999, **96**:4724-4729.
32. Chen Y, Levy DL, Nakayama K, Matthyse S, Palafox G, Holzman PS: **Dependence of impaired eye tracking on deficient velocity discrimination in schizophrenia.** *Arch Gen Psychiatry* 1999, **56**:155-161.
- In this study, 15 patients with chronic schizophrenia showed deficient processing of velocity information, providing evidence for an impairment of motion-sensitive areas such as MT (in addition to frontal areas).
33. Chen Y, Palafox GP, Nakayama K, Levy DL, Matthyse S, Holzman PS: **Motion perception in schizophrenia.** *Arch Gen Psychiatry* 1999, **56**:149-154.
34. Maruff P, Danckert J, Pantelis C, Currie J: **Saccadic and attentional abnormalities in patients with schizophrenia.** *Psychol Med* 1998, **28**:1091-1100.
35. Sweeney JA, Luna B, Srinivasagam NM, Keshavan MS, Schooler NR, Haas GL, Carl JR: **Eye tracking abnormalities in schizophrenia: evidence for dysfunction in the frontal eye fields.** *Biol Psychiatry* 1998, **44**:698-708.
- Twelve neuroleptic-naive first-episode patients showed impaired pursuit initiation, low steady-state pursuit gain, and preserved integrity in the processing of motion information, providing support for frontal eye field dysfunction in schizophrenia.
36. Thaker GK, Ross DE, Cassady SL, Adami HM, LaPorte D, Medoff DR, Lahti A: **Smooth pursuit eye movements to extraretinal motion signals: deficits in relatives of patients with schizophrenia.** *Arch Gen Psychiatry* 1998, **55**:830-836.
37. Jennings JM, McIntosh AR, Kapur S, Zipursky RB, Houle S: **Functional network differences in schizophrenia: a rCBF study of semantic processing.** *Neuroreport* 1998, **9**:1697-1700.
- This PET study employed a statistical model (structural equation model) to determine the interaction between brain regions during a semantic processing task. Connections between frontal and temporal regions that were highly positive in the control group were highly negative for the patients, and *vice versa*.
38. Fletcher P, McKenna PJ, Friston KJ, Frith CD, Dolan RJ: **Abnormal cingulate modulation of fronto-temporal connectivity in schizophrenia.** *Neuroimage* 1999, **9**:337-342.
- This PET study employed an anatomical model of connectivity to determine the influence of the anterior cingulate gyrus on frontal-temporal interaction; the product of cingulate and prefrontal activity predicted a decrease of superior temporal activity in normals, but not in the schizophrenic subjects.
39. Green MF: **What are the functional consequences of neurocognitive deficits in schizophrenia?** *Am J Psychiatry* 1996, **153**:321-330.
40. Addington J, Addington D: **Neurocognitive and social functioning in schizophrenia.** *Schizophr Bull* 1999, **25**:173-182.
41. Dickerson F, Boronow JJ, Ringel N, Parente F: **Social functioning and neurocognitive deficits in outpatients with schizophrenia: a 2-year follow-up.** *Schizophr Res* 1999, **37**:13-20.

42. Green MF, Nuechterlein KH: **Should schizophrenia be treated as a neurocognitive disorder?** *Schizophr Bull* 1999, **25**:309-319.
43. Norman RM, Malla AK, Cortese L, Cheng S, Diaz K, McIntosh E, McLean TS, Rickwood A, Voruganti LP: **Symptoms and cognition as predictors of community functioning: a prospective analysis.** *Am J Psychiatry* 1999, **156**:400-405.
44. Keefe R, Silva S, Perkins D, Lieberman J: **The effects of antipsychotic drugs on neurocognitive impairment in schizophrenia: a review and meta-analysis.** *Schizophr Bull* 1999, **25**:201-222.
45. Purdon SE: **Cognitive improvement in schizophrenia with novel antipsychotic medications.** *Schizophr Res* 1999, **35 (Suppl)**:S51-S60.
46. Friedman JI, Temporini H, Davis KL: **Pharmacologic strategies for augmenting cognitive performance in schizophrenia.** *Biol Psychiatry* 1999, **45**:1-16.
47. Honey GD, Bullmore ET, Soni W, Varatheesan M, Williams SCR, Sharma T: **Differences in frontal cortical activation by a working memory task after substitution of risperidone for typical antipsychotic drugs in patients with schizophrenia.** *Proc Natl Acad Sci USA* 1999, **96**:13432-13437.