Complexity and Integration of information processing: A new approach to schizophrenia

Schmid, G.B. [1], **Benz, M.** [1], **Vollenweider, F.X.** [1]

[1]Division for Affective Disorders and General Psychiatry ZH East

Background The *Connectivity Hypothesis* assumes that the complex behaviour of the brain is better described by functional gestalts within the overall neural network than by isolated, well-defined structural integrities or anomalies in brain anatomy (Sporns, Tononi et al. 2000). In this respect, a functional fronto-temporal disconnectivity was suggested to underlay the core symptoms of schizophrenia (Tononi and Edelman 2000).

Methods To further explore the disconnectivity hypothesis, three neural network models of information processing within 18 selected cortical and limbic brain regions were investigated in 15 first-episode unmedicated schizophrenic patients and matched healthy controls under conditions of a prepulse inhibition (PPI) experiment. Brain activity patterns were assessed during white noise; startling pulse; and startling pulse preceeded by a prepulse using H2O-PET. Functional integration of brain areas was calculated for each stimulus condition using measures of *integrated information*: $\Phi^{c}_{m}(S)$ (Tononi, Sporns et al. 1994). A *main complex*, that is, a network with positive Φ which is not included within a larger network with higher Φ and which generates a maximum amount of integrated information corresponding to Φ by entering into a particular state was identified for controls and persons suffering from schizophrenia, respectively.

Results Independent of model, we find that in schizophrenia patients as compared to controls: the phylogenetic older brain regions (thalamus, putamen, nucleus accumbens) exchange more information within and between themselves than they do with the rest of the brain, in particular, with the cortex, i.e. the functional connectivity prefers limbic to cortical networks.
The *main complex S* (VOI numbers in bold font within shaded fields) and the corresponding capacity to integrate information, $\Phi(S)$, for Model A1 are shown in the **Tables** for controls and schizophrenic patients, respectively, under the given conditions: NS=white noise only, P0=startling pulse alone, PP= startling pulse preceeded by a subaudible prepulse.

Model A1 **Controls**

$\Phi_{NS}(S)=0.18161\times10^{-3}$ / $\Phi_{PP0}(S)=0.10952\times10^{-3}$ / $\Phi_{PP}(S)=0.2882\times10^{-3}$

NS	P0	PP	L hemisphere	NS	P0	PP	R hemisphere
1	**1**	**1**	thalamus	**2**	**2**	**2**	thalamus
3	**3**	**3**	putamen	**4**	**4**	**4**	putamen
5	**5**	**5**	nucl. accumb.	**6**	**6**	**6**	nucl. accumb.
7	**7**	7	amygdala	**8**	**8**	8	amygdala
9	**9**	**9**	hippocampus	**10**	**10**	10	hippocampus
11	**11**	**11**	insula	**12**	**12**	12	insula
13	**13**	13	fr.med. cortex	**14**	**14**	14	fr.med. cortex
15	15	15	temp.lat. cortex	**16**	**16**	16	temp.lat. cortex
17	**17**	**17**	parietal cortex	**18**	**18**	**18**	parietal cortex

For controls, conditions NS and P0 connect the communication between virtually all the VOIs of the model. In the PP condition (the prepulse-pulse) the communication to the amygdale(l&r: VOIs 7&8), the hippocampus(r: VOI 10), the insula(r: VOI 12), the frontomedial cortex(l&r: VOIs 13&14), and the tempolateral cortex(r: VOI 16) is disconnected from the main complex found under conditions NS and P0. Here, the prepulse "warning" evokes gating mechanisms which result in differences in the way specific brain regions react to the overall acoustic stimulus.

Model A1 **Persons with Schizophrenia**

$\Phi_{NS}(S)=0.55496\times10^{-3}$ / $\Phi_{PP0}(S)=0.85728\times10^{-3}$ / $\Phi_{PP}(S)=1.06\times10^{-3}$

NS	P0	PP	L hemisphere	NS	P0	PP	R hemisphere
1	**1**	**1**	thalamus	**2**	**2**	**2**	thalamus
3	**3**	**3**	putamen	**4**	**4**	**4**	putamen
5	**5**	**5**	nucl. accumb.	**6**	**6**	**6**	nucl. accumb.
7	7	7	amygdala	8	8	8	amygdala
9	**9**	**9**	hippocampus	10	**10**	**10**	hippocampus
11	11	11	insula	12	12	12	insula
13	13	13	fr.med. cortex	14	14	14	fr.med. cortex
15	15	15	temp.lat. cortex	16	16	16	temp.lat. cortex
17	17	17	parietal cortex	18	18	18	parietal cortex

Schizophrenic patients display a heightened degree of connectivity between non-cortical regions only (condition NS: VOIs 1-6; conditions P0 & PP: VOIs 1-6, 9,10).

Conclusions The quantitiy of consciousness within a *complex* is given by the amount of integrated information Φ generated within that *complex* (Tononi & Koch 2008, p. 256). Independent of model and condition, we find that for subjects diagnosed with schizophrenia as compared to healthy controls:
(1) the phylogenetic older brain regions (thalamus, putamen, nucleus accumbens) exchange more information within and between themselves than they do with the rest of the brain, in particular, with the cortex, i.e. the functional connectivity involves limbic but no cortical regions;
(2) based on the Φ values for the *main complexes* involving those brain regions selected by the various models tested here, persons suffering from schizophrenia have several times as much consciousness concentrated within their limbic system as do healthy probands within both cortical and limbic systems combined.

This combination of
(1) disconnectivity between limbic and cortical systems
(2) concentration of consciousness within the limbic system
may help explain the mental behaviour of schizophrenic patients and can be understood as a kind of *limbic autism* in schizophrenia: *Limbic autism* (hyperconnectivity of limbic in comparison to cortical networks) may contribute to disturbances in schizophrenia - schism between thought and feeling observed in this illness as first proposed by Eugen Bleuler when he gave this illness its name.

Contact: Dr. Gary Bruno Schmid ◆ University Hospital of Psychiatry Zurich ◆ Lenggstr. 31 ◆ CH-8032 Zurich, Switzerland ◆ E-Mail: gbschmid@mac.com