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Letter to the Editor

Rich semantic networks applied to schizophrenia: A new framework

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Dear Editor,

The 'loosening of associations' is a core feature of language behavior in schizophrenia (Bleuler, 1911/1950). Most theories assume that words are arranged in a network which is disturbed due to a structural difference in their representation or activation. Despite considerable work using semantic priming and word association paradigms, critical issues remain unanswered, primarily because methodological limitations preclude the building of accurate models of meaning in the mental lexicon, and the questionable relevance of only testing small parts of this lexicon.

We introduce a framework sufficiently sensitive to investigate structural and dynamic processes in language production and how this is affected in serious mental illness. Our network-based proposal is influenced by Collins and Loftus (1975) but moves to a more realistic representation by removing experimenter bias and scaling it up to cover most words used in language. By representing a large variety of words (e.g., abstract or concrete, verbs, adjectives or nouns) it provides an alternative to the mental lexicon as a hierarchical taxonomic knowledge repository that typically focuses on concrete nouns. Instead, the lexicon also accounts for many thematic relations between words (De Deyne et al., 2015a, 2015b). Studying networks at this scale opens up a multi-level approach where both the global (macro), intermediate (meso) and detailed structure mutually constrain processes and potential representations (Baronchelli et al., 2013). Put differently, to understand the structure of the lexicon at the most detailed level depends on our understanding of higher level meso- or macroscopic levels as well. We argue that this novel approach is of particular use in the study of clinical disorders that affect language - such as schizophrenia - and we illustrate this with pilot data from a patient where we derived the macro, meso- and microscopic properties (see Fig. 1).

A 20 year old female Cantonese speaking patient was tested on multiple occasions while in an acute psychotic state. She was shown cue words and asked to generate as many associates as possible. These responses served as cues in subsequent testing sessions, thus gradually expanding in a snowball fashion (De Deyne et al., 2013). This approach is sensitive to capture the structure within basic level categories (e.g., birds) or entire domains (e.g., animals), but the wide scope contrasts with previous approaches which focus on a few categories or use spatial techniques to map the underlying structure (Elvevåg and Storms, 2003).

First, at a macroscopic level we can examine the degree of organization and efficiency of information retrieval by examining the 'small-world' structure, and by comparing with a random network that matches the number of nodes and degree distributions. This analysis shows that the network is not arbitrarily organized but rather shows high levels of organization (albeit potentially different from healthy controls). The global structure is indicated by the average path lengths, clustering coefficient and modularity score which are built from the patterns of interconnectivity of a node with its neighbors and indirect neighbors. Here the clustering coefficient is 0.12, indicating a high degree of structure (cf. random = 0.06).

Second, at a mesoscopic level the network informs what type of information is activated in language use by the flow between a subset of 'nodes'. The network is interpreted by inspecting the meaning of a few clusters, and summarizing the contribution of a subset of paths and connections. Here seven clusters contained on average 25 nodes (indicated by the color of nodes and edges), identified by comparing them to the probability of identifying a similar clustered structure in a matched network (Lancichinetti et al., 2011). This technique infers high density clusters of related words from the network automatically and are indicated by an arbitrary color in Fig. 1. Thus, the nodes in green are related to *good* (i.e., *helping others, exercise, caring for mother, friends, doctor, teacher and kindness*). The blue nodes are more negative (i.e., *wrong values, wrong doings, law, prison, but also society, justice, prison, fear, people do not like me, people gaze, hospitalization, home* and the name of a controversial politician in Hong Kong). The nodes in red (see left) indicate everyday objects (*electrical appliances and food*). Interestingly, the delusional content is mainly towards the 'bad' side of the network, and the strong cluster of 'positive' words may reflect a preoccupation with these words. Inspired by Osgood's semantic differential (Osgood et al., 1957), results from a Dutch study indicate that positive or negative connotation or its valence is a strong structural determinant of network structure where emotional response congruency between a cue and target determines the global network structure (De Deyne et al., 2015a, 2015b; Van Rensbergen et al., 2015), thus going beyond taxonomic principles but including potential affective or thematic structure as well.

Third, at the microscopic level the local density of connectivity for a node assays how accessible words are. In the figure, central nodes are nodes with many in- or outgoing links. A first pair of hubs in green corresponds to *happy* (two different words in Chinese: 開心, 快樂), while a second red cluster contains the hub word for *good* (好). This centrality is confirmed by the number of outgoing links which is highest for *happy* (開心), *doctor* (醫生) and *good* (好) and incoming links which has high ranks for *good* (好), and the two words for *happy*. The centrality conveys something about what concepts are subjectively important and are likely to differentiate homogeneous groups of persons.

Each level is highly interdependent, and thus it constrains possible interpretations to those that converge at each of these levels. The semantics encoded in such a network go far beyond classical views, as they reflect a contribution from language learning history, imagery

