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Neural circuit of verbal humor comprehension in schizophrenia - an fMRI study

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A B S T R A C T

Individuals with schizophrenia exhibit problems with understanding the figurative meaning of language. This study evaluates neural correlates of diminished humor comprehension observed in schizophrenia. The study included chronic schizophrenia (SCH) outpatients (n = 20), and sex, age and education level matched healthy controls (n = 20). The fMRI punchline based humor comprehension task consisted of 60 stories of which 20 had funny, 20 nonsensical and 20 neutral (not funny) punchlines. After the punchlines were presented, the participants were asked to indicate whether the story was comprehensible and how funny it was. Three contrasts were analyzed in both groups reflecting stages of humor processing: abstract vs neutral stories - incongruity detection; funny vs abstract - incongruity resolution and elaboration; and funny vs neutral – complete humor processing. Additionally, parametric modulation analysis was performed using both subjective ratings separately. Between-group comparisons revealed that the SCH subjects had attenuated activation in the right posterior superior temporal gyrus (BA 41) in case of irresolvable incongruity processing of nonsensical puns; in the left dorsomedial middle and superior frontal gyri (BA 8/9) in case of incongruity resolution and elaboration processing of funny puns; and in the interhemispheric dorsal anterior cingulate cortex (BA 24) in case of complete processing of funny puns. Additionally, during comprehensibility ratings the SCH group showed a suppressed activity in the left dorsomedial middle and superior frontal gyri (BA 8/9) and revealed weaker activation during funniness ratings in the left dorsal anterior cingulate cortex (BA 24). Interestingly, these differences in the SCH group were accompanied behaviorally by a protraction of time in both types of rating responses and by indicating funny punchlines less comprehensible. Summarizing, our results indicate neural substrates of humor comprehension processing impairments in schizophrenia, which is accompanied by fronto-temporal hypoactivation.

1. Introduction

Schizophrenia is a mental illness characterized by various psychopathological symptoms with a number of cognitive, emotional and communication impairments which together influence social functioning of the patients (Cechnicki, 2011; Howes and Murray, 2014; Nutt and Need, 2014). Recent reports indicate that diminished communication skills may be considered one of the most important features of

Abbreviations: ABS, absurd/nonsensical punchline; ACC, anterior cingulate cortex; BA, Brodmann's area; CON, healthy controls/control group; dACC, dorsal anterior cingulate cortex; dlPFC, dorsolateral prefrontal cortex; dmMFG, dorsomedial Middle Frontal Gyrus; EEG, electroencephalography; ERPs, EEG event-related potentials; FDR, False Discovery Rate; fMRI, functional magnetic resonance imaging; fNIRS, functional near-infrared spectroscopy; FUN, funny punchline; FWHM, full-width-at-half-maximum; GLM, general linear model; IFG, inferior frontal gyrus; IPL, Inferior Parietal Lobule; ISI, interstimulus-interval; k, number of voxels in analyzed cluster size; L, left hemisphere; MFG, medial frontal gyrus; MNI, Montreal Neurological Institute coordinates; MoCA, Montreal Cognitive Assessment; MOG, middle occipital gyrus; MRI, magnetic resonance imaging; MTG, middle temporal gyrus; NEU, neutral/unfunny punchline; SOA, stimulus onset asynchrony; ns, non-significant group difference; PANSS, Positive and Negative Syndrome Scale; PFC, prefrontal cortex; pSTG, posterior Superior Temporal Gyrus; R, right hemisphere; RHLB, Right Hemisphere Language Battery; RT, reaction time; SCH, schizophrenia outpatients/clinical group; SD, standard deviations; SEM, standard error of the mean; sLORETA, standardized low resolution brain electromagnetic tomography analysis; SFG, Superior Frontal Gyrus; STG, superior temporal gyrus; TP, temporal pole; TPJ, temporoparietal junction; ToM, theory of mind.

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schizophrenia outcome and recovery (Adamczyk et al., 2016; Falkenberg et al., 2007; Niznikiewicz et al., 2013; Titone, 2010; Wible, 2012).

Figurative meaning of speech (e.g. humor, metaphor, irony) is a key part of human language abilities. For example, the ability to use and experience humor is an important quality of human social functioning, which enriches social relations and improves cooperation between people (Goel and Dolan, 2001; Mobbs et al., 2003; Polimeni and Reiss, 2006a; Vrticka et al., 2013). Studies on humor appreciation in schizophrenia published to date point unequivocally toward disturbed processes related to comprehension and/or appreciation of humor, along with occasional contradictory conclusions concerning the relationship between the occurrence of this deficit and the severity of psychopathological symptoms (Adamczyk et al., 2016; Bozikas et al., 2007; Corcoran et al., 1997; Davenport, 2008; Falkenberg et al., 2007; Marjoram et al., 2006; Polimeni and Reiss, 2006b; Polimeni et al., 2010; Tsoi et al., 2008). It is notable that certain tests indicate that people with schizophrenia may benefit from humor training intervention during the recovery process, which improves their ability to understand and use humor (Cai et al., 2014) or reduces psychopathology and improves self-esteem and coping (Falkenberg et al., 2007; Gelkopf et al., 1993, 1994, 2006; Witztum et al., 1999). However, there is still insufficient data to fully explain this deficit and its causes. Aside from behavioral evidence, we do not know much about neural mechanisms of humor processing impairments in people with schizophrenia. Importantly, only one exceptional study to date has examined schizophrenia-related functional magnetic resonance imaging (fMRI) responses during humor processing. Namely, the study of Marjoram et al. (2006) on high-risk relatives of individuals with schizophrenia indicates reduced prefrontal cortex (PFC) activations during theory of mind (ToM) humor processing related to history of psychotic-like positive symptoms.

A literature review suggests that the nature of humor impairments observed in schizophrenia is related to deficiencies in set shifting and semantic cognition in a given linguistic context, with a general tendency to use literal language and difficulties in understanding figurative meanings (Kircher et al., 2007; Kuperberg and Caplan, 2003; Kuperberg et al., 1998; Polimeni et al., 2010; Rapp et al., 2013). Our previous results are in line with the above, since in a group of people with schizophrenia who were assessed with the Right Hemisphere Language Battery (RHLB, Bryan, 1995; RHLB-PL, Łojek, 2007) we observed a poorer performance of the humor subtest among others diminished specific communication skills, i.e. metaphors (Adamczyk et al., 2016). In the RHLB humor test, consisting of matching one of three available endings to stories in order to create jokes, people with schizophrenia made more mistakes than healthy controls by choosing mainly neutral or sometimes absurd endings. This may suggest that people with schizophrenia exhibit problems primarily with understanding figurative meanings and/or semantic reorganization of funny endings.

Humor seems to involve certain cognitive mechanisms involving set shifting, unexpected stimuli and social assessments. In humor research various forms of stimuli such as cartoons, short films or funny stories, i.e. jokes, were used (for an extended review see: Vrticka et al., 2013). In theory, a joke is complex linguistic material and its humorous nature is manifested by surprising endings. Comprehension of a joke elicits an emotional response of amusement. Theoretically, this response results from a correct reinterpretation of the story in agreement with the surprising ending. In other words, to comprehend a joke one needs to successfully resolve the surprising incongruity of the punchline and the remaining content of the joke (Suls, 1972; Wyer and Collins, 1992). The process of ‘getting a joke’ can be therefore divided into two major phases: comprehension and elaboration. In the comprehension phase a person detects the surprising incongruity of the punchline with the previous content of the story (setup) and then restores the coherence by a reinterpretation of the story. In the elaboration phase the implications resulting from this reinterpretation cause the emotional response of amusement (Wyer and Collins, 1992). In a revised model of neuronal networks involved in verbal joke processing, developed by Chan et al. (2013) based on the theoretical approach by Suls (1972), Wyer and Collins (1992) and previous neuroimaging studies (i.e. Bartolo et al., 2006; Bekinschtein et al., 2011; Chan et al., 2012; Chou et al., 2009; Goel and Dolan, 2001, 2007; Mobbs et al., 2003; Moran et al., 2004; Samson et al., 2008, 2009; Wild et al., 2003), emphasis was placed on a clear division of the two separate steps of the comprehension phase between incongruity detection and incongruity resolution. Finally, this hypothetical three-step model of the ‘getting a joke’ process consists of incongruity detection, incongruity resolution and elaboration, which evoke amusement. In a novel procedure implemented by the authors of this paper, subjects were presented with one of three possible endings to garden-path designed stories they have read: unfunny, nonsensical or funny. This made it possible to investigate separate processes in humor comprehension: the incongruity detection and resolution stages. Thus, this three-step model of humor comprehension may be considered a hypothetical model for studying verbal humor processing with fMRI. However, considering complex nature of humor as a specific psychobiological phenomenon (Veatch, 1998) and considering pioneering nature of neuroimaging studies on humor, it should be recognized, that this theoretical approach is still highly speculative and there is a lack of a fully acceptable model of humor processing. On the other hand, the theoretical approach of Suls (1972) and Wyer and Collins (1992) is commonly used across humor fMRI study design (see Vrticka et al., 2013).

Data from healthy controls indicates that humor processing involves neural network connections including frontal, temporal and parietal region activation as a response to the cognitive component of humor processing. In particular, neuroimaging studies by Chan et al. (2013) showed activation in the middle temporal gyrus (MTG) and medial frontal gyrus (MFG) of the right hemisphere during incongruity detection. Other research indicated engagement of the right temporal cortices in the processing of surprising, unexpected or less probable word meanings and its integration within semantic context (Federmeier and Kutas, 1999; Goel and Dolan, 2001; St George et al., 1999). Incongruity resolution activates the left hemisphere and includes the dorsomedial MFG and Superior Frontal Gyrus (SFG), temporoparietal junction (TPJ) and precuneus (Bartolo et al., 2006; Chan et al., 2013; Marjoram et al., 2006; Samson et al., 2008, 2009). Successful comprehension of jokes is related to TPJ activation, which is greater if the humor content is related to ToM processing (Bartolo et al., 2006; Campbell et al., 2015; Goel and Dolan, 2001; Kohn et al., 2011; Mobbs et al., 2003; Samson et al., 2008; Wild et al., 2003). This region is also activated during the detection and processing of unexpected stimuli, such as the process of incongruity detection and resolution (Neely et al., 2012; Vrticka et al., 2013). Other studies revealed activation of the SFG in relation to humor appreciation (Campbell et al., 2015). Neural correlates of the emotional component (e.g. feeling of amusement/mirth) were found in the orbitofrontal/ventromedial prefrontal cortex (PFC), ventral anterior cingulate cortex (ACC), insula, amygdala and parahippocampal gyri (Bartolo et al., 2006; Chan et al., 2012; Franklin and Adams, 2011; Goel and Dolan, 2001; Mobbs et al., 2003; Samson et al., 2008, 2009; Wild et al., 2003, 2006). Activation of the caudate nuclei correlates with enjoyable successful processing of jokes (Franklin and Adams, 2011; Mobbs et al., 2005). Lastly, cerebellum is also engaged in humor perception and appreciation and in laughter (Bartolo et al., 2006; Frank et al., 2012, 2013; Franklin and Adams, 2011; Goel and Dolan, 2007; Wild et al., 2003). It should be noted that activated regions differ across different studies, which may be due to differences in procedures implemented (for an extended review see Vrticka et al., 2013).

Although analysis of current literature data unequivocally indicates the presence of communication deficits in schizophrenia, the neural basis of the observed impairments of humor as an important figurative aspect of language is not sufficiently studied. To the best of our