ARTICLE IN PRESS

Schizophrenia Research xxx (xxxx) xxx

Contents lists available at ScienceDirect

Schizophrenia Research

journal homepage: www.elsevier.com/locate/schres

Happy thoughts: What computational assessment of connectedness and emotional words can inform about early stages of psychosis

Natália Bezerra Mota [a,b,*], Marina Ribeiro [b], Bárbara Luzia Covatti Malcorra [b], João Paulo Atídio [c], Bernardo Haguiara [c], Ary Gadelha [c]

[a] Department of Psychiatry and Legal Medicine, Federal University of Rio de Janeiro (UFRJ), Rio de Janeiro, Brazil
[b] Research department at Motrix Lab, Motrix, Rio de Janeiro, Brazil
[c] Schizophrenia Program (PROESQ), Department of Psychiatry, Escola Paulista de Medicina, Universidade Federal de São Paulo (EPM/UNIFESP), Brazil

ARTICLE INFO

Keywords:
First-episode psychosis
Education
Negative symptoms
Formal thought disorder
Natural language processing
Computational psychiatry

ABSTRACT

In recent years, different natural language processing tools measured aspects related to narratives' structural, semantic, and emotional content. However, there is a need to better understand the limitations and effectiveness of speech elicitation protocols. The graph-theoretical analysis applied to short narratives reveals lower connectedness associated with negative symptoms even in the early stages of psychosis, but emotional topics seem more informative than others. We investigate the interaction between connectedness and emotional words with negative symptoms and educational level in participants with and without psychosis. For that purpose, we used a speech elicitation protocol based on three positive affective pictures and calculated the proportion of emotional words and connectedness measures in the first-episode psychosis (FEP) group (N: 24) and a control group (N: 33). First, we replicated the association between connectedness and negative symptoms (R^2: 0.53, p: 0.0049). Second, the more positive terms, the more connected the narrative was, exclusively under psychosis and in association with education, pointing to an interaction between symptoms and formal education. Negative symptoms were independently associated with connectedness, but not with emotional words, although the associations with education were mutually dependent. Together, education and symptoms explained almost 70 % of connectedness variance (R^2: 0.67, $p < 0.0001$), but not emotional expression. At this initial stage of psychosis, education seems to play an important role, diminishing the impact of negative symptoms on the narrative connectedness. Negative symptoms in FEP impact narrative connectedness in association with emotional expression, revealing aspects of social cognition through a short and innocuous protocol.

1. Introduction

Does it matter how we feel about telling a story? We communicate our feelings, ideas, and interpretations of the environment through language. Capturing this expression in a structural conversation in a therapeutic setting gives crucial information for mental health professionals since the initial descriptions of psychiatric disorders. Since the original description of psychosis from Kraepelin, there has been the assumption of thought disturbances present in different manifestations of psychosis (Holzman et al., 1986). Bleuler pointed out the variety of thought disorder manifestations in schizophrenia as a core phenomenon, and multiple efforts were done to use language output to get this phenomenological core (Andreasen, 1986; Johnston et al., 1986; Liddle et al., 2002). After the deinstitutionalization movements and the adoption of community-based and recovery-oriented services, the assessment of social functioning is vital in the case of psychosis (Bowie et al., 2011). The opportunity to identify aspects of social cognition linked to cognitive and/or emotional expression through narrative can help us understand the complex impairment experienced in the social life of those under psychosis, especially during the initial stages of the disorder (Green et al., 2015).

Recently phenomenological investigations on formal thought disorders linked to psychosis have gained insights with the use of natural language processing tools (Bedi et al., 2015; Corcoran and Cecchi, 2020; Elvevåg et al., 2007; Hitczenko et al., 2021; Mota et al., 2012, 2014; Rezaii et al., 2019). Those computational approaches allow for higher precision to evaluate these language markers that were previously only described by trained professionals. An example is the use of graph

* Corresponding author at: Instituto de Psiquiatria UFRJ, Av. Venceslau Brás, 71 – Botafogo, Rio de Janeiro, RJ 22290-140, Brazil.
E-mail address: nataliamota@neuro.ufrn.br (N.B. Mota).

https://doi.org/10.1016/j.schres.2022.06.025
Received 29 March 2022; Received in revised form 17 June 2022; Accepted 22 June 2022

representation of word trajectories to measure structural aspects of narratives (Morgan et al., 2021; Mota et al., 2012, 2014, 2017; Palaniyappan et al., 2019; Spencer et al., 2021). The strategy was inspired by the description of symptoms like a derailment or fragmented speech, which careens the notion of an expected word trajectory that is aberrant in individuals who experience psychotic symptoms. By representing each word in a narrative as a node and the spontaneous sequence by directed edges, it is possible to calculate connectedness measures (which reveals how the narrative links all the different words on a single connected component, linking the beginning to the end). Indeed, those participants that also had a schizophrenia diagnosis produced low connected narratives in chronic (Mota et al., 2012, 2014) and initial stages of psychosis (Morgan et al., 2021; Mota et al., 2017; Spencer et al., 2021), even in different languages (Morgan et al., 2021; Palaniyappan et al., 2019; Spencer et al., 2021). In addition, connectedness significantly correlated with negative symptoms (Mota et al., 2014, 2017) and cognitive performance (Palaniyappan et al., 2019). The same aspects that change with cognitive decline increase in typical cognitive development, including the development of social cognitive basis such as the theory of mind abilities (Mota et al., 2016). The better the performance on IQ, theory of mind, reading acquisition (Mota et al., 2016), and verbal memory (Mota et al., 2020), the more connected the children's narratives are while telling a story based on a picture. Furthermore, educational level was the most important factor to explain the connectedness's variability in typical development, showing a slow dynamic that seems to change when a child starts to read and matures at the end of high school (Mota et al., 2018). Importantly, this effect of formal education on narratives was not observed in a psychotic sample, which suggests that psychotic symptoms could interact and play an important role in connectedness's variability (Mota et al., 2018).

Advances in language analysis and how to translate psychophenomenology into precise metrics have been developed, but the literature diverges in terms of speech elicitation protocols (Mota, 2021). Those advances have application purposes for the clinics, but there is a need to better understand the limitations and potentialities of each method, and to gain insight into basic knowledge on how those markers are associated with symptomatology, or environmental aspects that impact language (Stokes, 1997). Focusing on structural analysis based on graph theory, the narrative topic changes the associations between connectedness and symptomatology (Mota et al., 2014, 2017). Dream reports connectedness is negatively correlated with negative symptoms severity measured by PANSS negative subscale, but not in daily reports connectedness (Mota et al., 2014). Participants without a schizophrenia diagnosis produced more connected dream narratives compared to daily narratives, which did not happen in the schizophrenia group (that kept the same low connected narrative to report a dream or a daily event) (Mota et al., 2014). Contrasting narrative topics in terms of emotional load (positive/negative x neutral) or memory duration (short x long-term memories), emotional information on the narrative topic seems to contribute more to discriminating groups during the first-episode psychosis (Mota et al., 2017). In the emotional context, the participants created stories based on affective pictures with extreme positive, negative or neutral valence (pictures extract from the International Affective Pictures Database (IAPS) database (Lang et al., 1993)); the discriminative results were also accessed by narratives from short and long-term autobiographical memories (such as the report from the previous day and the oldest memory the participant could recall at the moment). Using narrative connectedness to classify the groups, the dream reports were the most informative topic, followed by negative and positive picture reports (Mota et al., 2017). Still, for application purposes, it seems that emotional reports discriminate between the groups, being the negative image report more informative than the positive image narratives (Mota et al., 2017). The side effects of negative image exposure could be an important limitation for large-scale application in clinical settings. Could a positive image speech elicitation protocol replicate the same associations with symptomatology? If so, what is the relationship between emotional expression and connectedness in the same narratives from individuals during a first-episode psychosis (FEP) or without psychosis? To conclude, what are the interactions between those language markers and symptomatology or educational level? We hypothesize that 1. A speech elicitation protocol based on positive affective images would be able to generate connectedness measures that are associated with negative symptoms at the first-episode psychosis; 2. There would be different associations between emotional expression and connectedness in participants with and without psychosis exclusively with the stimulus's congruent emotion (positive), but not with the incongruent emotion (negative); and 3. Negative symptoms and educational level would interact with both connectedness and emotional expression differently in participants with and without psychosis.

2. Methods

2.1. Participants

This study was approved by the Ethical Committee in UFRN (permit #742–116, and #3.613.186) and in UNIFESP (permit # 4.410.579). Participants from the FEP group ($N = 24$) were recruited at clinical settings during regular clinical appointments in their usual clinics (CAPS-Infantil in Natal, Brazil, or Proesq in São Paulo, Brazil). The protocol was explained, and informed consent was given by the participant and by a legal representative. Participants from the Control group ($N = 33$) were recruited at the university community by convenience, and they also gave informed consent. As inclusion criteria for the FEP group, the individuals were seeking treatment for psychotic symptoms for the first time (maximum duration of two years informed by the participant and legal representative), with diagnosis established according to diagnostic criteria of the Diagnostic and Statistical Manual of Mental Disorders (DSM V). As exclusion criteria for both groups, the participants should not present neurological symptoms or drug-related disorders. For the control group, an additional exclusion criterion was to not have psychiatric diagnoses or treatment for mental health issues.

2.2. Speech elicitation protocol (Fig. 1)

All the participants answered a socioeconomic questionnaire. For those in the FEP group, clinical questions were also answered. After that, the participants were presented with three images of positive affective content (a baby, a dog, and a dessert), chosen from the IAPS database (Lang et al., 1993), on a computer screen. They were instructed to pay attention to each of the images for 15 s and then report a story based on the picture (one for each image). To ensure a minimal number of words to perform the analysis, each narrative had at least 30 s (Mota et al., 2017). If the participant did not reach the minimum time, there was a request to keep talking with general stimuli such as “could you talk more about it?”. The interviewer explained this procedure previously to the participant. Part of the FEP sample ($N = 18$) also repeated the same protocol after the exposure of three negative images (a plane crash scene, a set of human bones in decomposition, a sick and skinny man in a hospital bed) and three neutral images (a truck, an umbrella, a boy showing a neutral facial expression), and those reports were used as controls for the analysis investigating the association between emotional expression and connectedness. The multilinear correlations using negative image reports were already described for this sample in a previous study (Mota et al., 2017).

Participants from the FEP group were evaluated psychiatrically using the psychometric scale PANSS (Kay et al., 1987) composed of three subscales (positive, negative, and neutral). For analysis purposes, the present study focuses on the PANSS negative subscale.

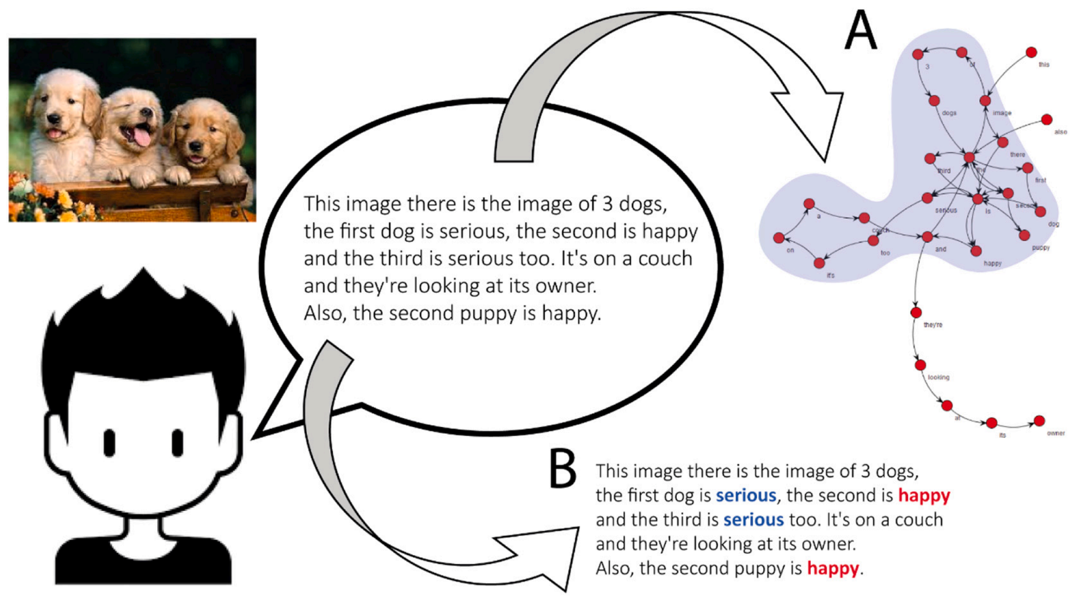

Fig. 1. Speech elicitation protocol and analysis. The participants were instructed to observe an image for 15 s and they were requested to narrate a story based on that image for at least 30 s without seeing the image. The interview was recorded and transcribed and the text was analyzed. A) Graph analysis: each word is represented as a node and the spontaneous sequence of words is represented by directed edges. Connectedness is assessed by the number of nodes on the largest connected component (for this example, LCC = 17), in the largest strongly connected component (LSC = 20), and the comparison of both metrics with a distribution of 1000 thousand random graphs designed with the same words in a shuffled order (LCCz = 1.37, and LSCz = 3.52). B) Emotional analysis: positive (in red) and negative (in blue) emotional words are identified after comparing them to a standard dictionary. The proportion of positive and negative emotional words is calculated considering the number of words in the narrative (for this example, Positive emotions = 5 %, and Negative emotions = 5 %). Further details in Methods. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.3. Natural language analysis (Fig. 1)

The narratives were recorded and fully transcribed. After that, two different computational language analyses were performed: first, the structural analysis using Speech Graphs software (Mota et al., 2014); second, the proportion of words using Linguistic Inquiry and Word Count (LIWC) (Pennebaker et al., 1999) with the Brazilian Portuguese Dictionary (Filho et al., 2013), both explained below.

2.3.1. Graph analysis (connectedness) (Fig. 1A)

Each word of the narrative was represented as a node, and the sequence between the words was represented by directed edges using the Speech Graphs software (Mota et al., 2014). From this, the total number of nodes in the most connected component (LCC) and the number of nodes in the most strongly connected component (LSC) were quantified. The LCC is defined as the largest graph component where each pair of nodes is linked somehow, and LSC is defined as the largest graph component where each pair of nodes is linked and mutually reachable (Mota et al., 2014). Then, each graph was compared to 1000 random graphs generated with the same set of words and edges. The LCC and LSC z-scores between each original graph attribute (LCC or LSC) and the corresponding random graph distribution were calculated, composing measures of similarity with random connectivity (LCCz and LSCz) (Mota et al., 2017). For further details, please reference (Mota et al., 2014) and (Mota et al., 2017).

To control for verbosity differences and ensure a minimum number of words to perform the analysis, we concatenated the three narratives and applied a moving windows analysis (Mota et al., 2014). We considered windows with a length of 30 words with a 3-word gap, which means that for the first 30 words we generated a graph, then jumped three words to again count 30 words and thus generate the next graph, and so on. The average graph attributes of all 30-word graphs for each oral narrative were calculated and used for statistical analysis. Although we controlled verbosity, graph attributes such as LCC and LSC have a close relationship with the number of nodes (here, different words, a proxy for lexical diversity, in a set of 30 words(Mota et al., 2018)). We verified the relationship between all graph attributes and their composites with Nodes (the number of nodes in the graph). To differentiate the contributions of connectedness independent from lexical diversity for those attributes with a close relationship with Nodes, we added Nodes as a confounding factor.

2.3.2. Emotional analysis (Fig. 1B)

The LIWC is software used to extract and analyze emotional, cognitive, and structural components present in speech (Pennebaker et al., 2007). The software searches for a specific class of words defined by pre-established dictionaries already validated for the language. In the current study, it was used to quantify the proportion of words with positive and negative emotional contexts using the Brazilian Portuguese Dictionary (Balage Filho et al., 2013).

2.4. Statistical analysis

Statistical analyses were performed using Matlab software.

2.4.1. Validation of speech elicitation protocol

To replicate the validity of the speech elicitation protocol based on positive affective pictures, we performed a multilinear correlation considering all the four connectedness attributes (LCC, LSC, LCCz, LSCz) versus the total score on PANSS negative subscale. First, we verified if the data presented collinearity between the four attributes (condition index should be smaller than 10). Next, if the correlation was significant, we defined a disorganization index (DI) considering the coefficients for each connectedness attribute. Then, to verify the discriminative performance of this protocol, we used all the connectedness attributes or exclusively the DI as input to a Naïve Bayes classifier with cross-validation (10-fold) implemented with Weka software. We considered discriminative if the area under the ROC curve was higher than 0.75 (Mota et al., 2017).

2.4.2. Association between connectedness and emotional analysis

Spearman correlations were used to investigate the association between each connectedness attribute (LCC, LSC, LCCz, LSCz) and the proportion of positive and negative emotional words in the FEP and control groups participants' narrative, with and without adjustment for years of education or the severity of negative symptoms measured by PANSS. For these analyses, the significance level was corrected by using the Bonferroni test for 8 comparisons ($\alpha = 0.0063$). As a control, we performed the same analysis using negative and neutral image reports collected from a small part of the FEP group.

2.4.3. Interaction between connectedness and emotional analysis and symptomatology and education

To evaluate the interactions between language markers and factors such as negative symptoms and education in the FEP group, we conducted two levels of correlation analysis. We considered the DI and the proportion of positive emotional words in the narrative as language markers.

First, we considered both language markers in interaction with negative symptoms, and with education separately. For that, we conducted a pair of Spearman correlations with and without adjustment for the third factor. Then, we considered both factors (negative symptoms and education) as predictors of an isolated language marker (positive emotional expression or disorganization index). For that purpose, we used a multilinear correlation.

3. Results

Demographic and clinical data from FEP and Control groups are presented in Table 1. There were important demographic differences between the groups. Participants from the FEP group had a higher proportion of men (62 % versus 36 % respectively), fewer years of age (18 versus 28 mean years old), and education (8 versus 15 years of formal education). These differences jeopardize direct comparisons between groups, so we followed the investigations inside each group.

3.1. Validation of speech elicitation protocol

To verify if the speech elicitation protocol based on positive affective pictures narratives would be able to reproduce the association with negative symptoms measured by the PANSS negative subscale, we performed a multilinear correlation between the four connectedness attributes and the total score of the PANSS negative subscale. Collinearity between connectedness attributes was controlled (condition index of LCC: 1; LSC: 1.36; LCCz: 2.82, LSCz: 8.65). The association between negative symptoms and connectedness was replicated ($R^2 = 0.53$, $p = 0.0049$, Fig. 2), with connectedness explaining 53 % of PANSS negative variance. This allows for the definition of a disorganization index (we weighted each connectedness attribute by the correlation coefficient with negative symptoms):

$$DI = 36.86 + LCC^{*}(-0.87) + LSC^{*}(-0.04) + LCCz^{*}(-0.01) + LSCz^{*}(1.21)$$

Years of education and total score on the PANSS negative subscale were not correlated (Rho $= -0.26$, $p = 0.2159$). The correlation between DI and negative symptoms kept the significance after adjusting for years of education (Rho $= 0.54$, $p = 0.0072$).

Using the four connectedness attributes as input to a machine learning algorithm (Naïve Bayes classifier), connectedness discriminates FEP from the Control group with AUC = 0.803. Using DI as input, we obtained AUC = 0.78. Although discriminative, it is important to point out the limitation of comparing both groups as mentioned before.

To verify the stability of the speech markers as psychosis progress at this initial stage, we performed additional Spearman correlations between speech markers (positive emotions, and connectedness attributes isolated or combined in the DI) and disorder duration (measured in days after psychosis onset). Neither positive emotions, nor connectedness attributes were associated with disorder duration (Psychosis onset x Positive emotions, DI, LCC, LSC, LCCz, and LSCz: Rho −0.23, 0.12, −0.03, −0.19, −0.16, 0.31, respectively; all p values were higher than 0.2), which seems to indicate a stability of those measures at this initial stage.

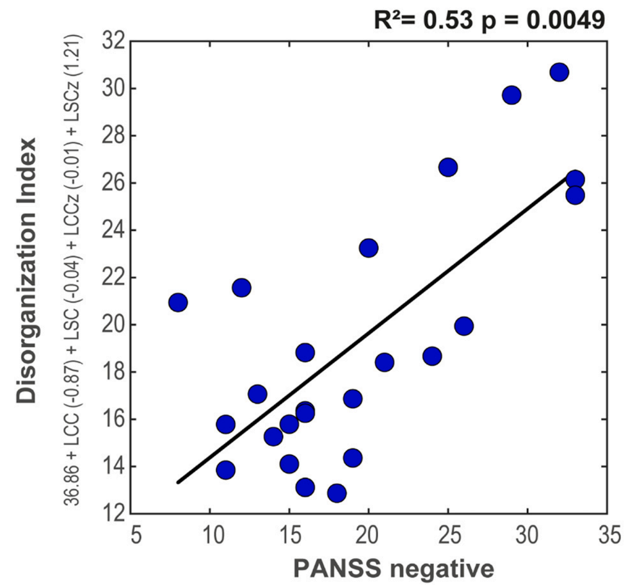

Fig. 2. Validation of speech elicitation protocol based on positive affective pictures. Multilinear correlation between connectedness attributes and total PANSS negative subscale. R square and p-value are indicated in the title. The sum of constant and connectedness attributes weighted by the correlation coefficients define the Disorganization Index (DI = 36.86 + LCC * (−0.87) + LSC * (−0.04) + LCCz * (−0.01) + LSCz * (1.21)).

3.2. Association between connectedness and emotional analysis

As both groups presented demographic and clinical differences, we conducted Spearman's correlations analysis between connectedness attributes and the proportion of positive and negative emotional words in each group, controlling for multiple comparisons (Bonferroni correction for 8 comparisons). The proportion of positive emotional words positively correlated with LCC and LSC exclusively in the FEP group (Fig. 3A, Table 2). Neither connectedness attributes correlated with negative emotional words in both groups (Fig. 3A, B, Table 2), nor with any

Table 1
Demographic and clinical information on FEP and Control groups. The proportion of gender distribution (% of males) is indicated, as well as the mean and standard deviation (SD) of Age (years old), Education (years of education), Chlorpromazine equivalent dose in use (mg/day), Disease duration (days) and PANSS negative subscale (points).

Group	Gender	Age		Education		AP equivalent dose		Disease duration		PANSS Negative subscale	
	(% male)	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
FEP (N = 24)	62.50 %	18.33	7.35	7.92	4.02	123.11	119.80	336.61	292.94	19.25	7.23
Control (N = 33)	36.36 %	27.91	8.57	15.00	3.35	…	…	…	…	…	…

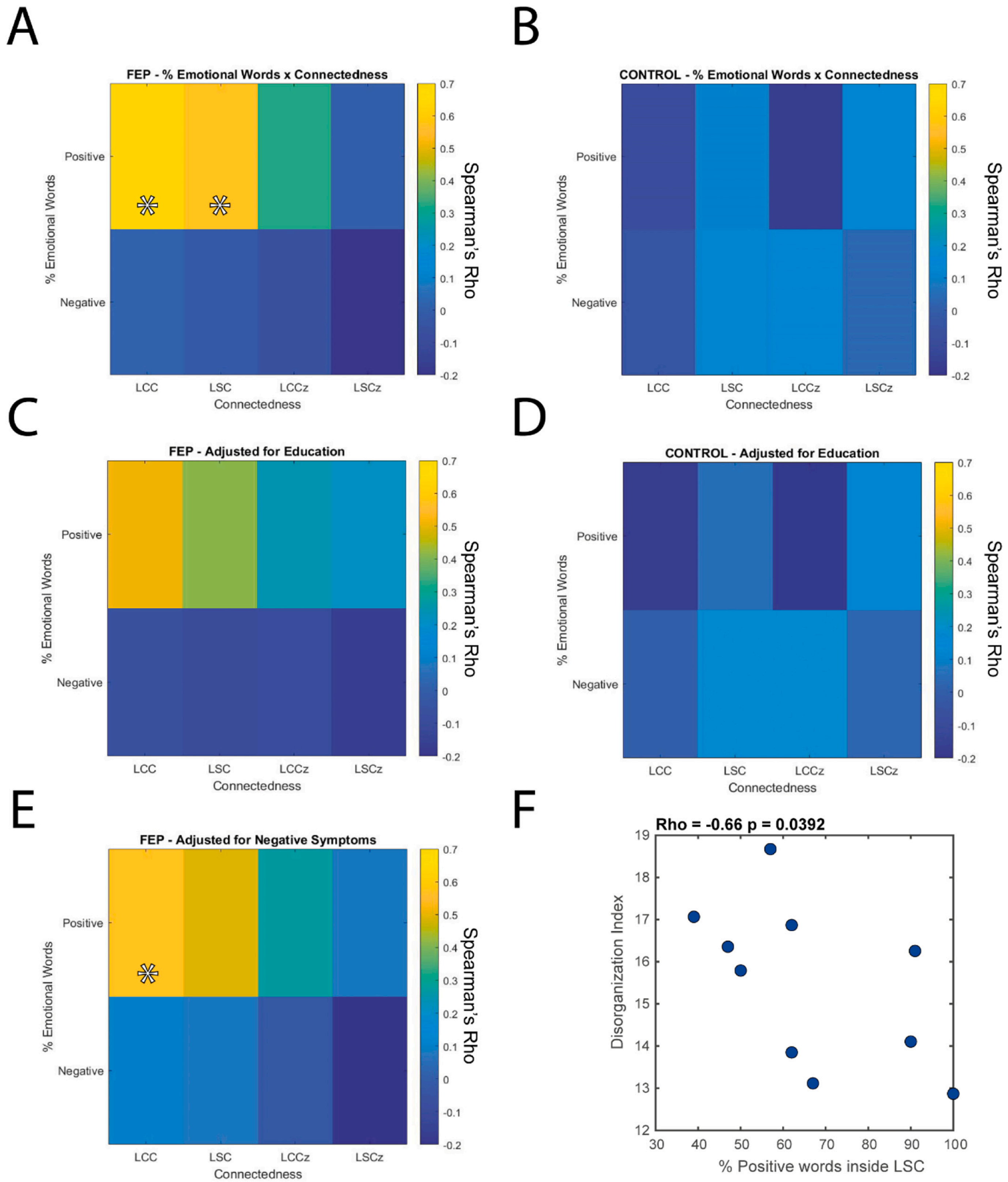

Fig. 3. Spearman correlation between each connectedness attribute and the proportion of positive and negative emotional words in the narratives. Spearman's Rho mapped on the colormap, and significant correlations are indicated in white * (after Bonferroni correction for 8 comparisons, $p < 0.0063$). A) Correlation in FEP group; B) Correlations in Control group; C) Adjusted correlations for years of education (FEP group); D) Adjusted correlations for years of education (Control group) and E) Adjusted correlations for total score PANSS negative subscale (FEP group). F) Scatter plot showing a Spearman correlation between the proportion of positive words inside the LSC and DI (disorganization index). Rho and p values at the title. Statistical results from subplots A to E are presented in Table 2.

Table 2
Statistical results of Spearman's correlation between connectedness attributes and proportion of negative and positive emotional words in the narrative for FEP and Control groups, with and without adjustment for years of education.

Emotions	LCC		LSC		LCCz		LSCz		LCC		LSC		LCCz		LSCz	
	Rho	p	Rho	p	Rho	p	Rho	p	Rho	p	Rho	p	Rho	p	Rho	p
	FEP - Spearman Correlation								Control - Spearman Correlation							
Positive	0.63	0.0009	0.57	0.0035	0.33	0.1204	0.00	0.9820	−0.09	0.6106	0.11	0.5355	−0.17	0.3505	0.14	0.4532
Negative	0.02	0.9307	−0.01	0.9579	−0.05	0.8013	−0.19	0.3650	−0.04	0.8105	0.13	0.4824	0.16	0.3621	0.04	0.8324
	FEP - Spearman (adjusted for education)								Control - Spearman (adjusted for education)							
Positive	0.51	0.0136	0.41	0.0492	0.24	0.2636	0.21	0.3264	−0.17	0.3383	0.06	0.7637	−0.19	0.3058	0.15	0.4007
Negative	−0.06	0.7999	−0.10	0.6565	−0.09	0.6945	−0.16	0.4557	0.01	0.9732	0.18	0.3251	0.18	0.3333	0.03	0.8795
	FEP - Spearman (adjusted for negative symptoms)															
Positive	0.57	0.0045	0.49	0.0174	0.27	0.2155	0.07	0.7356								
Negative	0.10	0.6502	0.07	0.7547	−0.03	0.9036	−0.22	0.3094								
	FEP - Spearman Correlation (Negative stimuli)								Control - Spearman Correlation (Neutral stimuli)							
Positive	0.01	0.9578	0.03	0.9059	0.30	0.2238	−0.09	0.7259	0.40	0.1297	0.40	0.1205	0.10	0.7117	0.17	0.5409
Negative	0.21	0.3989	0.27	0.2859	−0.07	0.7912	0.19	0.4425	0.13	0.6225	0.35	0.1904	0.36	0.1727	−0.05	0.8659

emotional word in the Control group (Fig. 3B, Table 2). Also, there was no significant correlation between connectedness and emotional expression using negative or neutral image reports (Table 2).

To verify the effect of education or negative symptomatology on the association between emotional expression and connectedness, we performed a partial Spearman's correlation adjusted for years of education or the total score of the PANSS negative subscale. For the FEP group, the correlations of the proportion of positive emotional words with LCC and LSC lost significance after being adjusted for years of education (Fig. 3C, Table 2), suggesting an important role of education in these associations, with no effects on the Control group (Fig. 3D, Table 2). The adjustment for negative symptoms revealed a smaller effect, losing the significance of the association between LSC and positive emotional expression, but keeping the significant association between LCC and positive emotional words (Fig. 3E, Table 2).

As there was a positive association between LCC and LSC in the FEP group, we calculated how many nodes representing positive emotions participated in the set of nodes inside the LCC and LSC. We isolated the set of nodes (words) inside the LCC and the LSC and estimated how many positive emotional words fall inside both. Then, we calculated the proportion of emotional words inside each component considering the number of positive words in the narrative. A major part of positive emotional words fit inside the LCC (on average, 75 % ± 20 %, maximum of 100 % and a minimum of 39 %) and LSC (on average, 66 % ± 21 %, maximum of 100 % and a minimum of 39 %). Also, the more positive emotions inside the LSC, the "more organized" was the narrative, and the smaller the DI (Rho $= -0.66$, $p = 0.0392$, Fig. 3F). There was no association between positive emotions inside the LCC and the DI (Rho $= -0.22$, $p = 0.5436$).

3.3. Interaction between connectedness and emotional analysis and symptomatology and education

As we found a complex interaction between connectedness and emotional expression in the FEP group (exclusively with the stimulus congruent emotion, or the positive valence) with a complex interaction with negative symptoms and education, we investigated the mediation effects of negative symptoms or years of education in the association between positive emotion expression and the disorganization index separately (Fig. 4A and B, Table 3).

We verified that the association between DI and negative symptoms kept the significance after adjusting for emotional expression, suggesting independence of this association with emotional expression. There was no direct association between emotional expression and symptomatology. The negative association between DI and positive emotional expression lost significance after adjusting for negative symptoms severity. These results suggest a direct, independent, and strong association of DI, with negative symptoms, and an indirect mediation of negative symptoms in the association between DI and emotional expression (Fig. 4A, Table 3).

On the other hand, we verified a negative association between educational level and DI. This association lost significance after adjusting for emotional expression. Also, the more years of education, the more emotional expression (the association lost significance after adjusting for DI). In addition, the already reported association between DI and emotional expression lost significance after adjusting for years of education. These results suggest an interdependent association between education, emotional expression, and DI based on connectedness (Fig. 4B, Table 3).

For the analysis of the effect of both factors (education and negative symptoms) in each language marker (DI and emotional expression), we performed multilinear correlations of education and symptomatology with DI or the proportion of positive emotional words. There was a significant correlation with DI ($R^2 = 0.67$, $p < 0.0001$, Fig. 4C). Both education and symptomatology explained 67 % of DI variance, with educational level presenting a slightly larger coefficient (−0.53)

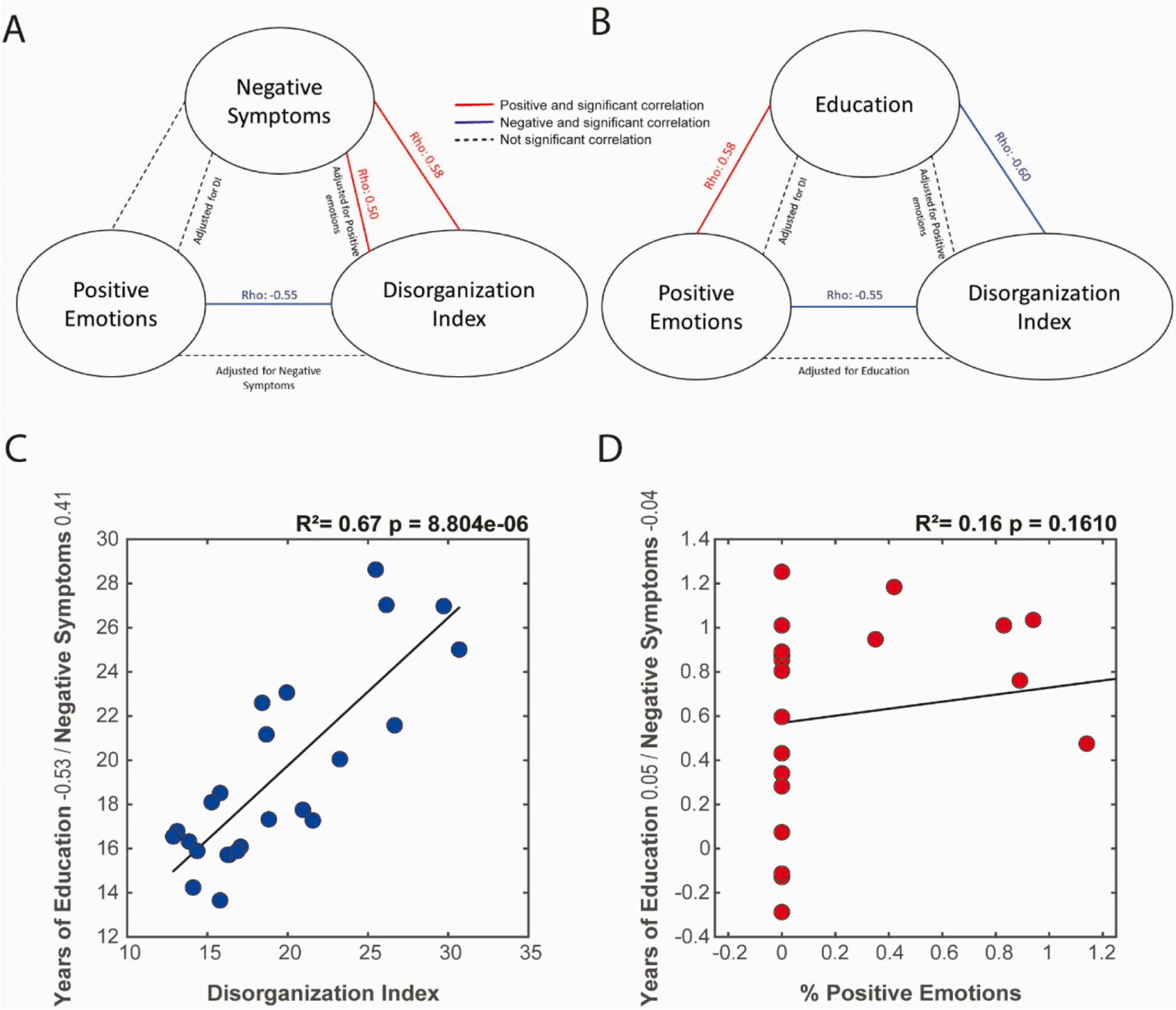

Fig. 4. Interactions between connectedness and emotional expression with negative symptoms and years of education in the FEP group. Significant correlations (considering both factors, education and negative symptoms, with a Bonferroni correction for multiple comparisons, $p < 0.0250$) A) Spearman's correlation between disorganization index and proportion of positive emotional words with PANSS negative subscale. Each pair of correlations was adjusted by the third factor as indicated. Significant correlations (Bonferroni corrected for multiple comparisons, $p < 0.0250$) are indicated by the full line in red (for positive Rho) and blue (for negative Rho). No significant correlations are indicated by a dashed line. Detailed Rho and *p*-values are displayed in Table 3. B) Spearman's correlation between disorganization index and proportion of positive emotional words with PANSS negative subscale. Each pair of correlations was adjusted by the third factor as indicated. Significant correlations are indicated by the full line in red (for positive Rho) and blue (for negative Rho). No significant correlations are indicated by a dashed line. Detailed Rho and p-values are displayed in Table 3. C) Multilinear correlation between years of education plus PANSS negative subscale with disorganization index. Coefficients are indicated in the y label; R square and p-value are indicated in the title. D) Multilinear correlation between years of education plus PANSS negative subscale with the proportion of positive emotional words. Coefficients are indicated in the y label; R square and p-value are indicated in the title. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

compared to negative symptoms (0.41), with coefficients in opposite direction (the fewer years of education combined with more severe negative symptoms, the more disorganized the narrative) (Fig. 4C, Table 3). There was no correlation between both factors (education and negative symptoms) and emotional expression (Fig. 4D, Table 3).

3.4. Understanding the contribution of lexical diversity (Nodes) to connectedness

The DI has a major contribution to LCC (coefficient: −0.87), a graph attribute closely associated with Nodes in graph theory. As Nodes mean different words in a word graph, this factor could be interpreted as a proxy of lexical diversity (Mota et al., 2018). As lexical diversity increases, LCC increases mostly if different words are not added to completely separated components. This relationship is not so direct for LSC and is even less clear for the comparison with random graphs (LCCz and LSCz, also with an important contribution to the DI (coefficient: 1.21). To verify the contributions of lexical diversity to understand the relationship between the variation of each graph attribute, we conducted Spearman correlations with the DI and all the graph attributes, and adjustments to the correlations with negative symptoms and education.

Table 3
Statistical results of Spearman's correlation on the FEP group between disorganization index (DI) and proportion of positive emotional words (%Positive) with PANSS negative subscale (Symptoms) and with years of education (Education). Each pair of correlations was analyzed with and without adjustment for the third factor.

Language markers x	Not Adjusted		Adjusted		Adjusted for
Symptoms or education	Rho	p	Rho	p	
DI x Symptoms	0.58	0.0031	0.50	0.0155	%Positive
%Positive x Symptoms	−0.34	0.1055	−0.03	0.8999	DI
DI x %Positive	−0.55	0.0050	−0.47	0.0251	Symptoms
DI x Education	−0.60	0.0019	−0.46	0.0262	%Positive
%Positive x Education	0.47	0.0198	0.21	0.3371	DI
DI x %Positive	−0.55	0.0050	−0.38	0.0715	Education

There was an important association between DI and Nodes (Spearman correlation Rho = −0.75, $p < 0.0001$, Pearson correlation $R = -0.83$, $p < 0.0001$, $R^2 = 0.69$), which means that the more connected the narrative, the higher the lexical diversity, with Nodes explaining 69 % of the variance in DI. In isolation, the association with Nodes was stronger for LCC (Rho = 0.82, $p < 0.0001$), followed by LSC (Rho = 0.62, $p = 0.0011$), but LCCz and LSCz were not associated with Nodes (Rho = 0.09 and − 0.03, $p > 0.05$).

Although both connectedness and lexical diversity are strongly associated, there was no association between Nodes and negative symptoms (Rho = −0.33, $p = 0.1189$), and neither the association with DI nor symptoms lost significance after adjustment by Nodes (Rho = 0.53, $p = 0.0088$). On the other hand, Nodes were associated with the level of education (Rho = 0.59, $p = 0.0024$), and the correlation between DI and education lost significance after adjustment by Nodes (Rho = −0.29, $p = 0.1734$).

4. Discussion

The speech elicitation protocol based on positive affective pictures replicated the association between connectedness and negative symptoms. The more severe the negative symptoms, the less connected were the narratives. Furthermore, connectedness explained more than half of negative symptomatology variance (53 %). This agrees with previous work that shows a higher discriminative performance of emotional reports such as dreams or stories based on negative pictures (Mota et al., 2014, 2017). Although it did not reach the discriminative levels of dreams and negative image reports (accuracy levels higher than 90 %) (Mota et al., 2014, 2017), it adds an important application benefit as it does not expose the patient to images that could cause psychological discomfort or do not require the patient to recall a dream. Importantly to mention, at this initial stage, none of the speech markers considered were associated with the duration of psychotic symptoms, which seems to indicate stability at this stage, but only longitudinal studies with repetitive assessments should be conclusive.

As predicted, we verified that connectedness was associated with positive emotional expression (congruent to the stimulus), but not with negative emotional expression. Also, a major part of emotional words were nodes inside the LCC and LSC, and the more positive emotional nodes inside the LSC, the smaller the DI (or the more "organized" was the narrative). This suggests a link between narrative connectedness and social cognition in FEP (as the participant should recognize this emotional information in the stimulus and create a narrative that expresses it, linking emotion recognition/expression and cognitive abilities to infer people's thoughts (Green et al., 2015))). Connectedness in storytelling narratives was also positively correlated with the theory of mind performance in typical children in a school setting (Mota et al., 2016). This was not true when using reports from negative and neutral images, which suggests that negative valence stimuli have different effects on language and thoughts compared to positive stimuli. To recognize positive emotions in the stimuli and express them in a narrative could be more socially adaptative, but this could not be the case for negative emotions.

To deepen this comprehension, it is important to investigate the interaction between both language markers and negative symptomatology, in contrast to educational level. On one hand, connectedness is closely and independently linked to negative symptoms, keeping the significance even after adjustments for years of formal education or emotional expression. Positive emotional expression, on the other hand, does not directly associate with symptoms, only indirectly through connectedness. Together with the negative result in the Control group, we conclude that connectedness is associated with different factors, under different circumstances. Without psychosis, it varies according to the developmental phases (following a slow dynamic that seems to mature at the end of high school (Mota et al., 2018)). After that, this pattern stabilizes until regular cognitive decline which is expected in typical aging (Malcorra et al., 2021), an effect that could be mitigated by reading and writing habits (Malcorra et al., 2022). During adolescence or early adult life, social cognition that supports spontaneous emotional expression plays an important role, but the emergence of negative symptoms impacts this developmental trajectory, mediating an association between both aspects. Such a statement evidences the complex interplay of cognitive and emotional markers expressed in spontaneous narratives, being both aspects important to speech production, already evidenced in association with poor social functioning under schizotypy (Marggraf et al., 2019).

This complex interaction claims to a better understanding of formal education in this scenario. Although the associations between education and connectedness reveal an interdependent correlation with emotional expression, the effect size is slightly higher than in the correlation with symptoms, as the coefficient in the multilinear correlation is higher. Almost the same strength, but in opposite directions, education seems to diminish the effect of negative symptoms under the narrative connectedness. The interaction of both factors with emotional expression was not verified, which suggests that the impact of both factors on the disorganization index precedes the impact on emotional expression. Also, lexical diversity (linked to vocabulary and stimulated by formal education) was an important mediator for the association between DI and education, but not with negative symptoms. We interpreted that lexical diversity was an important factor in connectedness variance led by education, but there are other aspects of connectedness that explain the strong association with symptoms. Elucidate these mechanisms is helpful to plan interventions that could mitigate the effects of symptomatology on language (and social behavior mediated by language).

These results express how crucial formal education is to keep an emotionally rich and well-organized narrative during the first-episode psychosis. In contrast with previous data which failed to find an association between education and connectedness in psychosis (Mota et al., 2018), the developmental stage of the individual at this early stage of psychosis could constitute a different context to the cognition. It is possible that during earlier stages there is more opportunity to deal with these cognitive deficits, and formal education seems to allow for a richer social environmental context.

Although we had gained insights into cognitive interactions of symptoms and education under the narrative connectedness and emotional expression, the study presents limitations. The FEP and Control groups were not paired, which allows us to characterize associations in different contexts, but jeopardizes the direct comparison between the groups. Another important issue is the small sample of both groups, which impacts representativeness to generalize the results. The small sample size was especially a limitation for the analysis of negative and neutral stimuli, so larger studies comparing stimuli should be encouraged. Taking into consideration these limitations, it is important to design an inclusive and harmonized data collection in a representative sample, as well as investigate if it would be possible to replicate the results. Other measurements based not only on transcriptions but also on acoustic signals and facial expressions could help us understand communication in-depth. Initiatives such as Discourse in psychosis (discourseinpsychosis.org) could allow us the opportunity to keep this investigation, and to understand the developmental perspective under both typical and atypical contexts. Narratives could be analyzed by different computational strategies in clinics, with complementarities (Morgan et al., 2021), but before that, we need to understand how each measure is associated with psychopathological phenomena and the mechanisms behind those associations (Hitczenko et al., 2021).

5. Conclusion

The protocol is short (the application time lasts around 5 to 10 min) and efficient, tested in clinical settings. As the analysis is not based on linguistics corpora, neither relies on the semantic content, it is from the definition invariant to language (Corcoran, 2021). It reveals naturalistic aspects linked directly with negative symptoms in the early stages of psychosis, also with protective factors such as education. Although promising, it still needs to be tested on a large scale on the most inclusive basis possible (Hitczenko et al., 2021; Mota, 2021; Palaniyappan, 2021) to understand confounding factors associated with social and demographic characteristics. Considering community-based and recovery-oriented practices such as those adopted in Brazil (Mota et al., 2022), computational tools accessible for different realities aligned with short and non-invasive speech elicitation protocols can help us the more precise follow-up to track psychosocial rehabilitation (Bowie et al., 2011).

CRediT authorship contribution statement

Natália B. Mota: Conceptualization, Data collection in UFRN, Data analysis, Supervisions of data analysis, Writing-Original draft preparation, Writing- Reviewing and Editing **Marina Ribeiro:** Data analysis, Writing- Reviewing and Editing **Bárbara Luzia Covatti Malcorra:** Writing- Reviewing and Editing **João Paulo Atídio:** Data collection in UNIFESP **Bernardo Haguiara:** Data collection in UNIFESP **Ary Gadelha:** Supervisions of data collection in UNIFESP.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

Dr. Mota, Ribeiro and Malcorra works at the Motrix, an EdTech startup. Dr. Mota has been a consultant to Boehringer Ingelheim. Dr. Gadelha has been a consultant and/or advisor to or has received honoraria from Aché, Daiichi-Sankyo, Torrent, Bayer, Cristalia, Daiichi-Sankyo, and Janssen.

Acknowledgments

We acknowledge the CAPS-Infantil Natal in the name of all the mental health professionals that build the communitarian assistance network in Brazil and enable preventive actions for those in mental distress in our country.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.schres.2022.06.025.

References

Andreasen, N.C., 1986. Scale for the assessment of thought, language, and communication (TLC). Schizophr. Bull. 12, 473–482. https://doi.org/10.1093/schbul/12.3.473.

Balage Filho, P.P., Pardo, T., Aluísio, S., 2013. An evaluation of the Brazilian Portuguese LIWC dictionary for sentiment analysis. In: Proceedings of the 9th Brazilian Symposium in Information and Human Language Technology, pp. 215–219.

Bedi, G., Carrillo, F., Cecchi, G.A., Slezak, D.F., Sigman, M., Mota, N.B., Ribeiro, S., Javitt, D.C., Copelli, M., Corcoran, C.M., 2015. Automated analysis of free speech predicts psychosis onset in high-risk youths. In: npj Schizophrenia 1. https://doi.org/10.1038/npjschz.2015.30.

Bowie, C.R., Gupta, M., Holshausen, K., 2011. Disconnected and underproductive speech in schizophrenia: unique relationships across multiple indicators of social functioning. Schizophr. Res. 131, 152–156. https://doi.org/10.1016/j.schres.2011.04.014.

Corcoran, C.M., 2021. Commentary on "Lower speech connectedness linked to incidence of psychosis in people at clinical high risk": the promise of graph theory and network neuroscience. Schizophr. Res. 228, 481–482. https://doi.org/10.1016/j.schres.2020.09.024.

Corcoran, C.M., Cecchi, G.A., 2020. Using language processing and speech analysis for the identification of psychosis and other disorders. Biol. Psychiatry. https://doi.org/10.1016/j.bpsc.2020.06.004.

Elvevåg, B., Foltz, P.W., Weinberger, D.R., Goldberg, T.E., 2007. Quantifying incoherence in speech: an automated methodology and novel application to schizophrenia. Schizophr. Res. 93, 304–316. https://doi.org/10.1016/j.schres.2007.03.001.

Filho, P.P.B., Pardo, T.A.S., Aluísio, S.M., 2013. An evaluation of the Brazilian Portuguese LIWC dictionary for sentiment analysis. In: Proceedings of the 9th Brazilian Symposium in Information and Human Language Technology. Fortaleza, pp. 215–219.

Green, M.F., Horan, W.P., Lee, J., 2015. Social cognition in schizophrenia. Nat. Rev. Neurosci. https://doi.org/10.1038/nrn4005.

Hitczenko, K., Mittal, V.A., Goldrick, M., 2021. Understanding language abnormalities and associated clinical markers in psychosis: the promise of computational methods. Schizophr. Bull. https://doi.org/10.1093/schbul/sbaa141.

Holzman, P.S., Shenton, M.E., Solovay, M.R., 1986. Quality of thought disorder in differential diagnosis. Schizophr. Bull. 12, 360–372. https://doi.org/10.1093/schbul/12.3.360.

Johnston, H., Holzman, P.S., Gasperettl, C., Coleman, M., Kestnbaum, E., Carpenter, J.T., 1986. Scoring manual for the thought disorder index. Schizophr. Bull. 12, 483–496. https://doi.org/10.1093/schbul/12.3.483.

Kay, S.R., Fiszbein, A., Opler, L.A., 1987. The positive and negative syndrome scale (PANSS) for schizophrenia. Schizophr. Bull. 13, 261–276. https://doi.org/10.1093/schbul/13.2.261.

Lang, P.J., Greenwald, M.K., Bradley, M.M., Hamm, A.O., 1993. Looking at pictures: affective, facial, visceral, and behavioral reactions. Psychophysiology 30, 261–273. https://doi.org/10.1111/j.1469-8986.

Liddle, P.F., Ngan, E.T.C., Caissie, S.L., Anderson, C.M., Bates, A.T., Quested, D.J., White, R., Weg, R., 2002. Thought and language index: an instrument for assessing thought and language in schizophrenia. Br. J. Psychiatry 181, 326–330. https://doi.org/10.1192/bjp.181.4.326.

Malcorra, B.L.C., Mota, N.B., Weissheimer, J., Schilling, L.P., Wilson, M.A., Hübner, L.C., 2021. Low speech connectedness in alzheimer's disease is associated with poorer semantic memory performance. J. Alzheimers Dis. 82, 905–912. https://doi.org/10.3233/JAD-210134.

Malcorra, B.L.C., Mota, N.B., Weissheimer, J., Schilling, L.P., Wilson, M.A., Hübner, L.C., 2022. Reading and writing habits compensate for aging effects in speech connectedness. Npj science ofLearning 7, 13. https://doi.org/10.1038/s41539-022-00129-8.

Marggraf, M.P., Davis, B.J., Hardin, K.L., Abplanalp, S.J., Haller, J.A., DeCrescenzo, P., Minor, K.S., 2019. Speech production and disorganization in schizotypy: investigating the role of cognitive and affective systems. J. Psychiatr. Res. 114, 11–16. https://doi.org/10.1016/j.jpsychires.2019.03.023.

Morgan, S.E., Diederen, K., Vértes, P.E., Ip, S.H.Y., Wang, B., Thompson, B., Demjaha, A., de Micheli, A., Oliver, D., Liakata, M., Fusar-Poli, P., Spencer, T.J., McGuire, P., 2021. Natural language processing markers in first episode psychosis and people at clinical high-risk. Transl. Psychiatry 11. https://doi.org/10.1038/s41398-021-01722-y.

Mota, N.B., 2021. Commentary on "Investigating the diagnostic utility of speech patterns in schizophrenia and their symptom associations": the current need for the harmonization of speech elicitation protocols in basic and applied science. Schizophr. Res. 238, 199–200. https://doi.org/10.1016/j.schres.2021.11.013.

Mota, N.B., Vasconcelos, N.A.P., Lemos, N., Pieretti, A.C., Kinouchi, O., Cecchi, G.A., Copelli, M., Ribeiro, S., 2012. Speech graphs provide a quantitative measure of thought disorder in psychosis. PLoS ONE 7. https://doi.org/10.1371/journal.pone.0034928.

Mota, N.B., Furtado, R., Maia, P.P.C., Copelli, M., Ribeiro, S., 2014. Graph analysis of dream reports is especially informative about psychosis. Sci. Rep. 4 https://doi.org/10.1038/srep03691.

Mota, N.B., Weissheimer, J., Madruga, B., Adamy, N., Bunge, S.A., Copelli, M., Ribeiro, S., 2016. A naturalistic assessment of the Organization of Children's memories predicts cognitive functioning and reading ability. Mind Brain Educ. 10 https://doi.org/10.1111/mbe.12122.

Mota, N.B., Copelli, M., Ribeiro, S., 2017. Thought disorder measured as random speech structure classifies negative symptoms and schizophrenia diagnosis 6 months in advance. npj Schizophrenia 3. https://doi.org/10.1038/s41537-017-0019-3.

Mota, N.B., Sigman, M., Cecchi, G., Copelli, M., Ribeiro, S., 2018. The maturation of speech structure in psychosis is resistant to formal education. npj Schizophrenia 4. https://doi.org/10.1038/s41537-018-0067-3.

Mota, N.B., Callipo, R., Leite, L., Torres, A.R., Weissheimer, J., Bunge, S.A., Copelli, M., Ribeiro, S., 2020. Verbal short-term memory underlies typical development of "thought organization" measured as speech connectedness. Mind Brain Educ. 14 https://doi.org/10.1111/mbe.12208.

Mota, N.B., Pimenta, J., Tavares, M., Palmeira, L., Loch, A.A., Hedin-Pereira, C., Dias, E. C., 2022. A brazilian bottom-up strategy to address mental health in a diverse population over a large territorial area – an inspiration for the use of digital mental health. Psychiatry Res. 311, 114477 https://doi.org/10.1016/j.psychres.2022.114477.

Palaniyappan, L., 2021. More than a biomarker: could language be a biosocial marker of psychosis? npj Schizophrenia 7, 42. https://doi.org/10.1038/s41537-021-00172-1.

Palaniyappan, L., Mota, N.B., Oowise, S., Balain, V., Copelli, M., Ribeiro, S., Liddle, P.F., 2019. Speech structure links the neural and socio-behavioural correlates of psychotic disorders. Prog. Neuro-Psychopharmacol. Biol. Psychiatry 88. https://doi.org/10.1016/j.pnpbp.2018.07.007.

Pennebaker, J.W., Francis, M.E., Booth, R.J., 1999. Linguistic Inquiry and Word Count (LIWC).

Pennebaker, J.W., Chung, C.K., Ireland, M., Gonzales, A., Booth, R.J., 2007. The development and psychometric properties of LIWC2007 the University of Texas at Austin. Development 1, 1–22. https://doi.org/10.1068/d010163.

Rezaii, N., Walker, E., Wolff, P., 2019. A machine learning approach to predicting psychosis using semantic density and latent content analysis. npj Schizophrenia 5. https://doi.org/10.1038/s41537-019-0077-9.

Spencer, T.J., Thompson, B., Oliver, D., Diederen, K., Demjaha, A., Weinstein, S., Morgan, S.E., Day, F., Valmaggia, L., Rutigliano, G., de Micheli, A., Mota, N.B., Fusar-Poli, P., McGuire, P., 2021. Lower speech connectedness linked to incidence of psychosis in people at clinical high risk. Schizophr. Res. 228, 493–501. https://doi.org/10.1016/j.schres.2020.09.002.

Stokes, D.E., 1997. Pasteur's Quadrant: Basic Science and Technological Innovation. Washington D.C.