

# Evolution of linguistic markers of agency, centrality and content during metacognitive therapy for psychosis

Amir H. Nikzad, M.D.,<sup>1,\*</sup> Paul H. Lysaker, Ph.D.,<sup>2,3</sup> Kyle S. Minor, Ph.D.,<sup>3,4</sup> Bethany Leonhardt, Psy.D.,<sup>3,5</sup> Mark Y. Liberman, Ph.D.,<sup>6</sup> Jenifer Vohs, Ph.D.,<sup>3,5</sup> Courtney N. Wiesepepe, Psy.D.,<sup>3</sup> Sunny X. Tang, M.D.<sup>1</sup>

1. Institute of Behavioral Science, Feinstein Institutes for Medical Research, Northwell Health
2. Department of Psychiatry, Richard L. Roudebush VA Medical Center
3. Department of Psychiatry, Indiana University School of Medicine
4. Department of Psychology, Indiana University – Purdue University Indianapolis
5. Prevention and Recovery Center for Early Psychosis, Sandra Eskenazi Mental Health Center
6. Linguistic Data Consortium, University of Pennsylvania

\* Corresponding author: [ANikzad@Northwell.edu](mailto:ANikzad@Northwell.edu)

## Abstract

Recovery from psychosis involves deep and subjective personal changes such as regained sense of agency and purpose. Metacognitive Reflection and Insight Therapy (MERIT) is a form of person-centred psychotherapy that promotes recovery-oriented outcomes by enhancing metacognitive capacity, i.e. one's ability to monitor and regulate cognition and behavior. Previous research has shown the feasibility, acceptability and clinical benefits of MERIT. However, it is not clear whether and how the subjective outcomes of MERIT are objectively manifested in the patient-therapist communications during therapy sessions. In this study, we used natural language processing (NLP) to detect and quantify objective markers of change in the psychotherapy transcripts of five participants diagnosed with psychosis across 24 sessions of MERIT. As hypothesized, analyses detected shifts in specific speech signals over time within psychotherapy transcripts including: 1) changes in patterns of pronoun usage with more active and central first-person plural pronoun (We); 2) transition in temporal focus of speech from past-focus towards present- and future-focus; and 3) increased words representing perceptual and cognitive processes. Our findings suggest that the speech of participants over MERIT reflected increasingly complex ways of thinking about themselves and others such as an increased sense of agency and a more goal-oriented mode of thinking. Results also suggest NLP can objectively quantify meaningful signals consistent with expected changes during psychotherapeutic interventions.

## INTRODUCTION

To date, the mainstay of treatment for psychosis are pharmacological interventions that target neurochemical abnormalities presumed to underlie symptoms.<sup>1,2</sup> However, evolving research has suggested that recovery from psychosis and reintegration with the community is a complex matter that goes beyond symptom reduction.<sup>3-6</sup> Recovery involves a range of deeply subjective and personal outcomes,<sup>7</sup> which includes, for example, developing feelings of mastery, control, and self-worth. Overarchingly, recovery may further require the development of a cohesive understanding of one's psychiatric and social challenges and the possibilities needed to decide how to actively manage and respond to them.<sup>8</sup> This study implements objective language-based markers to quantify and track the trajectories of therapeutic targets over the course of recovery-oriented psychotherapy for psychosis.

Person-centred psychotherapy has been developed and implemented in response to the need to promote self-management and recovery in psychosis. One approach in particular, Metacognitive Reflection and Insight Therapy (MERIT), has suggested that psychotherapy may promote these more subjective forms of outcome by enhancing metacognitive capacity. Within MERIT, metacognition is defined as a spectrum of activities that enable persons to monitor and regulate cognition and behavior.<sup>9,10</sup> Metacognition, therefore, involves the ability to notice and reflect upon discrete emotional, cognitive and embodied experiences as well as form a larger sense of one's and others' purposes, possibilities, and relative places in the world. With intact metacognitive capacity, persons are able to form an integrated as opposed to fragmented sense of themselves and the course of their lives. People with psychosis, on the contrary, demonstrate significant metacognitive impairments relative to healthy control participants as well as others with less severe forms of mental illness or those facing similar levels of adversity, such as individuals diagnosed with HIV.<sup>11-13</sup> Such deficits are central to the psychosis phenotype and contribute to difficulties forming a coherent sense of self, others, and life,<sup>14</sup> and are also related to canonical psychosis symptom dimensions and poor outcomes.<sup>15,16</sup> Metacognition has also been proposed as a potential mediator between neurobiological changes and psychosis symptoms.<sup>17</sup>

MERIT aims to enhance metacognitive capacity by promoting reflection about oneself, others, and one's communities. Over the course of treatment, individuals are encouraged to produce narrations about themselves and others, and form a more integrated sense of themselves and others.<sup>18-20</sup> Attention is paid to the content of therapeutic exchanges, including goals, life story, thoughts, and challenges, as well as to the therapeutic relationship and its impacts on the participant's experiences. Altogether, the purpose of MERIT is to collaborate with participants to develop an integrated sense of agency, reconstruct their

relationships to others, and realign with their prospective goals. To date, research has found MERIT can be feasibly delivered within outpatient settings and accepted by those with psychosis.<sup>21</sup> It has been linked with significant improvements in metacognitive capacity as well as improvements in insight into the nature of their disorder.<sup>22,23</sup> Qualitative studies have also reported improvements in the subjective experience of agency and self-direction<sup>24,25</sup> while case studies have revealed MERIT can be flexibly applied to those with differing clinical presentations.<sup>19</sup>

One limitation in research on MERIT and recovery-oriented psychotherapies in general is the lack of objective markers which identify and quantify psychotherapeutic processes. Given that MERIT is delivered as a treatment through interpersonal dialogue, it would be expected that its presumed effects will be reflected in the language used during therapy. One possible way to address this missing piece in the literature is through natural language processing (NLP). NLP is an emerging approach in psychotherapy research which can objectively quantify elements such as quality and progress of treatment.<sup>26</sup> Clinical applications of NLP include identification of successful conversational strategies, evaluation and improvement of therapeutic skills of psychotherapists, and better detection of high-risk clinical conditions such as suicidality.<sup>27-29</sup> Moreover, emotional and metacognitive conversational dynamics such as humorous or emotional exchanges were shown to be detectable using NLP models.<sup>30,31</sup> Specifically, two NLP approaches appear to be particularly informative about the kinds of conversational dynamics expected in the course of metacognitive therapy. First, semantic role labelling is able to identify and quantify agency in terms of active or passive linguistic relations.<sup>32</sup> For example, while "*Good things always happen to me*" and "*I bring joy to my life*" both have positive connotations, the latter utterance is associated with more sense of agency as reflected in the active role acquired by the first-person pronoun. An increase in the use of active roles for the first-person pronoun during therapy sessions has been shown to be associated with good psychotherapy outcomes.<sup>33</sup> Second, Linguistic Inquiry and Word Count Program (LIWC) is capable of quantifying semantic content of speech in terms of frequencies of words belonging to various semantic domains, such as time orientation, informal language, and affective, social and cognitive processes. LIWC semantic profiles were previously linked to personality traits with more prominent predictive signals for neuroticism, extraversion, and conscientiousness.<sup>34</sup> They were also found to be informative for the mental health of speakers, with positive and negative emotive words indicating well-being and psychological distress, respectively.<sup>35</sup> Finally, some particular domains of LIWC (e.g., emotion-related word categories) were found to be related to the core concepts of metacognitive therapy such as hope.<sup>36</sup>

Here, we utilize computational semantic analysis to detect linguistic signals of metacognitive changes

associated with MERIT for early psychosis (MERIT-EP).<sup>23</sup> Because the psychotherapeutic process involves a cooperative exchange between the participant and the therapist, we hypothesize that linguistic signals reflecting metacognitive changes will be detectable in the speech of participants as well as therapists over the course of treatment. We will examine: 1) changes in centrality and agency of self- and others-representations reflected in patterns of pronoun usages; and 2) sense of purpose and metacognitive capacities reflected in temporal focus and semantic themes related to mental processes. We will also explore the trajectories of such changes in different participants in the context of their individual clinical outcomes. Since the therapeutic process for MERIT is carried out by means of conversational exchanges (i.e., a linguistic process), our findings may also have implications for understanding the role of language in execution and modulation of metacognitive self-regulation in psychosis.

## METHODS

### Language Samples

Five participants diagnosed with early phase psychosis were recruited from community services and provided informed consent. Participants each underwent 24 sessions of MERIT for early psychosis, delivered by two psychotherapists with expertise in this modality (therapist 1 – 4 participants, therapist 2 – 1 participant, Table 1S). Disease severity and illness awareness were measured using the Positive and Negative Syndrome Scale (PANSS)<sup>37</sup> and the Scale to Assess Unawareness of Mental Disorder (SUMD),<sup>38</sup> respectively, at pre- and post-intervention time points (Table 1S). The protocol for the intervention has been previously described<sup>23</sup> and all procedures were approved by the Indiana University Institutional Review Board. All sessions were recorded and transcribed verbatim (n=120 transcripts). Personal identifiers were removed from transcripts prior to automated linguistic analyses. The first and the final MERIT sessions for each participant were excluded from further analysis due to their different therapeutic structures (introductory and concluding sessions), resulting in 110 therapy sessions across the five participants. The transcript for each session was then separated into the participant and therapist portions for the final analysis (220 total samples).

### Experiment 1. Frequency, Activity/Passivity, and Centrality of Pronoun Categories

For each sample, utterances were tokenized using SpaCy word-tokenizer,<sup>39</sup> and the frequency of different categories of pronouns were then counted. We categorized pronouns into four distinct groups: those that represent the speaker (*I*–including *I*, *me*, *my*, etc.), the interlocutor (*You*–including *you*, *yours*, *yourself*, etc.), both speech participants (*We*–including *we*, *us*, *ours*, etc.), and others (*They*–including *she*, *he*, *they*, *hers*, *his*, *their*, etc.).

Next, we generated semantic graph models to determine the activity/passivity, and centrality of the

pronoun categories.<sup>32</sup> All features are enlisted in Table 1. Speech graph methodology is illustrated in Figure 1. First, samples were parsed into its constitutive utterances based on grammatical completeness and the presence of pauses. Each utterance underwent semantic role labelling (SRL) using RESTful API available at [VerbAtlas.org](http://VerbAtlas.org).<sup>40</sup> Based on the English Propositional Bank formalism, active (A0) and passive (A1 and A2) arguments and verb-predicates were extracted per each utterance.<sup>41</sup> For example, by processing “*She brings joy to my life*”, ‘*she*’ was identified as the active argument, ‘*joy*’ and ‘*to my life*’ as the first and second passive arguments, and ‘*brings*’ as the verb-predicate. Within each set (A0: ‘*she*’, A1: ‘*joy*’, A2: ‘*to my life*’, Predicate: ‘*bring*’), pronouns were replaced with their prototypical forms: *I*, *You*, *We* and *They*. In the example above, ‘*she*’ is replaced with ‘*they*’ and ‘*my*’ is replaced with ‘*I*’. Non-content words such as prepositions and articles were excluded (e.g., ‘*to*’ was removed), and content words were replaced with their lemmatized form using SpaCy modules (‘*brings*’ was replaced with ‘*bring*’).<sup>39</sup> The final sets of active-argument, passive-argument and verb-predicate were then used to create semantic graph representations of speech using networkx library (A0: ‘*they*’, A1: ‘*joy*’, A2: ‘*I life*’, Predicate: ‘*bring*’).<sup>42</sup> Action graphs were generated by connecting the active-argument (A0) to the passive-arguments (A1 and A2) in each predicative block in a directed way (‘*they*→‘*joy*’ and ‘*they*→‘*I life*’). Activity and passivity of four pronoun categories of *I*, *You*, *We*, and *They* were quantified by measuring the out-degree and in-degree of their respective nodes to quantify their frequency in active and passive roles, respectively. To normalize for the effect of verbosity, we used dynamic measurements with a moving window of thirty predicative blocks and forward-moving steps of one predicate.<sup>32</sup> Action-predication graphs were generated by connecting predicates to all arguments (A0, A1, and A2), and active arguments (A0) to passive arguments (A1 and A2) in each predicative block in an undirected fashion to allow centrality computation (e.g., ‘*bring*’–‘*they*’, ‘*bring*’–‘*joy*’, ‘*bring*’–‘*I life*’, ‘*they*’–‘*joy*’ and ‘*they*’–‘*I life*’). Based on this graph model, we then computed betweenness centralities of nodes, i.e., how often a particular node mediates the shortest path between other nodes.<sup>43</sup> The betweenness centrality values for each pronoun category were then captured as the measure of the centrality of self- and others- mental representations. This measurement was not normalized for verbosity due to its fractional nature.

### Experiment 2. Word-Frequencies per Semantic Categories

Samples were also fed to LIWC program in order to obtain the normalized frequencies of semantic categories related to temporal focus (past, present, and future) and different domains of mental processes (cognitive, perceptual, biological, affective, and social) for each speaker at each session.<sup>44</sup> These categories were extracted because we hypothesized that they would be indicators of emerging sense of purpose and metacognitive ability during the course

of MERIT. Table 1 defines and exemplifies these categories in more detail.

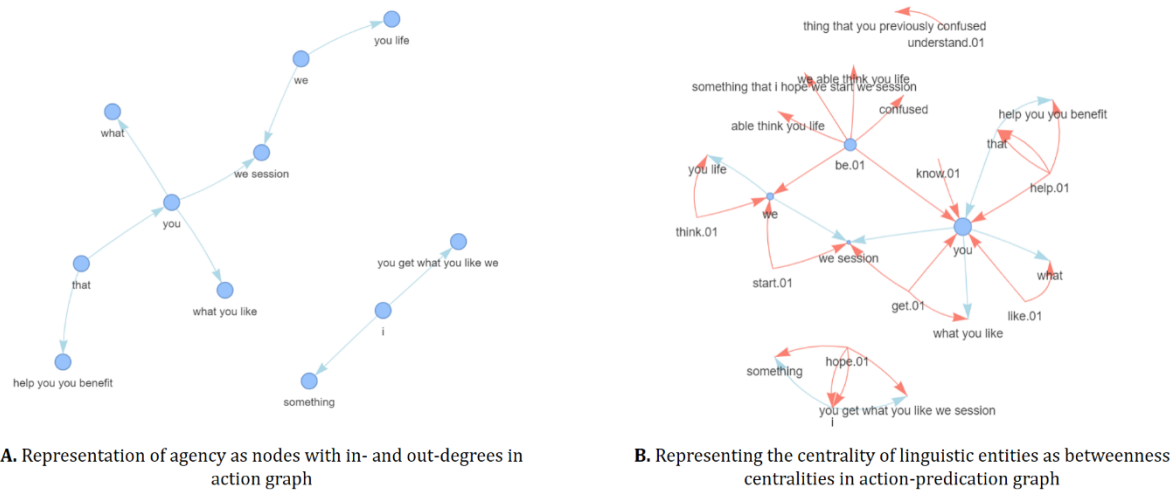
### Statistical analysis

We used mixed linear regressions to examine how participant and therapist speech evolve over the course of psychotherapeutic sessions, with a fixed effect of sessional progression (indexed as 2-23), a random effect of participant, and linguistic features as predictive targets. Bonferroni correction was used to account for multiple

comparisons as follows: Experiment 1. 4 comparisons for pronoun frequencies (corrected  $\alpha = 0.0125$ ), and 12 comparisons for graph features (corrected  $\alpha = 0.004$ ); and Experiment 2. 3 comparisons for temporal focus (corrected  $\alpha = 0.0167$ ), and 5 comparisons for mental processes (corrected  $\alpha = 0.01$ ). Therapist was included as a covariate to account for the delivery of MERIT by two different psychotherapists.

Feature Name	Definition
Normalized Pronoun Frequency	Number of instances of a pronoun category divided by the total number of words
Pronoun out-Degree	Number of outgoing edges emanating from the node representing a pronoun category (i.e. how much a pronoun category takes an active semantic role)
Pronoun in-Degree	Number of incoming edges landing on the node representing a pronoun category (i.e. how much a pronoun category takes a passive semantic role)
Pronoun Centrality	Betweenness centrality of the node representing a pronoun category (i.e. how much a pronoun category mediates connections between other entities)
LIWC Past Focus	Percentage of total words being past-tense verbs or references to past events/times – e.g. ago, did, and talked.
LIWC Present Focus	Percentage of total words being present-tense verbs or references to present events/times – e.g. today, is, and now.
LIWC Future Focus	Percentage of total words being future-tense verbs or references to future events/times – e.g. may, will, and soon.
LIWC Cognitive Processes	Percentage of total words being references to cognitive processes and activities – e.g. cause, know, and ought.
LIWC Perceptual Processes	Percentage of total words being references to perceptual processes and activities – e.g. look, heard, and feeling.
LIWC Biological Processes	Percentage of total words being references to biological processes and activities – e.g. eat, blood, and pain.
LIWC Affective Processes	Percentage of total words being references to affective processes and activities – e.g. happy and cried.
LIWC Social Processes	Percentage of total words being references to social processes and activities – e.g. mate, talk, and they.

**Table 1. Computational linguistic features.** Note: LIWC = Linguistic Inquiry and Word Count program.



**Figure 1. Semantic graph representation of therapy transcript.** This figure illustrates graph representation of the following sample of therapist speech: “Well something that I had hoped when we started our sessions is that we would be able to think about your life. Maybe understand things that you previously were confused about. But mostly I was hoping that you would get what you would like out of our sessions. That in some way would help, you know, help you to your benefit.” A. Action graph where nodes with active roles are connected to nodes with passive roles (all in blue). All nodes are in the same size. B. Action-Predication graph where predicates are connected to the arguments (red) and arguments with active role are connected to those with passive roles (blue). The size of the nodes is proportionate to their betweenness centrality.

## RESULTS

### Pre- and Post-Intervention Clinical Measures

Individual indices of disease severity (PANSS total) and illness awareness (SUMD and insight sub-scale of PANSS) at pre- and post-intervention time points are presented in the supplements (Table 1S). Participants differed in disease severity prior to the intervention, with PANSS total scores ranging from 44 to 81 (mean 57, standard deviation 15). Two participants experienced more severe symptoms after the intervention (Participants 3 and 4); however, all participants showed improved insight into their clinical condition, which was the primary endpoint for the intervention.

### Experiment 1. Frequency, Activity/Passivity, and Centrality of Pronoun Categories

We explored the longitudinal change in the pattern of pronoun usages in terms of the frequency, activity/passivity, and centrality of four categories of pronouns pertaining to the speaker – *I*, interlocutor – *You*, speech participants – *We*, and the others – *They*. There was an increasing trend in overall pronoun usage for participants and therapists, the latter of which was statistically significant ( $\beta = 0.17$ ,  $p < 0.05$ ). For individual pronoun categories, participants and therapists demonstrated inverse patterns. Participants used more *You*, and less *We* and *They* categories over time, whereas therapists used more *I* and *We*, and less *You* and *They* (Table 2). Only the increasing usage of *We* in

therapists' speech remained significant when corrected for multiple comparisons ( $\beta = 0.38$ , corrected  $p < 0.001$ ).

Semantic graph analysis of action relations showed decreased passive use of *We* in the participants' speech as reflected in a significant decline in in-degree of its representative node over the course of the treatment sessions ( $\beta = -0.29$ ,  $p < 0.01$ ). Conversely, the same pronoun category showed an increasing pattern of activity in the speech of therapists as reflected in the increasing out-degree of the *We* node ( $\beta = 0.27$ ,  $p < 0.01$ ). Both changes survived Bonferroni correction for multiple comparisons. Therapist speech also showed increased activity of *I* and decreased activity of *You* per sessional progression (Table 2).

There was no significant change in the centrality of pronoun categories in the speech of participants. However, the centrality of *I* ( $\beta = 0.25$ ,  $p < 0.01$ ) and *We* ( $\beta = 0.35$ ,  $p < 0.01$ ) increased significantly in therapist discourse, the latter of which survived Bonferroni correction (Table 2). A trend toward decreasing centrality of *You* in therapist speech was also detected ( $\beta = -0.13$ ,  $p = 0.12$ ).

All Bonferroni survived relations were subsequently re-examined with mixed linear models including therapist as a covariate to account for the delivery of MERIT by two different therapists. All relations maintained their significance in the reassessment.

	Normalized Frequency $\beta$ (p)	In-Degree $\beta$ (p)	Out-Degree $\beta$ (p)	Centrality $\beta$ (p)
<b>Participant Speech</b>				
<i>All Pronouns</i>	0.16 (0.06)			
<i>I</i>	0.01 (0.9)	-0.06 (0.5)	-0.04 (0.6)	-0.00 (0.9)
<i>You</i>	0.16 (0.03)*	0.03 (0.7)	0.07 (0.4)	0.10 (0.2)
<i>We</i>	-0.21 (0.02)*	-0.29 (0.002)** Bonf.	-0.06 (0.5)	-0.18 (0.08)
<i>They</i>	-0.17 (0.07)	-0.18 (0.06)	-0.09 (0.3)	-0.15 (0.1)
<b>Therapist Speech</b>				
<i>All Pronouns</i>	0.17 (0.04)*			
<i>I</i>	0.21 (0.02)*	-0.05 (0.6)	0.21 (0.022)*	0.25 (0.007)**
<i>You</i>	-0.19 (0.01)*	0.03 (0.7)	-0.21 (0.022)*	-0.13 (0.12)
<i>We</i>	0.38 (0.000)*** Bonf.	0.01 (0.9)	0.27 (0.003)** Bonf.	0.35 (0.000)*** Bonf.
<i>They</i>	-0.16 (0.08)	-0.13 (0.2)	-0.06 (0.517)	-0.11 (0.2)

**Table 2.** Beta-coefficient and p-Values of the mixed linear regression models to in-degree, out-degree and centrality of pronouns in semantic graph models and their normalized frequencies with the fixed effect of sessional progression and random effect of participants. Pronouns were classified into four categories representing the speaker (*I*– including I, me, my, etc.), interlocutor (*You*– including you, yours, yourself, etc.), speech participants (*We*– including, we, us, ours, etc.), and others (*They*– including she, he, they, hers, his, their, etc.). Significant results are tagged with asterisk. Results that survive Bonferroni correction for multiple comparisons are tagged with <sup>Bonf.</sup> (corrected  $\alpha = 0.004$  for graph features and 0.0125 for normalized frequency comparisons).

## Experiment 2. Word-Frequencies per Semantic Categories

The distribution of semantic categories in participant and therapist speech is presented in Table 3. The temporal focus of therapeutic exchanges showed a gradual shift with decreasing past-orientation ( $\beta = -0.31$  and  $-0.24$  for participant and therapist respectively) and increasing present- ( $\beta = 0.38$  and  $0.34$ , same order) and future-orientation ( $\beta = 0.19$  for both). Each of these relationships remained statistically significant when correcting for multiple comparisons (p-values  $< 0.01$ ), except for the increase in future orientation for therapists which became trend-level (p-value =  $0.02$ ).

When examining changes over time for the five domains of mental processes, we found significant increase

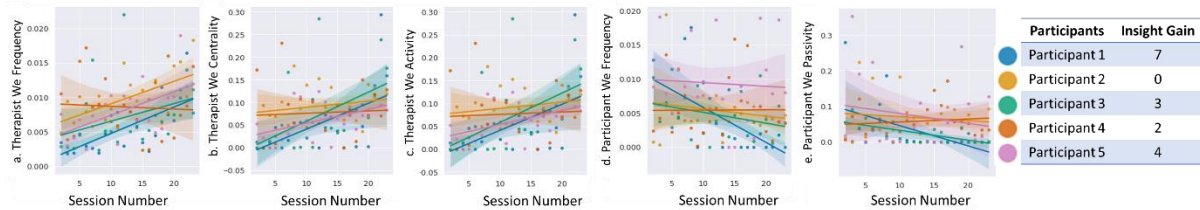
of using words that signify perceptual processes in participants ( $\beta = 0.20$ ,  $p = 0.01$ ) and therapists ( $\beta = 0.19$ ,  $p = 0.01$ ). There was also an increase in the usage of cognitive process category ( $\beta = 0.28$ ,  $p < 0.01$ ) and decreasing pattern in that of affective and social categories for therapists ( $\beta = -0.20$  and  $-0.17$  respectively). When correcting for multiple comparisons, only the increasing usage of words related to cognitive category by the therapists remained significant.

Here too, all Bonferroni survived relations were re-examined with mixed linear models including therapist as a covariate to account for the effect of multiple therapists delivering MERIT. All relations remained significant in the reassessment.

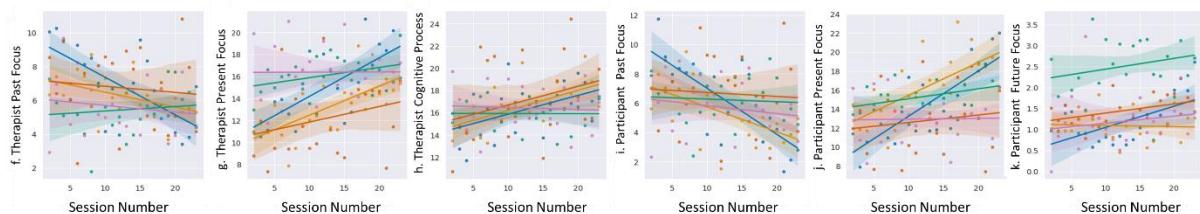
LIWC Feature	Participant Speech		Therapist Speech	
	$\beta$ coefficient	P-Value	$\beta$ coefficient	P-Value
<b>Time</b>				
Past	-0.31	0.001** Bonf.	-0.24	0.009** Bonf.
Present	0.38	0.000*** Bonf.	0.34	0.000*** Bonf.
Future	0.19	0.003** Bonf.	0.19	0.02*
<b>Mental Processes</b>				
Cognitive	0.15	0.09	0.28	0.004** Bonf.
Perceptual	0.20	0.01*	0.19	0.01*
Biological	0.01	0.9	0.01	0.9
Affective	0.01	0.8	-0.20	0.03*
Social	-0.09	0.4	-0.17	0.04*

**Table 3.** Beta-coefficient and p-Values of mixed linear regression models to predict the frequency of temporal focus and mental processing categories per LIWC with the fixed effect of sessional progression and random effect of participants. Significant results are tagged with asterisk. Results that survive Bonferroni correction for multiple comparisons are tagged with <sup>Bonf.</sup> (corrected  $\alpha = 0.01$ ).

## I. Experiment 1. Agency and Centrality of Pronoun Categories



## II. Experiment 2. Semantic Content and Themes



**Figure 2. Individual differences in linguistic feature trajectories.** Longitudinal changes in computational linguistic features I. Experiment 1 (a-c therapist features and d-e participant features) and II. Experiment 2 (f-h therapist features and i-k participant features). Insight gain is calculated for each participant by subtracting pre- and post-intervention scores on The Scale to Assess Unawareness of Mental Disorder (Table 1S).



### *Individual Trajectories of Computational Linguistic Features*

Eleven linguistic features showed significant correlations with sessional progression when accounting for multiple comparisons. These include normalized frequency and in-degree of *We* category, and past, present and future temporal focus in participant speech, and normalized frequency, out-degree and centrality of *We* category, past and present temporal focus, and cognitive mental processes in therapist speech. Figure 2 illustrates individual differences in the trajectories of these linguistic features during the course of therapy. Although the sample size is not sufficient for conclusive inter-individual comparisons, we explored variations in trajectories for the computational linguistic features in individual participants. We found that the participants with highest insight gain also appears to demonstrate large magnitudes of change in multiple linguistic markers (Participant 1 with SUMD change = 7, mean SUMD change for all participants = 3, more details in Table 1S). This effect is observable in both participants and therapist transcripts.

### **DISCUSSION**

In this study, we used automated semantic analysis to identify longitudinal linguistic changes in transcripts of individuals with psychosis receiving MERIT. Following our initial hypotheses, we were able to detect meaningful speech signals over the course of the psychotherapy. First, we observed significant changes in the frequency and nature of pronoun use which may reflect growing sense of agency. Second, we detected a shift in themes related to temporality, cognitive and perceptual processes in favor of improved sense of purpose.

Consistent with our first hypothesis, during the course of therapy, an increasingly more active and central representation of a shared identity emerged in the speech of participant and therapist. This emergence was captured in person pronoun categories with non-identical but complementary patterns for therapist and participant. On the participant's side, the frequency of *You* – referring to the therapist – was increased and the frequency and passivity of *We* were decreased. In a complementary fashion, the frequency, centrality and activity of *We* and *I* increased in the speech of therapist, whereas the frequency and activity of *You* – referring to the participant – were decreased. Altogether, these changes are consistent with a directed conversational relationship, through which a collaborative and active mutual identity is produced by the leading role of therapist, reflected in her active linguistic representation. Given that insight was improved in all five participants, our results resonate with previous findings indicating more active first-person pronoun usages in successful psychotherapies.<sup>33</sup>

The findings also supported our second hypothesis: over time, the psychotherapeutic exchanges became more directed toward present and future temporal

foci, and less towards the past, suggestive of more projective and goal-oriented discussions. Here, too, an increase in the usage of words related to the cognitive processes in therapist speech indicates a directed therapeutic relationship which is scaffolded by the therapist. This adds another perspective to the study of language behavior in psychosis during therapy sessions. Psychotherapy is permitted through an implicit agreement to cooperate by means of language. It has also been suggested that explicit activation of cooperation in the course of therapy may increase metacognitive abilities, hence improved outcomes.<sup>45</sup> However, the non-identical but complementary patterns of change associated with both experiments in our study implies the guiding role of the therapist throughout this cooperative relationship. Here, the communicative cooperation is based on a process of joint reflection, in which therapists may scaffold increasingly integrated ideas about participants and their actions in the world.

Our results offer possible quantitative correlates for psychotherapeutic processes, but do not directly demonstrate or prove the mechanisms at work. However, they are consistent with active inference models of psychosis and psychotherapy. As active inference model of psychosis suggests formal thought disorders (FTD) can be conceptualized as underlying imprecise predictions (or priors) about different hierarchical levels of interlocutor's discourse (e.g. intentions, narrations, sentences, and lexicon), which are then manifested as failures to commit to conversational goals or distortions in the structure of speech.<sup>46</sup> Following the similar logic, active inference model of psychotherapy conceptualizes the therapeutic interventions as attempts to modify maladaptive priors.<sup>47,48</sup> Previous studies on MERIT have indicated that the therapeutic effects of MERIT may go beyond the development of clinical insight and include reduction in disorganized FTD symptoms.<sup>21</sup> Therefore, it may be argued that the therapeutic effects of MERIT may unfold through modulation of the underlying hierarchy of predictive processing by integrating pertinent metacognitive information and allowing for more accurate updating of the priors.

The effect of communication on metacognition as the primary target of MERIT may further be explained through the framework of Vygotsky's theories on psycholinguistics. In this framework, language is conceptualized as having two primary functions: communication and self-regulation.<sup>49</sup> While the communicative function of language facilitates social exchanges between individuals, its self-regulatory function in the form of egocentric speech or inner speech serves as a means of mental and behavioral regulations. Some psychosis symptoms, such as self-talking and auditory verbal hallucination, can be considered as disturbances of the self-regulatory function of language where normal self-regulatory language is instead perceived as being external in origin.<sup>50</sup> Moreover, inner speech as the primary form of self-regulatory function of language in adults is thought to be

central to metacognition.<sup>51</sup> Following the same logic, metacognitive psychotherapy of psychosis can be conceptualized as a process through which self-regulatory functions are restored by the influence of communicative function of language (Figure 1S). Thus, language serves not as a mere reflection of inner processes, but as both the substrate and the tool for the therapeutic mechanism. This is consistent with previous assertions that the capacity for intersubjectivity and metacognition may grow together and as a deeper sense of a shared connection with others emerges what one wants the others to know may become clearer and more nuanced.<sup>52</sup>

There are limitations. This was an exploratory study implementing a novel analytical approach. The current study is limited due to its sample size, and we lack a control group. Participants were also heterogeneous and demonstrated different psychosis severity and disease trajectories. However, as presented in Table 1S, all participants showed enhanced insight in at least one of the scoring scales following the course of MERIT treatment. Future studies with more participants can provide a more solid ground to investigate the therapeutic effect of language on psychosis. Another limitation comes from the nature of our speech data which was confined to in-session verbal exchanges. Although we found meaningful longitudinal patterns of change during therapy, it is yet unclear whether and how these changes translate to real-life conversational behavior and sustained social relationships. Future studies may try to detect similar outcomes, i.e. increased agency and goal-directedness, from speech samples collected in everyday life setting. Objective measurement of change in language behavior during psychotherapy sessions and further validation of transmission of altered language behavior to other social settings may contribute to better understanding of psychotherapeutic processes. This may also help to evaluate and improve therapeutic efficacy of distinct approaches and therapeutic skills of individual therapists based on scalable and objective criteria.

## CONCLUSION

Our findings suggest that automated semantic analysis can objectively quantify meaningful signals consistent with deeply subjective changes related to recovery from psychosis during psychotherapeutic interventions. The changes in the language found across psychotherapy transcripts are consistent with first-person accounts of the experience of self-directed recovery and the theorized mechanisms of MERIT. In this framework, firstly, participants experience themselves as increasingly able to think about themselves in the moment and form ideas of challenges they face in ways that others could relate to and understand, and secondly, this sense-making occurred in the context of action in the world as participants were increasingly able to experience themselves as making sense of how they want to and have been responding to those challenges. These findings also potentially reflect increased

sense of agency and more collaborative mode of thinking—additional intended effects from MERIT-EP. In general, semantic analyses may reveal deeper changes in how individuals with psychosis make sense of and respond to the world as they move towards recovery. Moreover, semantic analysis of conversational dynamics during therapy sessions, in which metacognitive impairments are targeted by language interventions, may expand the applicability of NLP in psychosis beyond the bio-marker paradigm. In other words, language be conceptualized not only as a domain where psychosis disease processes are reflected, but also as a channel to deliver adequate compensatory interventions.

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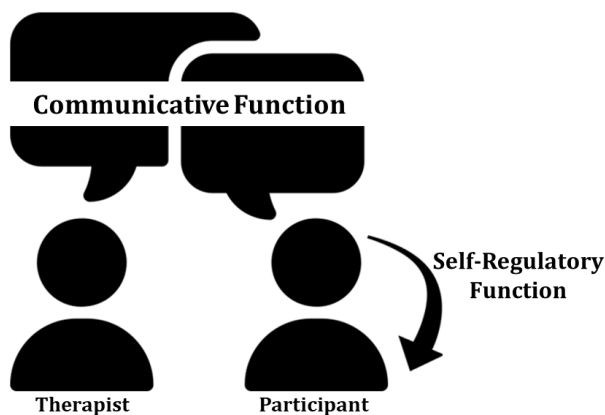
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## Supplements

Participant	Therapist	PANSS-total <sup>a</sup> Pre	PANSS-total Post	Insight <sup>b</sup> Pre	Insight Post	SUMD total <sup>c</sup> Pre	SUMD total Post
Participant 1	Therapist 1	59	50	4	3	13	6
Participant 2	Therapist 2	47	42	4	3	7	7
Participant 3	Therapist 1	44	65	4	4	13	10
Participant 4	Therapist 1	56	60	4	3	8	6
Participant 5	Therapist 1	81	57	5	3	10	6

**Table 1S.** Participants characteristics. <sup>a</sup>PANSS-total = total score for Positive and negative syndrome scale. Insight = insight sub-scale of PANSS rating. SUMD = The Scale to Assess Unawareness of Mental Disorder, evaluates three dimensions of insight: (1) illness awareness; (2) consequences of illness; and (3) need for treatment. Each dimension is rated on a 5-point scale from 1 = complete awareness to 5 = severe unawareness. Total score is the sum of scores per three domains, and lower scores indicate better insight. Lower scores are associated with better insight.



**Figure 1S.** Metacognitive therapy as an interaction between communicative and regulatory functions of language. Language is conceptualized as having two functions of communication, i.e. social inter-individual exchanges, and self-regulation, i.e. self-directed external or internal speech that mediates mental or behavioural self-regulation, à la Vygotsky’s psycholinguistics. In metacognitive therapy the psychotherapist utilizes the communication to modulate participant’s self-regulatory function of language.