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# Discourse coherence in first-episode psychosis and depression: shared referential alterations and links to cortical hierarchy

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## Abstract

Disrupted discourse coherence is documented in psychosis, but whether depression shows similar alterations, and how these relate to cortical hierarchical organization, remains unclear. This is the first study to examine conceptual and referential dimensions of coherence and their associations with cortical hierarchy across first-episode psychosis and depression. We analysed spontaneous speech from 85 German speakers (29 controls, 28 with first-episode psychosis, 28 with first-episode depression), of whom 80 underwent resting-state fMRI. Using large-model embeddings, automated coreference resolution, and graph-theoretical measures, we quantified conceptual relations (i.e., how ideas are linked) and referential relations (i.e., how entities are introduced and maintained), and related them to gradient dispersion between networks and within the semantic-associative network. Both clinical groups showed reduced referential continuity, and less small-world organization of conceptual content than controls, whereas differences in local semantic similarity depended on diagnosis and language model. Negative symptom severity was associated with altered conceptual and referential relations. Between-network gradient dispersion did not differ between groups. However, after controlling for diagnosis, individual variation in gradient organization was associated with distinct conceptual and referential relations. Visual-default mode network dispersion was associated with conceptual network organization, while somatomotor-default mode network dispersion was associated with local conceptual and referential coherence. Dispersion within the semantic-associative network was linked with topic reorganization. These findings identify reduced referential continuity as a shared, automatically measurable speech alteration across early psychosis and depression, linked to negative symptoms and cortical hierarchy, and support

developing scalable speech-based markers for transdiagnostic assessment and differential diagnosis.

**Keywords**: referentiality, coherence; first-episode psychosis; first-episode depression; cortical hierarchy; transdiagnostic, speech markers

## Introduction

Psychotic and depressive disorders carry a substantial global burden[1] and frequently co-occur [2–4], suggesting partly shared disturbances. Cognitive [5–7] and language impairments [8,9], including disturbances of coherent speech, are hallmarks of psychosis and depression, yet their neural correlates have rarely been linked to brain organization. Producing coherent speech requires the successful integration of linguistic and cognitive processes – including working memory, executive function, and social-cognitive abilities [10–12]. It is unclear which aspects of discourse coherence are altered across psychiatric diagnoses, how these alterations relate to clinical symptom dimensions, and whether they are associated with the functional organization of the brain. To advance the development of inexpensive, non-invasive, and repeatable speech-based markers for transdiagnostic assessment and differential diagnosis, these questions must be addressed.

We characterize discourse coherence in speech along two dimensions: *conceptual* and *referential*. Conceptual relations capture how meaningfully concepts are connected (e.g., *watchman*, *ship*, and *binoculars* form part of a coherent maritime scene), while referential relations capture how speakers introduce discourse entities and subsequently refer to them. Referential relations require speakers - similar to conceptual relations - to maintain and update these entities across an unfolding context, thereby contributing to discourse coherence. (For example, in "*A watchman notices a ship through his binoculars. He tries to warn its crew.*" *He* refers to the *watchman*, while *its crew* introduces a new discourse entity associated with the previously mentioned ship.) Both dimensions can be quantified automatically from transcribed spontaneous speech. Language models (LMs) estimate the semantic relatedness of concepts, whereas coreference-resolution methods track how discourse entities are introduced and subsequently referred to. Importantly, these dimensions capture distinct aspects of discourse

coherence: alterations in conceptual coherence need not coincide with alterations in referential coherence.

These dimensions are relevant for understanding first-episode psychosis (FEP) and first-episode depression (DEP) because alterations in these dimensions are observable in spontaneous speech [13–17]. However, research has predominantly focused on conceptual relations (i.e., semantic similarity), while evidence concerning referential relations in DEP remains limited. Consequently, it has not been determined whether alterations in conceptual and referential relations reflect shared or diagnosis-specific dimensions of coherence disturbance across FEP and DEP.

A further question is whether disruptions in conceptual and referential coherence are associated with alterations in the large-scale functional organization of the brain. This question is relevant to FEP and DEP, in which alterations in cortical functional hierarchy have been reported [18–22], including shared somatomotor alterations across recent-onset psychosis and depression in a large transdiagnostic sample [23].

The human cortex is hierarchically organized, progressing from modality-specific sensory processing to increasingly abstract and integrative representations in transmodal regions (comprising heteromodal association, paralimbic, and limbic cortices) [24]. In Mesulam's taxonomy, transmodal cortex is an umbrella term that comprises heteromodal association cortex (prefrontal, posterior parietal, lateral temporal association cortices) as well as paralimbic and limbic territories. This hierarchy can be represented by large-scale gradients of functional connectivity (hereafter, gradients), which provide a low-dimensional representation that captures the principal axes of cortical functional organization. The principal gradient (G1) is anchored at one end by regions serving primary sensory and motor functions and at the other by transmodal regions that, in humans, correspond to the default mode network (DMN) [25]. Meanwhile, the secondary gradient (G2) differentiates the visual system from other

sensorimotor systems [25]. Higher-order cognitive functions, including semantic processing, are associated with regions toward the transmodal end of G1, namely DMN, [25,26], where this network integrates sensory, cognitive, and mnemonic information to support context-dependent sense-making [27].

In gradient space, the spatial relationship between sensory, motor, and transmodal networks may provide insight into the balance between functional segregation and integration underlying these cognitive functions [28,29]. *Gradient dispersion* quantifies the separation between functional networks (e.g., visual network [VN], somatomotor network [SMN], and DMN) along a cortical hierarchy. Greater between-network dispersion indicates greater functional separation, whereas lower dispersion indicates reduced differentiation between networks, that is, more similar connectivity profiles, which may reflect greater functional integration. Following [29], we focused on three measures of between-network gradient dispersion: VN-DMN and SMN-DMN dispersion along G1, and VN-SMN dispersion along G2. These pairs involve the networks that anchor the extremes of each gradient: VN and SMN at the unimodal end and the DMN at its transmodal end of G1, and VN and SMN at opposite poles of G2. Other networks generally occupy more intermediate positions along these gradients [25] and were not included in the present between-network analyses. Reduced VN-DMN and increased SMN-DMN dispersion have been reported in FEP relative to non-clinical control persons (NC), suggesting a reorganization of the DMN's position relative to sensory and motor systems [29]. Previous studies have linked the functional separation between sensorimotor and higher-order association cortical regions to language processing and semantic cognition [30,31]. Because coherent discourse requires integrating perceptual and conceptual information with contextual representations, variation in this functional separation may be associated with conceptual and referential coherence.

Within this macroscale organization, the semantic-associative network (SemN) has been linked to semantic processing and conceptual representation [29,32]. SemN is not a separate canonical network but includes left-hemispheric default mode and limbic regions [29], consistent with the observation that the semantic system is "virtually identical" to the DMN [32]. These studies defined SemN as comprising two functionally distinct components: (1) the frontal-parietal heteromodal association cortex to process information from the different sensory systems, mainly comprising the dorsomedial and dorsolateral prefrontal cortex (dmPFC, dlPFC), middle frontal gyrus, inferior frontal gyrus (IFG), the angular gyrus (AG), the adjacent supramarginal gyrus (SMG), and the lateral temporal lobe; and (2) the self-related medial limbic cortex, mainly comprising the ventromedial temporal lobe, ventromedial and orbital prefrontal cortex, and the posterior cingulate gyrus (PCC) and adjacent ventral precuneus (Prec) [32]. Both SemN components fall within transmodal cortex as defined above: the first is heteromodal and the second limbic. Because "limbic" is a loosely defined concept in neuroscience, we use it only in two operational senses: the medial limbic component of the SemN [32] and the limbic network (LN) of the Yeo seven-network parcellation [33]. These two definitions overlap only partially.

Given the complementary roles of these components and evidence from previous studies, we reasoned that the functional organization of the SemN may be relevant to the construction of conceptual relations and the maintenance and updating of referential representations during discourse. The SemN is of clinical interest. Semantic brain networks are disorganized in schizophrenia [34], and in FEP, dispersion along the first SemN-specific functional gradient (SemN-G1) was reduced and associated with altered syntactic structure in spontaneous speech [29]. Whether comparable alterations occur in first-episode depression has not been examined. We therefore examined SemN-G1 dispersion, which quantifies the spread

of parcel coordinates around their centroid within the predefined SemN, rather than the separation between distinct large-scale networks.

Importantly, emerging evidence links this macroscale cortical organization with the processing of discourse coherence [35]. During discourse comprehension, the dmPFC, a heteromodal region associated with the DMN, contributes to coherence by supporting the inferential integration of successive sentences [36]. During speech production, coherence-related neural responses involve DMN regions and vary along cortical functional gradients [37]. More broadly, higher-order semantic representations are supported by the heteromodal association cortex [38,39]. At the brain-language level, changes in the recruitment of cortical regions have been associated with semantic graph structure and gradient organization [29], including SMN and DMN dispersion [40]. However, whether these associations extend to referential relations remains to be seen. Given the DMN's position at the transmodal pole of G1 [25] and its proposed role in integrating information during discourse [41], we hypothesized that alterations in conceptual and referential relations in spontaneous speech would be associated with between-network gradient dispersion and SemN-G1, independent of diagnosis.

Existing studies examining brain-language associations have largely focused on English-speaking individuals with FEP, without investigating referential relations or extending these associations to DEP. By studying German-speaking individuals with FEP and DEP, we extend this research to a language with a referential system that differs from English and assess whether previously reported brain-language associations can be observed in German [29]. We examined the organization of functional networks in gradient space by calculating gradient dispersion from resting-state data in individuals with FEP, DEP, and control persons (NC). Consistent with the translational Research Domain Criteria (RDoC) framework, this study had three aims: (1) to determine whether conceptual and referential relations derived from LMs in spontaneous speech show shared and disorder-specific alterations across FEP and DEP; (2) to

test whether between-network gradient dispersion and SemN-G1 dispersion differ across FEP, DEP, and NC; and (3) to examine whether, independent of diagnosis, alterations in conceptual and referential relations are associated with these measures of cortical functional organization.

## Materials and Method

Fig. 1 summarizes the analytical workflow.

<Insert Fig. 1>

### *Participants*

The speech sample was comprised of 85 participants (NC = 29, FEP = 28, DEP = 28). Resting-state fMRI data were available for most of them (i.e., 80 participants, NC = 28, FEP = 24, DEP = 28). The remaining five (one NC, four FEP) declined to take part in the MRI session. Both patient groups were recruited through the Department of Psychiatry and its Early Recognition Service of the University Hospital Cologne, Germany. Both patient groups were in an early phase of illness, defined as a first diagnosis of a psychotic disorder (FEP) or of major depression (DEP) within the past five years. NC persons were recruited from the local community via advertisements and had no current or past psychiatric episodes.

Symptom severity in patient groups was assessed using the Positive and Negative Syndrome Scale (PANSS)[42], the Scale for the Assessment of Positive Symptoms (SAPS)[43], and the Scale for the Assessment of Negative Symptoms (SANS)[44] (see Table 1 for Demographic and clinical data). Depressive symptoms were assessed using the Quick Inventory of Depressive Symptomatology (QIDS) [45], the Beck Depression Inventory (BDI) [46], and Childhood Trauma Questionnaire (CTQ)[47] . The study was approved by the University of Cologne Ethics Committee (23-1199), and all participants provided written informed consent (see S1 for eligibility criteria).

<Insert Table 1. Demographic and clinical data of non-clinical controls (NC), first-episode psychosis (FEP), and first-episode depression (DEP) >

*Speech and Imaging dataset*

Participants described three modernized versions of The Thematic Apperception Test (TAT) [48], and narrated a wordless cartoon, which lasted approximately four minutes. Imaging data were acquired at the Max Planck Institute for Metabolism Research (Cologne, Germany). Resting-state functional MRI data (452 whole-brain functional images; TR = 1.3 s, TE = 30 ms, flip angle = 70°, 3 mm isotropic resolution) were acquired on a Siemens MAGNETOM Prisma Fit scanner (3 Tesla) using a 64-channel head/neck coil (see S2 for fMRI acquisition & preprocessing).

*Pre-processing of resting-state data*

Using the same pipeline of a previous study [29], images were preprocessed using fMRIPrep 24.1.1 [49,50] based on Nipype 1.8.6 [51,52]. Resting-state data underwent additional post-processing, nuisance correction was implemented using Nilearn, including regression of head-motion parameters (rotational and translational on the three coordinate axes), confounds derived from white matter and cerebrospinal fluid, and high-pass filtering to account for low-frequency signal drifts. The first volume was removed.

*Cortical functional hierarchy with gradient dispersion*

Following the methodology of a previous study [29], time series were extracted from the 1000 regions of interest (ROIs) of the Schaefer parcellation [53], which includes annotations of the seven Yeo networks [33]: visual (VN), somatomotor (SMN), dorsal attention (DAN), ventral attention (VAN), limbic (LN), frontoparietal control (FPN) and default mode (DMN). For each participant, a 1000 × 1000 functional connectivity (FC) matrix was computed from Fisher z-transformed Pearson correlations. Gradients were derived with the BrainSpace toolbox [54]. FC matrices were thresholded to retain the strongest 10% of positive connections per row,

converted into affinity matrices using a cosine kernel [25], and decomposed with diffusion map embedding into 10 gradients. Individual gradients were aligned to group-level template gradients via Procrustes rotation. We analyzed G1, which separates unimodal (VN, SMN) from transmodal (DMN) cortex, and G2, which separates SMN from VN [30, 55]. Between-network dispersion was defined as the difference in mean G1 values between VN and DMN and between SMN and DMN, and as the difference in mean G2 values between SMN and VN. The same pipeline was applied within a left-lateralized semantic-associative network (SemN) of default-mode and limbic parcels matched to the semantic system [32], and SemN-G1 dispersion was the sum of squared distances of SemN parcels from their centroid along SemN-G1. Parcel-wise group differences, adjusted for age, sex and education, were tested with surface-based linear models in BrainStat [56] with FDR correction (see S3 for gradient extraction).

*Pre-processing of speech and feature extractions*

The recordings were transcribed with Whisper large [57] and manually addressed misunderstandings and hallucinations. At the first level, we extracted textual features (e.g., perplexity; number of first-person pronouns) directly from the transcriptions without further processing. Conceptual features (e.g., semantic similarity, semantic-graph measures) were derived from FastText [58] , BERT [59], Sentence-Transformer [60] and GPT-2 models. Referential features (e.g., noun-phrase types (NP), referential transitions, coreference chains and coreference graphs) were derived from Large Language Model Meta AI (LLaMA-3 70B)[61] and automated coreference resolution [62] . NP extraction and automated coreference resolution showed moderate to good agreement with manual annotation of a subset of transcript (n= 44: *F1* = 0.87 for coreference; 0.73 for joint coreference and NP extraction) (see Table 2 and speech feature extractions in S4).

<Insert Table 2a & 2b. Dimensions of coherence with definitions and examples>

## Statistical analysis

Analyses were conducted using R [version 4.4.1] [63]. Gradient measures were compared with Kruskal-Wallis and Mann-Whitney tests. Coherence features and brain-language gradient associations were modelled with generalized estimating equations (GEEs) and implemented with the geeglm function from the geepack package [64]. Linguistic models included group, age, sex, education, task, and feature-specific normalization terms. Continuous measures were analysed using Gaussian GEEs, whereas graph-edit-distance measures were analysed using negative-binomial GEEs with robust standard errors. Pairwise group comparisons were obtained using estimated marginal means. Brain–language associations were adjusted for diagnosis, age, sex, education, and task, using CR2 cluster-robust standard errors. Clinical associations were examined using partial Spearman correlations adjusted for diagnostic subgroup and demographic covariates. P-values were adjusted using the Benjamini–Hochberg FDR procedure within each analysis family, with significance defined as $q < .05$. Complete statistical specifications are provided in Supplementary Methods S5.

## Results

We first analysed whether dimensions of coherence in speech differ across groups (see Table 2).

### *Conceptual relations*

Conceptual features (e.g., watchman, ship) showed fewer group differences than referential features (e.g., a watchman, he) (Table 2a for examples; Table S1). Relative to NCs, BERT-based first-order semantic similarity (SemSim) was significantly higher in FEP ($\beta = 0.001$, $q < .001$), whereas FastText-based first-order SemSim was significantly lower in DEP ($\beta = -0.002$, $q < .001$). Both clinical groups showed lower small-worldness than NCs ($qs < .05$). FEP showed lower lexical diversity (MATTR; FEP: $\beta = -0.026$, $q < .001$) but the reduction in DEP

was small but significant ($\beta$ = -0.001, $q$ = .019). Both had higher perplexity (DEP: $\beta$ = 0.735, $q$ < .001; FEP: $\beta$ = 0.481, $q$ = .035) than NCs (Table S1).

*Alterations in referentiality features*

FEP and DEP showed consistent difficulties in introducing and maintaining reference across utterances (Table 2b for examples, Table S1). Relative to NC, both groups produced more indefinite NPs, which typically introduce new referents (DEP: *IRR* = 1.06; FEP: *IRR* = 1.11), and had fewer personal pronouns, which signal maintenance of reference (DEP: *IRR* = 0.71; FEP: *IRR* = 0.67). Both groups produced approximately 34-36% fewer pronoun-to-pronoun transitions (*er* → *er*), indicating reduced maintenance of the same referent through speech (DEP: *IRR* = 0.64; FEP: *IRR* = 0.66; *qs* ≤ .001). In contrast, both groups produced more topic-reorganizing transitions, both *er*/*he* → *der*/*that* (DEP: IRR = 1.78; FEP: IRR = 3.26; qs = .002) and *der*/that → *der*/*that* (DEP: IRR = 1.57; FEP: IRR = 4.66; qs < .001). FEP and DEP had shorter co-reference chains than NC (DEP: $\beta$ = -0.52; FEP: $\beta$ = -0.46). Their referential networks were less interconnected, showing lower closeness centrality (both $\beta$ = -0.004) and clustering coefficients (DEP: $\beta$ = -0.008; FEP: β = -0.009; *qs* < .001). Demonstrative use (i.e., *der/that*) was higher in FEP (*IRR* = 1.77, $q$ < .001) and smaller but significant increase in DEP (*IRR* = 1.10, $q$ = .005).

*Differentiation of conceptual and referential representations*

The distance between conceptual and referential graph representations (i.e., GED measures) were reduced in both patient groups relative to NC (*qs* < .006; Table S1).

*Associations between clinical measures and coherence dimensions*

We examined associations between discourse organization and clinical symptom severity (Fig. S1). Negative symptom severity showed the most consistent associations with coherence dimensions. For conceptual features, greater negative symptom severity on both PANSS and SANS was associated with higher FT closeness centrality and global efficiency ($r$ = .45–.51)

and lower small-world organization (Sigma; $r$ = -.51; $qs$ < .01). For referentiality features, higher PANSS negative scores were associated with less topic maintenance (definite NPs: $r$ = -.39, $q$ < .05; pronoun use: $r$ = -.36, $q$ < .05; third-person NPs ($r$ = -.49), uses of the personal pronoun *er*/*he* ($r$ = -.33). Negative symptom severity on both scales was also associated with smaller graph edit distances between lexical, phrasal and coreference graph representations (PANSS: $r$ = -.43 to -.48; SANS: $r$ = -.34 to -.38; $q$s < .05).

*Alterations in cortical hierarchy in first-episode psychosis and depression*

We examined group differences in cortical hierarchical organization at network and parcel levels, focusing on the G1 and G2 functional gradients, which capture complementary dimensions of sensory, motor, association, and heteromodal/transmodal cortical organization. Network-level analyses assessed mean gradient values within the VN, SMN, and DMN, and dispersion between these networks, while parcel-wise analyses examined spatially localized differences.

At the network level, no significant group differences were observed in mean gradient values (Table S2) or in between-network dispersion (Table S3; Fig. 2a-b).

*Parcel-wise group differences*

Parcel-wise analyses identified significant group differences along G1 and G2 (Fig. 2c; Table S4). Significant parcels are reported using Schaefer parcel identifiers and their corresponding Yeo seven-network assignments.

Along G2, FEP showed higher gradient values than NCs and DEP in SMN parcels (all $q$s ≤ .04). Relative to NCs, DEP showed higher values in one DMN parcel and lower values in one SMN parcel (both $q$s ≤ .03). Along G1, FEP showed higher values than NCs in SMN and DMN parcels, but lower values in a frontoparietal control network (FPN) parcel (all $q$s ≤ .02). DEP showed higher values than FEP in one SMN parcel ($q$ = .03), with no significant differences relative to NCs. Thus, although no differences emerged at the network level, parcel-

wise differences were localized predominantly within the SMN, with fewer in the DMN and FPN, and occurred mainly in comparisons involving FEP.

<Insert Fig. 2>

*Gradient within the semantic-associative network*

Further, we examined functional-gradient organization within the predefined left-lateralized SemN [29, 32]. Diffusion embedding was applied separately to functional connectivity matrices within the SemN, yielding network-specific gradients distinct from the whole-cortex gradients (see Supplementary Methods S3). Our primary analysis focused on SemN-G1 dispersion.

SemN-G1 dispersion differed significantly across groups ($H$ (2) = 7.45, $p$ = .024; Table S5; Fig. 3b). Pairwise Mann-Whitney comparisons revealed significantly lower dispersion in FEP than in DEP ($U$ = 191, $q$ = .024). Although FEP showed numerically lower dispersion than NC, this difference did not survive FDR correction ($U$ = 221, $p$ = .036, $q$ = .053). DEP and NC did not differ significantly ($U$ = 374, $q$ = .774).

*Parcel-wise group differences along SemN-G1*

Parcel-wise analyses examined group differences along SemN-G1 (Fig. 3c; Table S6). We distinguished the heteromodal association and medial limbic components of the SemN, which overlap predominantly with the Yeo DMN and limbic network (LN), respectively. Relative to NCs, FEP showed bidirectional differences across DMN-assigned parcels and higher values in orbitofrontal LN parcels. DEP showed lower values in DMN-assigned parcels and higher values in orbitofrontal and temporal-pole LN parcels. Differences between DEP and FEP were bidirectional across DMN-assigned parcels, whereas LN-assigned parcels consistently showed higher values in DEP. Overall, group differences were spatially heterogeneous rather than reflecting a uniform shift across SemN-G1.

<Insert Fig. 3>

*Discourse-coherence features are associated with cortical organization*

Finally, after accounting for group, age, sex, education, and task, we tested whether individual variation in cortical organization was associated with the two dimensions of coherence (Fig. 4). We examined four measures: VN-DMN and SMN-DMN dispersion along G1, VN-SMN dispersion along G2, and SemN-G1 dispersion. After FDR correction, significant associations were limited to a subset of conceptual and referential features.

Generalized estimating equation models (GEE) showed that conceptual features were associated primarily with between-network gradient differences. SMN-DMN dispersion was positively associated with FastText-based first-order semantic similarity ($z = 5.05$, $q < .001$), ST clustering ($z = 2.99$, $q < .05$), and negatively associated with lexical diversity (MATTR; $z = -2.81$, $q < .05$). VN-DMN dispersion was negatively associated with FastText-based closeness centrality ($z = -3.42$, $q < .01$) and global efficiency ($z = -4.90$, $q < .001$) but positively associated with FT small-worldness ($\sigma$; $z = 3.77$, $q < .01$). VN-SMN dispersion was negatively associated with ST global efficiency ($z = -3.65$, $q < .01$) but positively associated with ST based small-worldness ($\sigma$; $z = 4.53$, $q < .001$).

Referential features showed a complementary pattern of associations with gradient organization. SemN-G1 dispersion was associated with topic reorganization in opposite directions: negatively with *er/he* → *der/that* transitions ($z = -5.13$, $q < .001$) and positively with *der/that* → *er/he* transitions ($z = 3.23$, $q < .05$). SemN-G1 dispersion was not significantly associated with any conceptual feature. VN-DMN dispersion was negatively associated with *der*/*that* → *er*/*he* transitions ($z = -3.26$, $q < .05$) and first-person NPs ($z = -2.97$, $q < .05$). Greater SMN-DMN dispersion was associated with higher closeness centrality in coreference networks ($z = 5.63$, $q < .001$).

<Insert Fig 4. >

## Discussion

We characterized conceptual and referential coherence in the spontaneous speech of individuals with FEP and DEP, compared with NC, and examined their associations with cortical hierarchical organization. Three principal findings emerged. First, on the language level, reduced referential continuity emerged as a shared alteration across FEP and DEP, whereas conceptual features showed a combination of shared changes in semantic-network topology and partly distinct patterns of local semantic similarity. Second, on the neural level, no significant diagnostic differences emerged in whole-network gradient dispersion, although localized parcel-wise differences were observed. Third, integrating language and neural data, and after controlling for diagnosis, both conceptual and referential features were associated with individual variation in cortical hierarchy. Conceptual features were associated primarily with dispersion between VN, SMN, and DMN, whereas referential features were associated with SMN-DMN, VN-DMN, and SemN-G1 dispersion. SemN-G1 dispersion was associated with referential features, specifically with topic reorganization (i.e., transitions between pronouns and demonstratives), in opposite directions for shifts toward and away from demonstratives.

With respect to conceptual coherence, FEP and DEP showed both shared and distinct alterations across levels of conceptual relations. Both groups exhibited reduced semantic-network small-worldness (Sigma) (i.e., a weaker balance between locally clustered concepts and short global paths connecting them) and increased perplexity, whereas first-order semantic similarity (SemSim) differed across diagnostic groups and embedding models. FEP showed higher BERT-based SemSim, consistent with previous findings interpreted as a possible narrowing of semantic space in psychosis[40,65], whereas DEP showed lower FastText-based SemSim. BERT SemSim captures contextualized similarity between successive phrases, whereas FastText SemSim reflects context-independent lexical relatedness between successive

words. The FEP effect may thus indicate more tightly linked successive phrases (i.e., less semantic progression across the discourse, whereas the DEP effect may indicate weaker lexical cohesion between adjacent words). Given the different representational properties of BERT and FastText, these effects should not be interpreted as opposing changes along a single semantic dimension. The reduction in Sigma in FEP is consistent with the recent study [40], although their findings of increased closeness centrality and global efficiency were not replicated at the group level. These findings extend previous studies that found evidence of altered semantic organization in schizophrenia-spectrum disorders (SSD) across languages [13,14,29] and in depression [16].

This distinction between linguistic measures is relevant given that word-level semantic similarity was not consistently associated with human-rated coherence across English, Danish, and Chinese, whereas perplexity showed more consistent, albeit weak, associations [40]. Thus, first-order semantic similarity, semantic-network topology, lexical diversity, and referential relations should be considered complementary measures of discourse organization rather than interchangeable indicators of overall coherence.

Compared with conceptual coherence, referential coherence showed more consistent alterations across FEP and DEP. Beyond the shared reduction in referential continuity, both clinical groups showed less central and clustered coreference networks. These suggest increased reliance on referential expressions that introduce new referents (e.g., indefinite NPs), alongside reduced maintenance of established referents and lower interconnectedness among them. This pattern converges with cross-linguistic evidence of altered referential relations in SSD (e.g., English, Turkish, Spanish and Chinese)[16, 17, 65–68], while extending the comparison to DEP. These results suggest that reduced referential continuity may represent a shared dimension of coherence impairment across FEP and DEP. Unlike neuroimaging, speech can be recorded quickly, non-invasively and at minimal cost, and its referential features can be

extracted automatically, so these measures could be collected repeatedly to monitor discourse coherence over the course of illness and treatment.

An important question is to what extent alterations in discourse coherence are shared across languages and to what extent they are shaped by language-specific linguistic properties and measurement approaches. The convergence of several findings with previous studies across languages, reduced semantic-network small-worldness in psychosis [29] and alterations in referential relations, including reduced referential continuity and increased use of indefinite NPs in SSD [14,17,66–69], suggests that some dimensions of coherence may extend beyond individual language systems. Notably, increased demonstrative use in German-speaking individuals with FEP parallels findings in Turkish-speaking patients with psychosis [67], despite differences between the two languages in their referential systems. This convergence raises the possibility of a broader alteration in referential choice, although the discourse functions of demonstratives may differ across languages.

Linguistic theories of referentiality provide a framework for interpreting these findings. Speakers select referring expressions partly according to the cognitive accessibility of discourse entities: indefinite noun phrases typically introduce new entities, whereas personal pronouns generally refer to highly accessible entities [70,71]. Therefore, the observed alterations may reflect differences in how speakers maintain and update referential representations during discourse. One possible explanation involves common-ground updating, through which speakers and listeners establish and maintain shared representations of discourse entities [72]. Because this process involves representing the listener's knowledge state, referential relations draw on mentalizing processes associated with regions overlapping with the DMN [73–75]. Although neither common-ground updating nor mentalizing was directly assessed, these mechanisms offer a possible cognitive account of the observed referential alterations.

Negative symptom severity was associated with both dimensions of discourse coherence: with semantic-network topology in the conceptual relations (e.g., closeness centrality and global efficiency) and with fewer definite NPs, third-person NPs and personal pronouns in the referential relations, and with smaller graph edit distances, indicating less differentiation between lexical, phrasal and coreference graph representations. These results suggest these dimensions capture aspects of cognitive-language functioning relevant to psychiatric symptomatology. The conceptual profile of increased centrality and global efficiency, alongside reduced small-worldness, resembles the semantic-network alterations previously reported in FEP relative to NC [29]. This similarity suggests that aspects of semantic-network organization may be associated with negative symptom severity after accounting for diagnostic subgroup, rather than being specific to psychosis independent of symptomatology. From a transdiagnostic perspective, these findings support examining coherence dimensions in relation to symptom dimensions alongside categorical diagnoses. Nevertheless, these associations should not be interpreted as evidence that negative symptoms mediate diagnostic differences in language, given differences in clinical scale coverage and symptom distributions across groups.

At the cortical level, the reduced VN-DMN and increased SMN-DMN dispersions previously reported in FEP [29] were not replicated. Group differences emerged only in individual parcels, mostly somatomotor, and not at the level of whole networks. Our findings converge with a recent multisite study of 1,071 participants, in which recent-onset psychosis and depression showed higher SMN values along the visual-to-somatomotor gradient, and between-network dispersion differed only when clinical groups were combined, not in separate diagnostic comparisons [23]. Methodological and sample differences from the previous study [29] may contribute to this discrepancy including field strength (3 T vs 7 T), treatment status, illness stage, language (English vs. German), and the inclusion of a depression group. Because parcel-

wise gradient values and between-network dispersion capture different aspects of cortical organization, localized alterations need not change between-network dispersion Although SemN-G1 dispersion in FEP did not differ from NC after correction, the direction of this difference was consistent with the reduced SemN-G1 dispersion reported previously [29].

Our third aim was to examine whether conceptual and referential relations were associated with gradient organization after controlling for diagnosis and demographics. Within the conceptual dimension, greater VN-DMN and VN-SMN dispersion were associated with higher small-worldness of FastText- and Sentence-Transformer-based semantic graphs. Small-worldness captures the extent to which semantic graphs combine local clustering with relatively short paths between nodes, reflecting the topology of conceptual associations. These findings suggest that individual differences in cortical differentiation may relate to semantic graph organization independently of diagnostic group differences.

The involvement of visual-network dispersion is relevant given that the speech tasks included visually presented stimuli. Generating descriptions of visual scenes requires speakers to select, relate, and linguistically express conceptual information derived from perceptual input. This is compatible with distributed accounts of semantic representation involving modality-specific and multimodal cortical systems [41].

The findings extend previous research linking cortical gradients to conceptual association retrieval [30, 31] and semantic graph organization [29]. Notably, the associations with VN-DMN dispersion were reversed relative to those reported in minimally treated, English-speaking FEP using the same picture-description task [29], where small-worldness was negatively, and centrality and efficiency measures positively, associated with VN-DMN dispersion. The discrepancy may reflect differences in illness stage, field strength (7 T vs 3 T), sample composition, and language (English vs German).

SMN-DMN dispersion showed associations with measures from both dimensions of discourse coherence. These associations suggest that greater SMN-DMN separation occurs in speech in which successive words are more closely related and concepts more locally clustered, but drawn from a less varied vocabulary. The shared association with SMN-DMN dispersion may therefore reflect overlapping demands for organizing conceptual and referential relationships across discourse, without implying that greater functional differentiation necessarily corresponds to more coherent speech.

Referential features showed a more specific pattern of associations with SemN-G1 dispersion. SemN-G1 dispersion was associated with topic reorganization. In German, personal pronouns typically refer to highly prominent discourse entities, whereas demonstrative pronouns preferentially refer to less prominent entities or signal changes in referential prominence and topic [76]. Because *er*/*he* → *der*/*that* shifts reference away from the prominent entity whereas *der*/*that* → *er*/*he* re-establishes it, the opposite signs suggest that SemN-G1 organization relates to the direction of topic reorganization, that is, to how speakers update the relative prominence of discourse entities.

This association is theoretically relevant given that the SemN comprises heteromodal association regions implicated in the integration of information across sensory modalities to support multimodal conceptual representations, alongside medial limbic regions associated with episodic and self-referential processing. Both components belong to the broader transmodal cortex, as distinguished in the Introduction [32,38]. Although we hypothesized that SemN-G1 functional organization would be associated with both conceptual and referential relations, the significant associations observed for SemN-G1 dispersion involved the referential transitions. These results complement previous findings linking SemN-G1

dispersion to syntactic and predicate-structure measures rather than to semantic-graph measures [29].

## Limitations

Several limitations should be acknowledged. First, the cross-sectional design precludes causal inference. Second, the sample was modest, and the imaging sample was smaller than the linguistic sample as five participants declined MRI. This limited our power to detect group differences in gradient dispersion of the magnitude previously reported, so the null results at the network level cannot be interpreted as evidence of absent effects. Third, FEP and DEP did not differ in PANSS Negative or depressive symptom severity, although FEP showed significantly higher SANS scores. Shared alterations may reflect overlapping symptoms rather than a transdiagnostic coherence dimension. Fourth, medication was not controlled, although in a large multisite sample, antipsychotic dose was unrelated to ventral attention network gradient alterations in recent-onset psychosis [23]. Fifth, picture-based tasks may favor visual-network associations, and resting-state fMRI does not capture activity during speech production. Sixth, 3 T acquisition may be less sensitive to subtle gradient differences than 7 T.

## Conclusions

The present study identifies shared alterations in referential continuity and conceptual-network organization in FEP and DEP. Several features that differed between both clinical groups, including semantic-network small-worldness, lexical diversity, and coreference-based closeness centrality, were also associated with gradient dispersion, suggesting them as candidate markers that link coherence alterations to individual differences in cortical organization. Conversely, features that differed robustly between groups, such as indefinite NP use, coreference-chain length, and graph edit distances, were not associated with gradient dispersion. Group differences in discourse coherence and individual brain-language associations may therefore capture partly distinct sources of variation. Together, diagnostic

comparisons, symptom dimensions, and brain-language associations offer complementary perspectives on cognitive-language disturbances and support investigating referential alongside conceptual coherence in transdiagnostic translational research. These coherence markers might eventually help disentangle differential diagnoses and show whether they add clinical value beyond established assessments. Our findings support the need for a multidimensional approach to investigating discourse coherence and cortical hierarchical organization across clinical populations.

**Author contributions:**
Conceptualization: D.Ç., W.H, & KvH, Methodology: D.Ç., MV, R.H. & W.H., Formal analysis: DÇ & MV; Software: MV & RH; Investigation: D.Ç.& MV; Data curation: AB, KV, & JK; Pre-processing MRI Data: AB, Writing-original draft: D.Ç. & MV; Writing, review and editing: D.Ç., MV, KV, AB, WH & KvH; Funding acquisition: D.Ç., JK, KV, KvH &W.H.

**Data availability**

Analysis scripts and gradient features are available at the following link. Raw speech recordings and MRI data cannot be shared publicly to protect participant privacy but are available from the corresponding author upon reasonable request, subject to ethics approval: https://osf.io/z6edn/overview?view_only=00b5962a99884c51a5247f73161d2e6d

**Conflicts of Interest**

The authors declare no competing interests.

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**Figure legends**

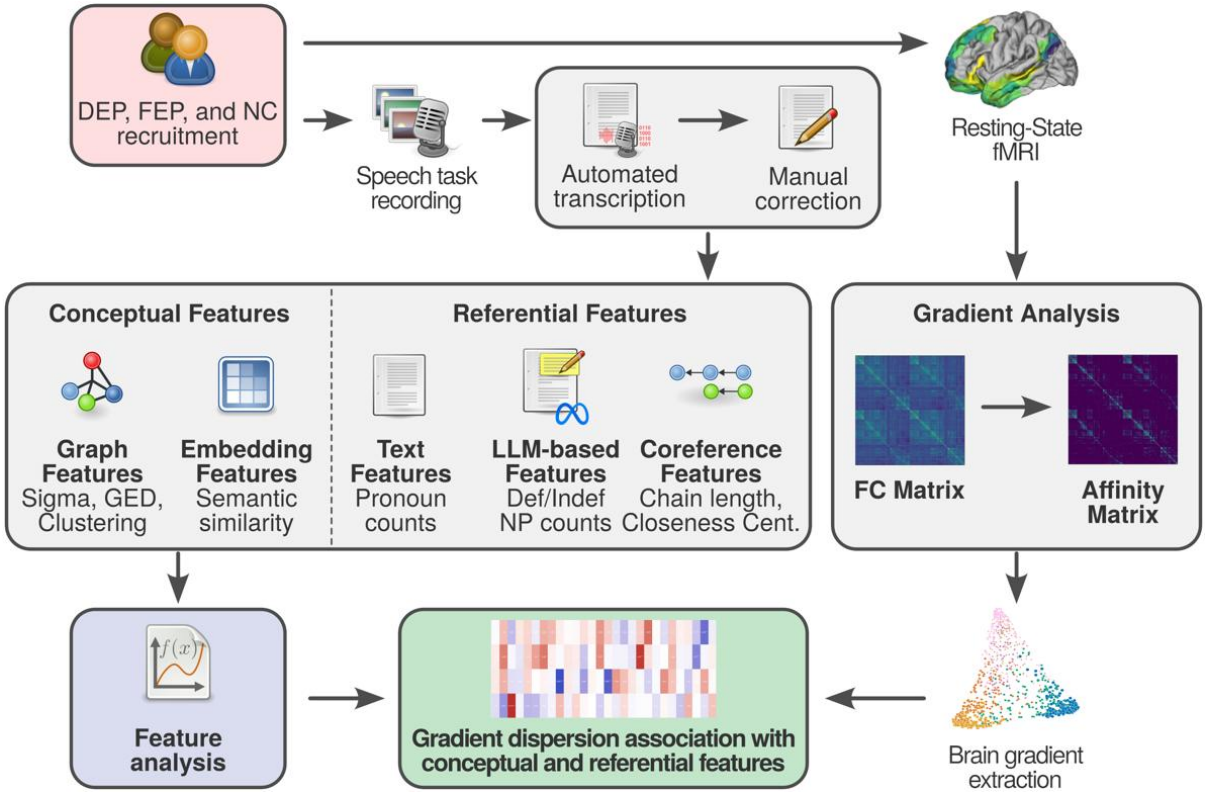
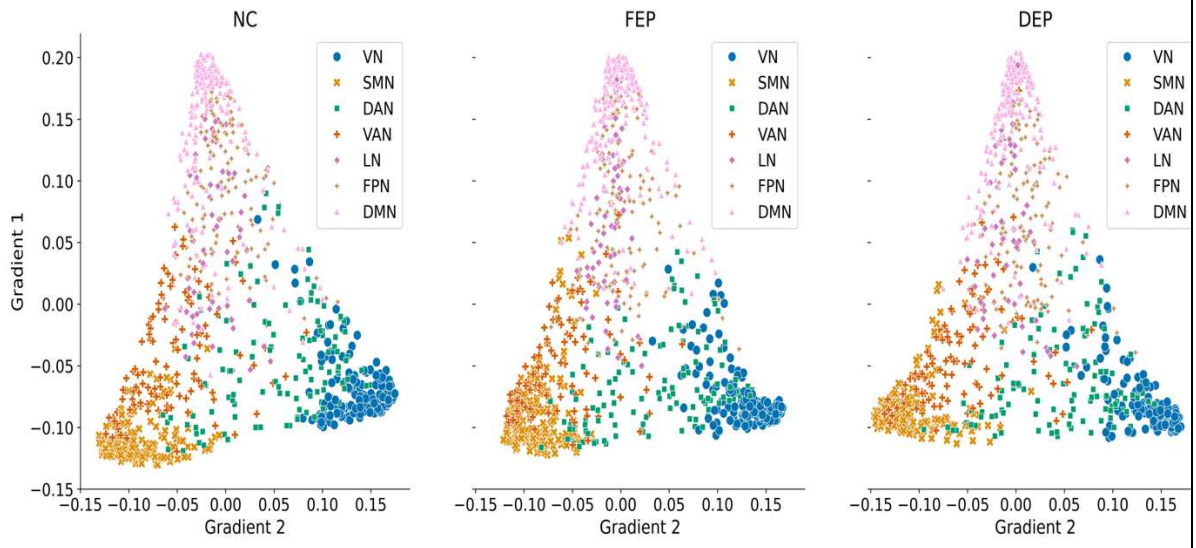
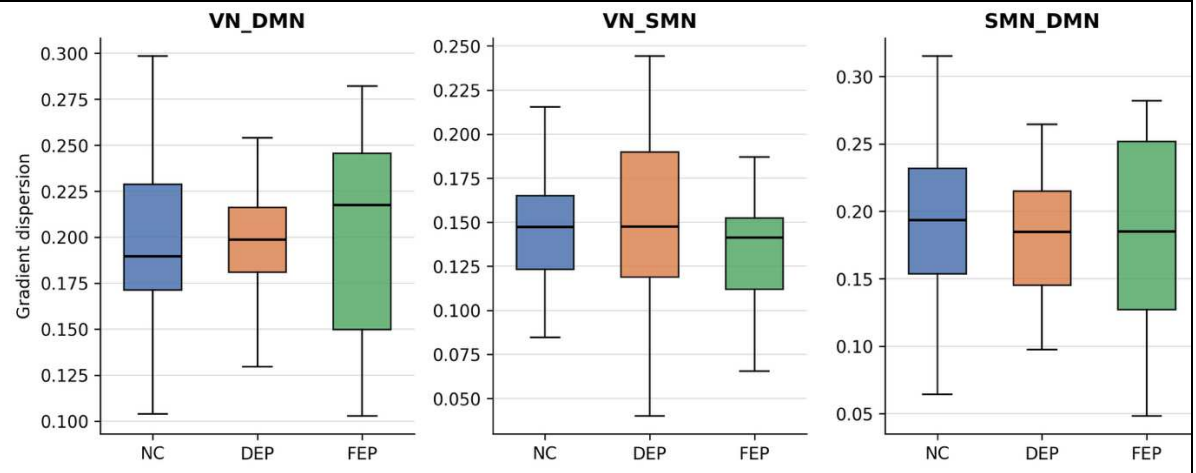


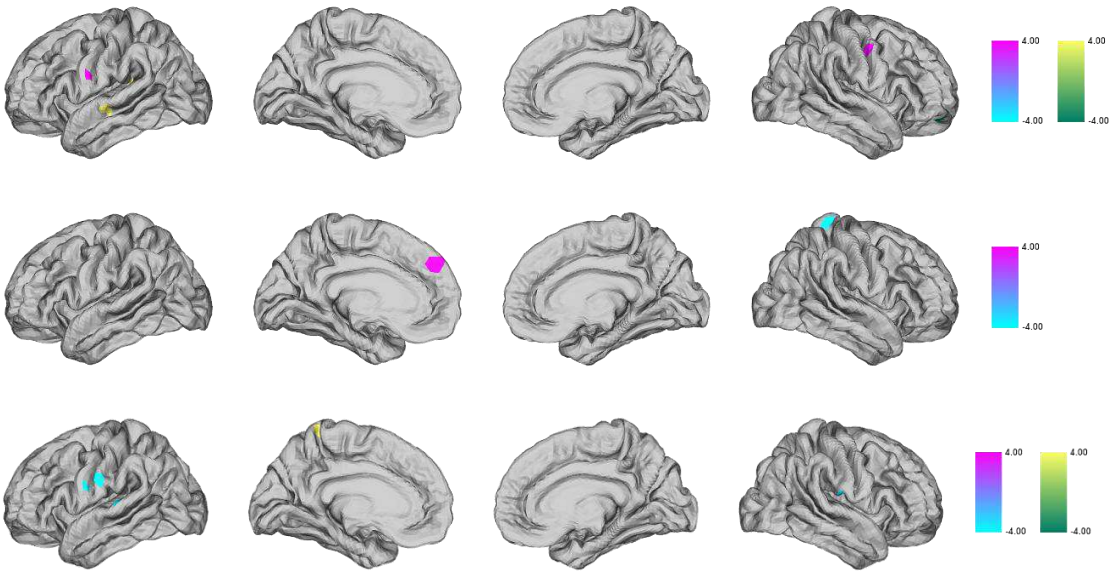

**Fig 1. Workflow of the current study.** The analyses proceeded from the characterization of conceptual and referential relations in spontaneous speech to the examination of cortical functional organization and, finally, to tests of brain-language associations.




(a) Scatter Plots of G1 and G2 across all cortical network in NC, FEP, and DEP.




(b) Group comparisons of gradient dispersion

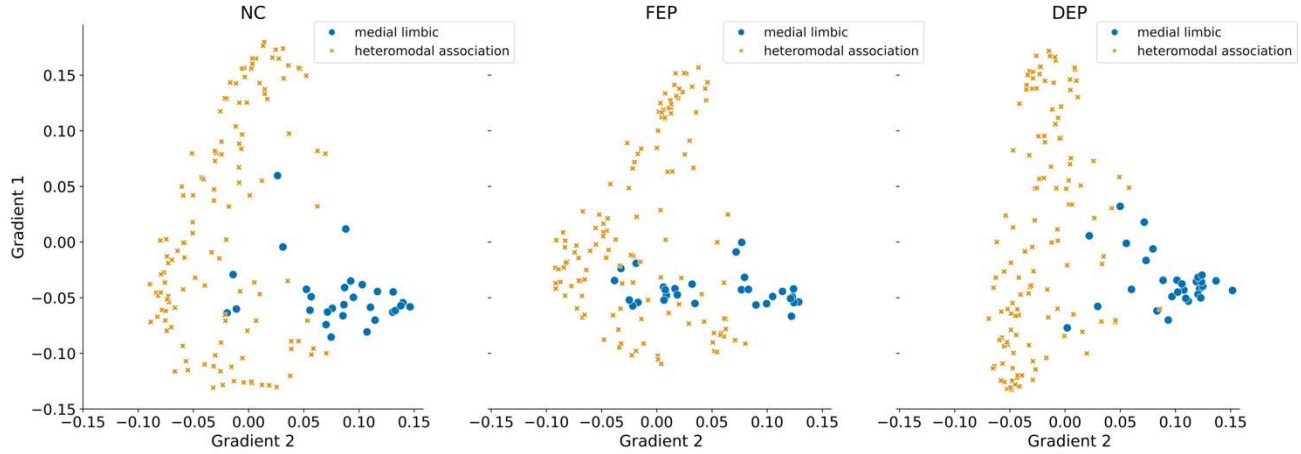



(c) T-Maps of significant differences in G1 (green-yellow scale) and G2 (cyan-pink scale).

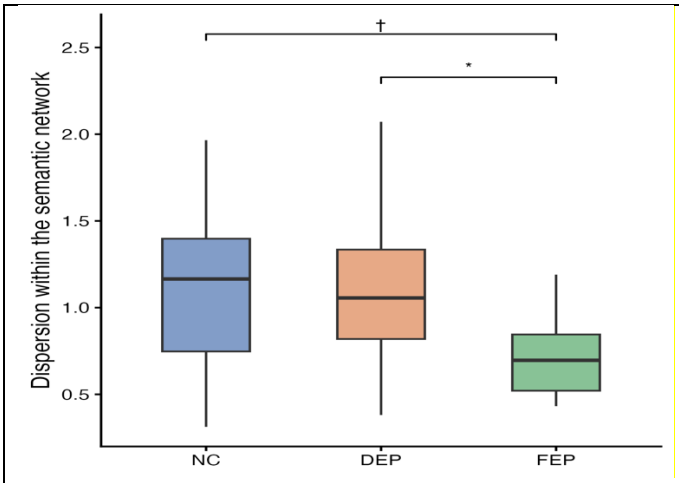
**Fig 2. Cortical functional hierarchy in non-clinical controls, first-episode psychosis and first-episode depression.** (a) Scatterplots of the first (y-axis) and second (x-axis) gradients in non-clinical control persons (NC, left), patients with first-episode psychosis (FEP, middle), and patients with first-episode depression (DEP, right). Each point represents a cortical parcel, colored by its Yeo seven-network assignment: blue = visual (VN); orange = somatomotor (SMN); green = dorsal attention (DAN); red = ventral attention (VAN); purple = limbic (LN); brown = frontoparietal control (FPN); pink = default mode (DMN). G1 reflects the unimodal-to-transmodal hierarchy: VN and SMN anchor its unimodal end and DMN anchors its transmodal end. G2 differentiates the visual system from other somatomotor network: VN and SMN anchor its opposite poles. Thus, VN and SMN lie at the same (unimodal) end of G1 but at opposite ends of G2, whereas DMN anchors only G1 and falls at an intermediate position on G2. DAN, VAN, LN, and FPN occupy intermediate positions on both gradients. (b) Group comparisons of gradient dispersion between VN and DMN (left), VN and SMN (middle), and SMN and DMN (right). No group comparison was significant after FDR correction (Table S3). (c) Parcel-wise *t*-maps showing significant

group differences in G1 (green-yellow scale) and G2 (cyan–pink scale). From top to bottom: FEP vs. NC, DEP vs. NC, and DEP vs. FEP. Only parcels surviving FDR correction at $q < .05$ are displayed. For G1, yellow indicates positive and green indicates negative $t$ values; for G2, pink indicates positive and cyan indicates negative $t$ values. No G1 map is shown for DEP versus NC because no G1 parcels survived correction.

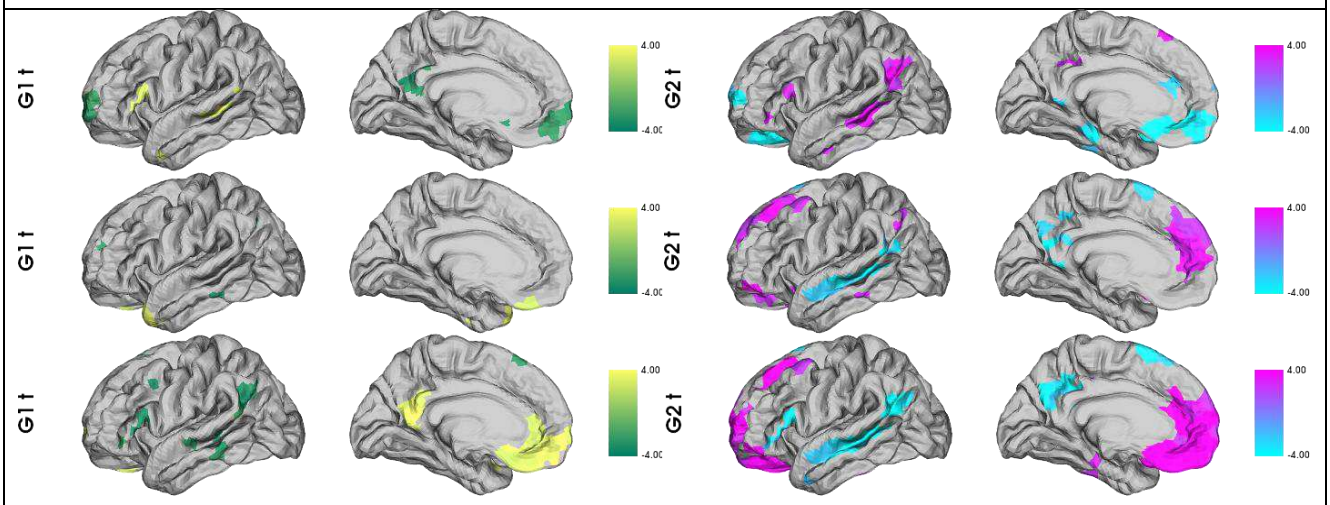
**Fig 2. Cortical functional hierarchy in non-clinical controls, first-episode psychosis and first-episode depression.** (a) Scatterplots of the first (y-axis) and second (x-axis) gradients in non-clinical control persons (NC, left), patients with first-episode psychosis (FEP, middle), and patients with depression (DEP, right). Each point represents a cortical parcel, colored by its Yeo seven-network assignment: blue = visual (VN); orange = somatomotor (SMN); green = dorsal attention (DAN); red = ventral attention (VAN); purple = limbic (LN); brown = frontoparietal control (FPN); pink = default mode (DMN). G1 reflects the unimodal-to-transmodal hierarchy: VN and SMN anchor its unimodal end and DMN anchors its transmodal end. G2 differentiates the visual system from other somatomotor network: VN and SMN anchor its opposite poles. Thus, VN and SMN lie at the same (unimodal) end of G1 but at opposite ends of G2, whereas DMN anchors only G1 and falls at an intermediate position on G2. DAN, VAN, LN, and FPN occupy intermediate positions on both gradients. (b) Group comparisons of gradient dispersion between VN and DMN (left), VN and SMN (middle), and SMN and DMN (right). No group comparison was significant after FDR correction (Table S3). (c) Parcel-wise $t$-maps showing significant group differences in G1 (green-yellow scale) and G2 (cyan-pink scale). From top to bottom: FEP vs. NC, DEP vs. NC, and DEP vs. FEP. Only parcels surviving FDR correction at $q < .05$ are displayed. For G1, yellow indicates positive and green indicates negative $t$ values; for G2, pink indicates positive and cyan indicates negative $t$ values. No G1 map is shown for DEP versus NC because no G1 parcels survived correction.




(a) Scatter Plots of G1 and G2 for the semantic-associative network in NC, FEP, and DEP.




(b) within semantic-associative network dispersion




(c) T-Maps of significant differences in G1 (left) and G2 (right) for the semantic-associative network.

**Fig 3. Group differences in functional-gradient organization within the semantic-associative network**. (a) Scatterplots of the first (y-axis) and the second (x-axis) gradient in non-clinical control persons (NC, left) and patients suffering from first-episode psychosis (FEP, middle), and first-episode depression (DEP, right). Each point represents a SemN parcel, coloured according to its anatomical component: orange = heteromodal association cortex; blue = medial limbic cortex. (b) Group comparisons of SemN-G1 dispersion. Significance levels: † q < .10, * q < .05 (FDR-corrected Mann–Whitney tests; Table S5). (c) Parcel-wise *t*-maps showing significant group differences in G1 (green-

yellow scale) and G2 (cyan–pink scale) for the semantic-associative network. From top to bottom: FEP vs. NC, DEP vs. NC, and DEP vs. FEP. Only parcels surviving FDR correction at $q < .05$ are displayed. For G1, green indicates negative and yellow indicates positive $t$ values; for G2, pink indicates positive and cyan indicates negative $t$ values. SemN-G2 maps are shown for illustration only; our analyses focused on SemN-G1, and SemN-G2 was not analysed further.

**Fig 3. Group differences in functional-gradient organization within the semantic-associative network**. (a) Scatterplots of the first (y-axis) and the second (x-axis) gradient in non-clinical control persons (NC, left) and patients suffering from first-episode psychosis (FEP, middle), and patients with first-episode depression (DEP, right). Each point represents a SemN parcel, colored according to its anatomical component: orange = heteromodal association cortex; blue = medial limbic cortex. (b) Group comparisons of SemN-G1 dispersion. Significance levels: † q < .10, * q < .05 (FDR-corrected Mann-Whitney tests; Table S5). (c) Parcel-wise *t*-maps showing significant group differences in G1 (green-yellow scale) and G2 (cyan–pink scale) for the semantic-associative network. From top to bottom: FEP vs. NC, DEP vs. NC, and DEP vs. FEP. Only parcels surviving FDR correction at $q < .05$ are displayed. For G1, green indicates negative and yellow indicates positive $t$ values; for G2, pink indicates positive and cyan indicates negative $t$ values. SemN-G2 maps are shown for illustration only. Our analyses focused on SemN-G1, and SemN-G2 was not analysed further.

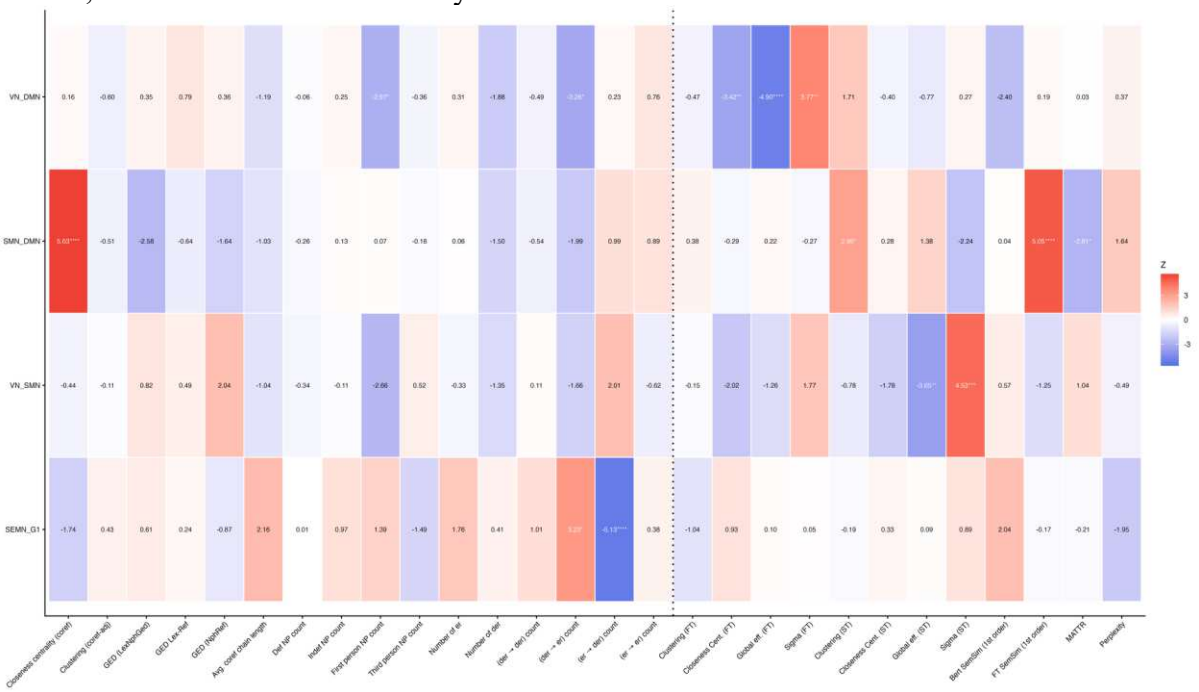



**Fig 4**. **Associations between cortical gradients (y-axis) and coherence dimensions (x-axis).** Rows represent gradient dispersion measures (VN-DMN, SMN-DMN, VN-SMN, and

SemN-G1), and columns represent semantic graph, referential, discourse, and lexical measures. SemN-G1 is within-network dispersion along the SemN-specific principal gradient, calculated as the sum of squared distances of SemN parcels to their centroid. Values correspond to z-statistics from generalized estimating equation (GEE) models in which each dispersion measure was predicted by one linguistic measure, controlling for diagnostic group, age, sex, education, and task. Diagnostic group was entered as a categorical covariate with NC as the reference category. Positive values (red) indicate positive associations, and negative values (blue) indicate negative associations. Statistical significance was assessed using CR2 small-sample-corrected Wald tests and corrected for multiple comparisons using the false discovery rate (FDR). Asterisks indicate FDR-corrected significance levels: *q < .05, **q < .01, ***q < .001, ****q < .0001.

**Table 1**. Demographic and clinical data of non-clinical controls (NC), first-episode psychosis (FEP), and first-episode depression (DEP)

| Characteristic | NC (n = 29) | FEP (n = 28) | DEP (n = 28) | Overall *p* | DEP v. NC | FEP v. NC | DEP v. FEP |
|---|---|---|---|---|---|---|---|
| Age | 23.83 (2.79) | 25.81 (4.91) | 26.19 (5.39) | .182 | .211 | .298 | .787 |
| Education (degree) | 2.41 (0.5) | 1.81 (1.08) | 2.3 (0.87) | .018 | .154 | .025* | .154 |
| Education: level 0 | 0 (0.0%) | 4 (14.8%) | 0 (0.0%) | | | | |
| Education: level 1 | 0 (0.0%) | 4 (14.8%) | 2 (7.4%) | | | | |
| Education: level 2 | 17 (58.6%) | 14 (51.9%) | 19 (70.4%) | | | | |
| Education: level 3 | 12 (41.4%) | 3 (11.1%) | 3 (11.1%) | | | | |
| Education: level 4 | 0 (0.0%) | 2 (7.4%) | 2 (7.4%) | | | | |
| Education: level 5 | 0 (0.0%) | 0 (0.0%) | 1 (3.7%) | | | | |
| Sex, Female n (%) | 17 (59%) | 14 (52%) | 15 (56%) | .961 | 1.000 | 1.000 | 1.000 |
| PANSS Total | 30.69 (1.07) | 61.04 (16.05) | 48.36 (10.8) | < .001 | < .001*** | < .001*** | .002** |
| PANSS Positive | 7.1 (0.31) | 13.82 (5.91) | 8.39 (1.83) | < .001 | < .001*** | < .001*** | < .001*** |
| PANSS Negative | 7 (0) | 15.21 (6.21) | 13.89 (6.23) | < .001 | < .001*** | < .001*** | .397 |
| PANSS General | 16.59 (0.95) | 32 (9.22) | 26.07 (5.92) | < .001 | < .001*** | < .001*** | .009** |
| QIDS Total | 3.83 (3.67) | 12.89 (6.9) | 13.11 (6.58) | < .001 | < .001*** | < .001*** | .876 |

| Characteristic | NC (n = 29) | FEP (n = 28) | DEP (n = 28) | Overall *p* | DEP v. NC | FEP v. NC | DEP v. FEP |
|---|---|---|---|---|---|---|---|
| BDI Total | 2.35 (3.73) | 18.95 (11.23) | 20.25 (11.15) | < .001 | < .001*** | < .001*** | .716 |
| CTQ Total | 18.41 (4.31) | 32.75 (14.29) | 28.04 (11.8) | < .001 | < .001*** | < .001*** | .221 |
| SAPS Total | — | 14.21 (12.48) | 2.5 (3.33) | < .001 | — | — | < .001*** |
| SANS Total | — | 28.32 (13.42) | 13.54 (9.72) | < .001 | — | — | < .001*** |
| SAPS Hallucinations | — | 1.46 (1.97) | 0.21 (0.5) | .015 | — | — | .015* |
| SAPS Delusions | — | 1.86 (1.69) | 0.14 (0.36) | < .001 | — | — | < .001*** |
| SAPS Thought Disorder | — | 1.64 (1.45) | 0.25 (0.52) | < .001 | — | — | < .001*** |

Note. Values are mean (SD) unless otherwise indicated. Education and sex were unavailable for one FEP and one DEP participant; percentages and tests for these variables are based on available data (NC n = 29, FEP n = 27, DEP n = 27). q = Benjamini-Hochberg FDR-corrected p-value. Continuous variables and ordinal education level were compared using Kruskal-Wallis rank-sum tests, followed by pairwise Wilcoxon rank-sum tests. Sex was compared using Fisher's exact test. SAPS and SANS scores were analysed in patient groups only. Significance symbols: ***q < .001, **q < .01, *q < .05, †q < .10. Education levels correspond to the German educational system: Level 0 = no school-leaving certificate (kein Schulabschluss), Level 1 = lower secondary school certificate (Hauptschulabschluss), Level 2 = intermediate secondary school certificate (Realschulabschluss/Mittlere Reife), Level 3 = university entrance qualification (Fachabitur/Abitur), Level 4 = completed vocational training (Berufsausbildung), and Level 5 = university degree (Bachelor, Master, Diplom, Staatsexamen, or equivalent).

**Abbreviations:** PANSS, Positive and Negative Syndrome Scale (positive, negative, and general psychopathology subscales); SAPS, Scale for the Assessment of Positive Symptoms; SANS, Scale for the Assessment of Negative Symptoms; QIDS, Quick Inventory of Depressive Symptomatology; BDI, Beck Depression Inventory; CTQ, Childhood Trauma Questionnaire.

**Table 2. Dimensions of coherence with definitions and examples**

**Example:** *A watchman notices with his telescope that a ship is approaching. He tries to warn the ship that the coast is dangerous.*

*But then he notices that the power is out.*

**Table 2a: Conceptual Relations**

| Level | Feature | Definition | Example |
|---|---|---|---|
| Word | MATTR | Moving Average Type–Token Ratio; vocabulary diversity computed over a sliding window. | Varied words such as *watchman, telescope, ship, coast, dangerous,* and *power* contribute to lexical diversity. |
| Word/phrase | FastText (FT) Semantic similarity (SemSim) (first order); BERT SemSim (first order) | Average cosine similarity between consecutive word or phrase embeddings. | Semantically related units, such as *ship–coast* and *power–out*, produce higher similarity than unrelated units. |
| Network | Sigma (FT) & Sentence Transformer (ST) | Small-worldness coefficient: normalized clustering coefficient divided by normalized path length. | *Ship, coast,* and *dangerous* form a semantically related cluster, while *watchman, telescope,* and *power* remain reachable through relatively few links. |
| Network | Clustering (FT/ST) | Average clustering coefficient of semantic discourse graphs; the proportion of closed triangles. | The related concepts *ship, coast,* and *dangerous* form a semantic cluster. |
| Network | Closeness centrality (FT/ST) | Average inverse shortest-path distance between nodes in the semantic graph. | *Ship* is connected through short paths to *watchman, coast,* and *dangerous*, giving it relatively high closeness centrality. |
| Network | Global efficiency (FT/ST) | Average efficiency of connections across the semantic graph, based on inverse shortest-path distances. | The concepts form an integrated network in which *watchman* and *coast* can be connected through *ship* using relatively few links. |

**Table 2b: Referential Relations**

| Level | Feature | Definition | Example |
|---|---|---|---|
| Topic introduction | Indefinite noun phrase (Indef NP) count | Number of indefinite noun phrases used to introduce new referents. | *A watchman* introduces a new entity. |
| Topic maintenance | Definite NP count, Third-person count (e.g., *he*) | Number of definite NP and pronoun used to identify or reidentify discourse referents. | The ship reidentifies the previously introduced ship. |
| Topic shift | Demonstrative count | Frequency of demonstratives marking a shift in topic. | *Der (that one)* changes topic. |
| Topic reorganization | *Er*[1] → *der*[2] count, *der* → *er* count, *der* → *der* count, er[1] → er | Frequency of referential-form transitions. | *Er*/*he* → der/*that one* represents a referential-form change |
| Perspective taking | First-person NP count | Number of expressions referring to the speaker. | The discourse contains *I* or *we* as first-person pronouns. |
| Information organization | Average coreference-chain length | Average number of mentions belonging to the same coreference chain, indexing referential persistence. | *A watchman* → *his* → *He* forms a three-mention chain, while *a ship* forms a two-mention chain. |
| Coreference network | Clustering (coref-adj)<br>Closeness centrality (coref)<br>Global efficiency (coref) | Graph measures indexing local interconnectedness, centrality, and global integration within the coreference network. | The recurring *watchman* and ship mentions are interconnected because both chains participate in the warning event. |
| Graph edit distance (GED) | Lex–Nph (lexical-conceptual)<br>Nph–Ref (phrasal-semantic)<br>Lex–Ref (lexical-conceptual) | Graph edit distance between pairs of lexical-conceptual, phrasal-semantic, and coreference graphs, quantifying their structural dissimilarity. | Lex–Nph compares lexical-conceptual and phrasal-semantic graphs; Nph–Ref compares phrasal-semantic and coreference graphs. |

Note. BERT = Bidirectional Encoder Representations from Transformers; coref = coreference graph; coref-adj = adjacency-based coreference graph; Def = definite; *der* [2]= demonstrative pronoun (*that one*); *er*[1] = third-person personal pronoun (*he*); FT = FastText; GED = graph edit distance; GPT-2 = Generative Pre-trained Transformer 2; Indef = indefinite; Lex = lexical-conceptual graph; MATTR = moving-average type–

token ratio; Nph = phrasal-semantic (noun-phrase) graph; NP = noun phrase; Ref = coreference graph; SemSim = semantic similarity; ST = Sentence Transformer; σ = small-worldness coefficient.

## Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryMaterials17102026.docx