Semantic coherence in psychometric schizotypy: an investigation using Latent Semantic

Analysis

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Abstract:

Technological advancements have led to the development of automated methods for assessing semantic coherence in psychiatric populations. Latent Semantic Analysis (LSA) is an automated method that has been used to quantify semantic coherence in schizophrenia-spectrum disorders. The current study examined whether; 1) Semantic coherence reductions extended to psychometrically-defined schizotypy and 2) Greater cognitive load further reduces semantic coherence. LSA was applied to responses generated during category fluency tasks in baseline and cognitive load conditions. Significant differences between schizotypy and non-schizotypy groups were not observed. Findings suggest that semantic coherence may be relatively preserved at this point on the schizophrenia-spectrum.

Keywords:

schizotypy, latent semantic analysis; semantic coherence

1. Introduction

People with schizophrenia often exhibit gross reductions in semantic coherence (Breier and Berg, 1999). Following recent technological advances, computational assessments of semantic coherence have emerged that are potentially more objective, faster, and require less training compared to traditional symptom-rating measures (Cohen and Elvevag, 2014; Elvevag et al., 2007; Elvevag et al., 2010). Latent Semantic Analysis (LSA; Landauer and Dumais, 1997; Landauer et al., 1998) is one computational method that has shown promise for differentiating semantic coherence in schizophrenia-spectrum samples from healthy controls (Bedi et al., 2015; Davis et al., in preparation; Elvevag et al., 2007; Elvevag et al., 2010; Nicodemus et al., 2014). LSA is a statistical technique that enables quantification of semantic coherence in transcribed speech passages; it is based on the principle that when examined across large corpora, semantically-related words or groups of words occur together more frequently compared to words that are not semantically related (see Landauer and Dumais; 1997 and Landauer et al., 2007 for more details). LSA can be used to generate variables that assess different aspects of semantic coherence. In the schizophrenia literature, average cosine and vector length are commonly used metrics of semantic coherence (Elvevag et al.,2007; Elvevag et al., 2010; Halshausen et al., 2014; Nicodemus et al., 2014). Average cosine is a measure of the degree of semantic relatedness between sequences of words or sentences; whereas vector length is a quantification of the typicality or unusualness of each word.

While LSA has typically been applied to free speech samples, several studies have used LSA to examine semantic coherence of sequential responses on structured speech tasks, namely, category fluency tasks (Elvevag et al., 2007[Experiment 2]; Holshausen et al., 2014; Nicodemus et al., 2014; Davis et al., in preparation). Category fluency tasks are likely to provide a fertile

context for examining semantic coherence as the nature of the task requires participants to quickly generate exemplars from specific semantic category. Schwartz and colleagues (2003) describe an application of the "spreading activation" theory in category fluency tasks, noting that the structure and organization of memory network is such that words are conjointly activated depending on their semantic proximity. In addition to semantic information processing, there is an executive functioning component - inhibiting and monitoring responses –believed to be involved in this task (Crawford and Henry, 2005). Semantic information processing and executive function impairments have been found to be associated with formal thought disorder in schizophrenia patients (Kerns and Berenbaum, 2002) indicating semantic coherence and verbal fluency performance may be driven by the same underlying cognitive processes.

Using a category fluency task, Elvevag and colleagues (2007) observed reductions in semantic coherence in schizophrenia patients by applying LSA to responses on a category fluency task. Davis and colleagues (in preparation) found a similar pattern of results in an early psychosis sample. In a larger sample, Nicodemus et al., (2014) differentiated schizophrenia patients from unaffected first degree family member and healthy controls based on LSA-derived measures of semantic coherence using responses generated on a category fluency task. Although LSA has been used to demonstrate reduced semantic coherence in early and chronic stages of psychosis, it is unknown if semantic coherence is also reduced in individuals with schizotypy— those who endorse attenuated schizophrenia-like traits and are at increased risk for developing psychotic and other psychiatric disorders (Gooding et al., 2005; Meehl, 1962). Reductions in semantic coherence could be particularly important to the development of psychotic disorders, as Bedi et al., (2015) found that LSA-derived indices of semantic coherence predicted conversion to psychosis in clinically high risk (CHR) youths.

The presence of additional cognitive demand may further reduce semantic coherence in schizophrenia-spectrum populations. According to cognitive load theory (Sweller, 1983), greater cognitive load reduces the cognitive resources in working memory that are available to other functions such as producing semantically coherent speech; in turn, performance on both tasks suffer. Although cognitive-load's effect on semantic coherence hasn't been explicitly examined in schizotypy, a recent meta-analysis of neurocognitive performance in psychometric schizotypy (Chun, et al., 2013) revealed that working memory deficits (d = -.27) were the most affected domain in this population, suggesting a particular vulnerability to increased cognitive load. Further, Kerns and Becker (2008) found that working memory performance significantly predicted reductions on a behaviorally-based measure of semantic coherence, after accounting for schizotypy status. Taken together, these results indicate that working memory may play a critical role in semantic coherence in schizotypy. If diminished semantic coherence – a core deficit of schizophrenia – and cognitive reactivity are present in individuals at-risk for, but not yet experiencing, overt psychosis symptoms, this would suggest that subtle discourse deviations may be identifiable risk factors for schizophrenia. In this study, when compared to a non-schizotypy group, we expected those with schizotypy to exhibit: 1) Reduced semantic coherence, as measured by average cosine and vector length values; and 2) A steeper decline in semantic coherence from baseline to cognitive load conditions. An exploratory aim of this study was to examine whether semantic coherence variables would be associated with positive, negative, or disorganized schizotypy traits.

2. Method

2.1. Sample

Participants were recruited from a public university in the Southeastern United States.

Participants were recruited via e-mail to complete a schizotypy questionnaire on-line and were

compensated by receiving course credit if offered by the instructor or were entered into a

drawing to win a $25 gift card. A total of 1,296 participants completed the schizotypy

questionnaire. Schizotypy and non-schizotypy groups were determined from questionnaire

responses using gender- and ethnicity- derived means. Individuals included in the schizotypy

group obtained a *z*-score >1.65 above the mean (above the 95th percentile) on positive, negative

or disorganized subscales; while those in the non-schizotypy group scored obtained z-scores <

mean on *each* of the three subscales. Individuals who met criteria for either group (non-

schizotypy or schizotypy) were invited to the laboratory for further testing. Eighty participants

were included in the final sample (schizotypy *n* = 42; non-schizotypy *n* = 38). All study

procedures were approved by the university's institutional review board. Groups did not

significantly differ on age, gender, ethnicity, or verbal intelligence (see Table 1).

2.2. Measures

The Schizotypy Personality Questionnaire – Brief Revised (SPQ-BR; Cohen et al., 2010)

consists of 34 Likert-scale items (1 = *Strongly Disagree*, 5 = *Strongly Agree*) and was used here

to assess schizotypy. It has shown good internal consistency across all three subscales (positive,

negative, and disorganized). Previous research suggests individuals with elevations on

schizotypy measures to be at an increased risk for developing psychotic and other psychiatric

disorders (Chapman et al., 1994).

Category fluency tests were administered across three conditions (two baseline and one

cognitive load) and each participant completed all three conditions. For each condition,

participants had 60 seconds to provide as many examples of a category as possible. In cognitive load conditions, participants provided examples while simultaneously completing a computerized '1-back' task which consisted of 30 geometric shapes presented consecutively on a computer screen. Participants were instructed to press the "S" key if the shape on-screen was the same as the previous shape or the "L" key if the shape was not the same. Two categories (fruit, vegetable) were counterbalanced across participants, so that approximately half of the participants completed the fruit test in baseline condition and the vegetable test in the cognitive load condition, and vice versa. The order in which participants completed the cognitive load and baseline conditions was counterbalanced. Additionally, all participants completed a second baseline test (animals) so that results could be compared directly to previous studies (Davis et al., in preparation; Elvevag et al., 2007). The second baseline test was always completed last.

Two LSA-derived variables were generated to assess semantic coherence: average cosine and vector length. Average cosine scores were calculated for each participant on the three category fluency tests following steps outlined in Elvevag and colleagues (2007). The semantic space consisted of a large text corpus composed of the type and amount of reading to which an average first-year college student would be exposed. This corpus consists of 37,561 documents 92409 unique words (http://lsa.colorado.edu/) Analyses were conducted using 300 dimensions. This corpus and dimensional representation is consistent with Elvevag' et al., (2007) analytic approach. Word-to-word comparisons were used, with each value being represented by a cosine ranging from -1 to +1. For each test, cosines were averaged for the participant by summing cosine values for each sequential comparison and dividing by the number of word-to-word comparisons, resulting in a mean coherence score adjusted for number of words generated. Greater positive values indicated greater semantic coherence (see Elvevag et al., 2007; Foltz et

al., 1998 for more detail). For example, if a participant generated: 'carrot, radish, cucumber' on the vegetable-naming fluency test, the similarity of each word to the next would be calculated as: carrot $\rightarrow$ radish (cosine = 0.32), radish $\rightarrow$ cucumber (cosine = 0.29) resulting in an average cosine of 0.31 (0.32 + 0.29 = 0.61/2).

As a second measure of semantic coherence, vector length values were calculated for each response as a measure of word unusualness. Vector length quantifies the amount of informational value provided by each response, with low frequency (unusual) words generally having higher vector length values. Average vector length scores were calculated for each participant on each task, by summing the vector length scores of each response and dividing by the total number of responses. We observed that responses containing two words had higher vector lengths than responses containing one word (e.g. "red pepper" = 2.01 versus "pepper" = 0.4). We controlled for multi-word responses by dividing vector length by the number of words contained in the response (e.g. "red pepper" = 2.01/2 = 1.01).

2.3 Analysis

Two 2×2 repeated-measures analysis of variance (ANOVA) were conducted. Group (schizotypy, non-schizotypy) served as the between-subjects independent variable (IV) and condition (baseline, cognitive) served as the within subjects IV. For the first analysis semantic coherence served as the dependent variable. For the second analysis vector length, served as the dependent variable. A series of independent-samples *t*-tests were also conducted to examine group differences on each category fluency measure. Finally, correlations were conducted within the schizotypy group to test relationships between specific schizotypy traits (positive, negative, disorganized) and LSA variables (average cosine, vector length) in baseline and cognitive conditions.

3. Results

3.1 Verbal Fluency Performance

As reported elsewhere (Minor et al., 2015), groups did not differ with respect to number of words generated in either the baseline or cognitive conditions. There was a significant main effect of condition, indicating that fewer words were produced in the cognitive load condition compared to the baseline condition across both groups (see Table 2 for fluency performance data).

3.2 LSA Analysis in Low and High Conditions

Prior to analysis, we observed that the vegetable-naming test produced higher cosine and vector length values than the fruit-naming fluency task in both the baseline and cognitive load conditions (see Table 3). To compare group performance, raw average cosine and vector length scores were standardized (i.e. converted to z-scores) for each participant. Results of the first analysis suggested that our hypothesis that the schizotypy group would demonstrate less semantic coherence across category fluency tests was not supported, $F(1,78) = 1.14$, $p = 0.29$. A similar pattern emerged on the animal naming test, with no observed group differences in semantic coherence, $t(78) = -1.44$, p = 0.15. The main effect of condition also did not reach the level of significance, $F(1,78) = 0.47$, $p = 0.49$, indicating that semantic coherence did not differ from baseline to cognitive load conditions. There was also no group $\times$ condition interaction, $F(1,78) = 0.66$, $p = 0.42$, indicating that our hypothesis that the schizotypy group would

demonstrate a sharper decline in semantic coherence from baseline to cognitive load condition was not supported.

The results of the ANOVA with vector length serving as the dependent variable indicated that groups did not differ on a measure of word unusualness across category fluency tests, $F(1,78) = 0.56$, $p = 0.46$. Similar results emerged for the animal-naming test, with no group differences in average vector length, $t(78) = 0.68$, $p = 0.50$. The main effect of condition was not significant, $F(1,78)$, $p = 0.69$, indicating that vector length did not differ from baseline to cognitive-load conditions. The group × condition interaction also failed to reach significance, $F(1,78) = 0.11$, $p = 0.74$, indicating the schizotypy group did not experience a steeper change in average vector length moving from baseline to cognitive conditions.

3.3 Relationship between LSA variables and Schizotypy traits.

Within the schizotypy group, bivariate correlations were calculated to examine the relationship between schizotypy traits (positive, negative, disorganized) and LSA variables across study conditions. Positive schizotypy traits were associated with coherence in the cognitive load condition, $r(42) = 0.35$, $p = 0.02$; however there were no significant relationships between schizotypy traits and any other LSA variables (see Table 5).

4. Discussion

Our primary goal was to examine semantic coherence in psychometric schizotypy across baseline and cognitive conditions. Previous LSA studies in early psychosis (Davis et al., in preparation) and chronic schizophrenia (Elvevag et al., 2007; Holshausen et al., 2014; Nicodemus et al., 2014) have shown reductions in semantic coherence. Our findings suggest

reductions, as measured by sequential coherence and word unusualness, do not extend to psychometric schizotypy. This may reflect a genuine lack of impairment in semantic coherence at this point on the schizophrenia-spectrum. In general, this is consistent with previous psychometric schizotypy studies which have found little objective impairment across several functional domains, despite reports of subjective impairment resembling outpatients with schizophrenia (Chun et al., 2013). However, in a clinical high risk sample, Bedi and colleagues (2015) found that semantic coherence was an important indicator for conversion to psychosis, suggesting that semantic coherence could be a useful prognostic indicator. It is possible that differences in semantic coherence exist within the schizotypy group – between those who will convert and those who will not. Given that theoretically only a small proportion of those with schizotypy eventually convert to psychosis, differences at the broader group level may not be able to be detected. Similarly, Nicodemus and colleagues (2014) found differences in semantic coherence between schizophrenia patients and controls but not between first-degree relatives and controls. Taken together, these findings suggest that putative risk alone may not result in reduced semantic coherence in schizophrenia-spectrum disorders.

An additional aim of the study was to examine relationships between LSA scores and schizotypy traits. Positive schizotypy and semantic coherence under cognitive load was the only significant relationship that emerged. It is unclear why having a higher level of positive schizotypy would result in better sequential coherence under the cognitive load condition. It was somewhat surprising that disorganized schizotypy traits were not significantly linked to any of the semantic coherence variables given that the subscale is partially comprised of traits assessing unusual or odd speech characteristics. Perhaps this is another example of the inconsistency

between subjective impairment (e.g., self-reported disorganization) and objective non-impairment (e.g. semantic coherence using LSA) in schizotypy.

In line with previous LSA studies in schizophrenia and clinical high risk samples, we implemented a task designed to elicit verbal output. Verbal fluency tasks are highly structured and produce a limited range of verbal output (e.g. category exemplars) and thus, may not truly reflect coherence as is relates to conversational discourse. It is possible that average cosines and vector length values are not sensitive enough to detect decreased semantic coherence under the constraints of this task; whereas previous studies that have tested semantic coherence in schizotypy (Minor et al., 2011; Minor and Cohen, 2012) and clinical high risk samples (Bedi et al., 2015) have used natural speech. Another limitation of the verbal fluency task is that there are a wide array of approaches one could use to complete this task. Participants are instructed to generate as many words as possible and retrieving semantically-related exemplars is just one strategy. It is possible that some participants may have organized their approach using a different strategy (e.g. phonological – all vegetables that start with the letter "p", then "b", etc) that may have resulted in lower semantic coherence scores.

Although recent findings from our lab indicate lower fluency in the cognitive load condition (Minor et al., 2015), results from the current study suggest that semantic coherence is not affected as participants progressed from baseline to cognitive load conditions. Although a similar cognitive load task to the one designed for this study has been shown to tax resources in a first episode sample (see Minor et al., 2016), it might be the case that the 1-back task did not sufficiently challenge the college students in this study enough to disrupt semantic coherence. Alternatively, it is also possible that by generating fewer words on fluency tests in the cognitive load condition, semantic activation networks may have been more restricted in this condition

(e.g. generating only "jungle" animals) and cognitive resources were not sufficient to activate broader semantic categories. This would explain why, despite generating fewer exemplars in the cognitive load condition, semantic coherence did not decrease. Future studies should examine LSA-derived coherence and vector length in natural speech and implement a cognitive load task that is more cognitively demanding in order to determine whether cognitive reactivity could be elicited. The use of an undergraduate sample is both a strength and limitation of the study. Undergraduate samples are commonly used in psychometric schizotypy studies (Becker and Kerns, 2008; Minor and Cohen, 2010) and are near the peak age of onset for schizophrenia-spectrum disorders. However, this could also limit our ability to observe group differences, given that these individuals are functioning well enough to maintain enrollment in college. Another limitation is that '1-back' performance was not recorded. Examining performance could potentially reveal participants' strategies in the dual-task condition (e.g., focusing cognitive resources on generating category exemplars while ignoring the '1-back' test).

In this study, semantic coherence was assessed in psychometric schizotypy using LSA. Contrary to hypotheses, reductions in semantic coherence were not observed. Furthermore, cognitive load did not decrease semantic coherence in either group. Future studies should examine semantic coherence in community-based schizotypy samples to determine if reductions can be detected in these at-risk populations.

Conflicts of interest:

None.

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Table 1: Demographic Information

	Schizotypy (n = 42)	Non-schizotypy (n = 38)	
	Mean (SD)	Mean (SD)	
Age	19.48 (1.61)	18.94 (1.09)	$p = 0.09$
Gender	79% female	71% female	$p = 0.44$
Ethnicity	89% Caucasian	83% Caucasian	$p = 0.60$
Verbal Intelligence (WRAT 4)	105.15 (10.66)	104.19 (11.75)	$p = 0.71$

Note: WRAT 4 = Wide Range Achievement Test, 4th edition (Wilkinson and Robertson, 2006);

SD = standard deviation

Table 2: Group performance on verbal fluency tasks (number of valid exemplars generated)

Category Fluency Test	Schizotypy (n= 42)		Non-schizotypy (n = 38)	
	Mean	SD	Mean	SD
Baseline	13.05	3.88	13.05	3.85

Cognitive Load	11.26	4.05	11.24	3.66

Note: SD = standard deviation

Table 3: Average cosine across category fluency conditions

	Schizotypy ($n = 42$)			Non-schizotypy ($n = 38$)			Effect size
Category Fluency Test	n	M (SD)	z	n	M (SD)	z	d
Animal Baseline	42	0.28 (0.04)	0.15	38	0.26 (0.05)	-0.17	0.44
Vegetable Baseline	20	0.37 (0.06)	0.05	22	0.31 (0.06)	-0.04	1.00
Fruit Baseline	22	0.22 (0.06)	0.09	16	0.21 (0.05)	-0.12	0.18
Vegetable Cognitive Load	22	0.31 (0.08)	0.10	16	0.30 (0.05)	-0.14	0.15
Fruit Cognitive Load	20	0.22 (0.04)	0.08	22	0.21 (0.04)	-0.12	0.25

Note: M: mean cosine values for raw scores; SD = standard deviation for raw scores; z: average cosine values for standardized scores; d = Cohen's effect size

Table 4: Vector length across category fluency conditions

	Schizotypy ($n = 42$)	Non-schizotypy ($n = 38$)	Effect

Category Fluency Test	n	M (SD)	z	n	M (SD)	z	size d
Animal Baseline	42	0.91 (0.22)	-0.07	38	0.94 (0.16)	0.08	0.16
Vegetable Baseline	20	0.39 (0.11)	0.02	22	0.39 (0.09)	-0.02	0.10
Fruit Baseline	22	0.28 (0.07)	0.22	16	0.24 (0.04)	-0.31	0.70
Vegetable Cognitive Load	22	0.38 (0.12)	0.04	16	0.37 (0.11)	-0.06	0.09
Fruit Cognitive Load	20	0.27 (0.06)	0.06	22	0.27 (0.05)	-0.05	0.00

Note: M: mean semantic coherence values for raw scores; SD = standard deviation for raw scores; z: average semantic coherence values for standardized scores; d = Cohen's effect size

Table 5: Correlations between LSA variables and schizotypy traits in the schizotypy group

	Schizotypy Group (n=42)					
	Positive Traits		Negative Traits		Disorganized Traits	
	r	p	r	p	r	p
Coherence Baseline	-0.12	0.44	-0.03	0.87	0.06	0.70
Coherence cognitive load	0.35	0.02	0.12	0.43	0.02	0.91
Vector Length Baseline	-0.03	0.88	-0.06	0.72	-0.27	0.09
Vector Length Cognitive Load	0.03	0.88	0.19	0.23	-0.15	0.33

Highlights:

- Latent semantic analysis was used to assess semantic coherence in schizotypy.

- Semantic coherence was examined across baseline and cognitive load conditions.

- Semantic coherence did not differ between groups or within conditions.