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4

5 **Neuroanatomical correlates of macrolinguistic aspects in narrative discourse in**
6 **unilateral left and right hemisphere stroke: A voxel-based morphometry study**

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45

46 **Abstract**

47 A growing body of literature has demonstrated the importance of discourse assessment
48 in patients who suffered from brain injury, both in the left and in the right hemisphere,
49 as discourse represents a key component of functional communication. However, little
50 is known about the relationship between grey matter density and macrolinguistic
51 processing. This study aimed to investigate this relationship in a group of participants
52 with middle-low to low socioeconomic status. Twenty adults with unilateral left
53 hemisphere (LH, n = 10) or right hemisphere (RH, n = 10) chronic ischemic stroke and
54 10 matched (age, education and socioeconomic status) healthy controls (HC) produced
55 three oral narratives based on sequential scenes. Voxel-based morphometry (VBM)
56 analysis was conducted using structural magnetic resonance imaging (MRI). Compared
57 to HC, the LH group showed cohesion impairments whereas the RH group showed
58 impairments in coherence and in producing macropropositions. Cohesion positively
59 correlated with grey matter (GM) density in the right primary sensory area
60 (PSA)/precentral gyrus and the *pars opercularis*. Coherence, narrativity, and index of
61 lexical informativeness were positively associated with the left PSA/insula and the
62 superior temporal gyrus (STG). Macropropositions were mostly related to the left
63 PSA/insula and STG, left cingulate, and right primary motor area/insula. Overall, the
64 present results suggest that both hemispheres are implicated in macrolinguistic
65 processes in narrative discourse. Further studies including larger samples and with
66 various socioeconomic status should be conducted.

67 **Keywords:** narrative oral production; macrolinguistic processing; cohesion; coherence;
68 lexical informativeness; stroke; left hemisphere; right hemisphere; brain density.

69

70

71 **Introduction**

72 The study of complex communication abilities, such as discourse, can contribute
73 to the diagnosis and treatment of atypical language processing, which explains the wide
74 clinical applications of this type of study (Bryant et al., 2017). Besides, some atypical
75 linguistic processes are better documented in discourse production and/or
76 comprehension rather than in isolated words or sentences (Coelho et al., 2012;
77 Thompson et al., 2012). Discourse may be modulated by *linguistic aspects*, such as text
78 genres and complexity, or presentation modality (whether visual or auditory). Discourse
79 may also be modulated by *cognitive aspects*, such as shared and differential processing
80 demands related to comprehension or production (e.g., AbdulSabur et al., 2014), or still
81 by *individual-related aspects*, such as sociodemographic variables, including the level
82 of education and the socioeconomical status (SES).

83

84 Regarding age and education, Steibel et al. (2016) investigated the effect of
85 these variables in the memorization of items such as names, pictures and stories using
86 the Rivermead Behavioral Memory Test (Wilson et al., 1985). Their participants were
87 divided according to age (60-69, 70-79 and 80 or more years old), and to education
88 level (less than 8 years or 8 years or more of formal education). Performance improved
89 as the level of education of the participants increased, while advancing age correlated to
90 poorer performance. Similarly, Tripathi et al. (2014) assessed the impact of education
91 and age on neuropsychological functions (episodic memory, attention, executive
92 functions and language) in 180 older adults with no history of cognitive impairment.
93 Education had an effect on all tasks analyzed, while age impacted on three out of 12
94 tasks. Similarly, SES has been associated with the quality of content and discourse
95 productivity (Snow et al., 1997) as well as with cohesion (Coelho, 2002) in studies

96 involving patients who suffered from a traumatic brain injury (TBI). Coelho (2002)
97 classified the participants (55 patients with a TBI and 47 neurotypical matched controls)
98 based on their SES, as professionally skilled and unskilled workers. The only significant
99 difference between unskilled (i.e., low SES) and professionally skilled workers has been
100 found on intersentential cohesion, regardless of story task. Studies in aphasia have also
101 associated SES to the severity and patterns of recovery. For example, Song et al. (2017)
102 studied the impact of SES - measured by the level of education, occupation and income
103 - on the functional outcome after three months following an ischemic stroke. Their
104 results suggested that people with lower SES present poorer outcome after stroke.
105 Multinomial logistic model analysis also showed that low educational level and manual
106 laboring has a more significant impact on the functional outcome than low-income
107 level. Despite the relevance of studies on the impact of low education level and low
108 SES, such studies are still very scarce both in neurotypical adults and patients suffering
109 from language impairments.

110

111 For analyzing oral discourse production, two main approaches have been
112 proposed: (1) *structural* and (2) *functional*. In the *structural approach*, the focus is on
113 discrete linguistic variables, such as phonology, syntax, and lexicon in addition to
114 macrolinguistic variables, such as cohesion, coherence, and macropropositions.
115 *Cohesion* is accomplished by the use of cohesive devices, which are linguistic markers
116 that form the structural and semantic connectivity between elements of speech (Halliday
117 & Hasan, 1976). These authors proposed five categories of cohesive devices: (1)
118 reference, (2) conjunctive, (3) ellipsis, (4) substitution, and (5) lexical. Similarly,
119 Antunes (1996, 2005) pointed out that cohesion builds up a *continuity* of meaning,
120 which is generally expressed by the relationship among *reiteration*, *association*, and

121 *connection*. Yet *coherence* refers to the meaning conveyed by the discourse (Barker et
122 al., 2017). More specifically, coherence builds the “discursive weave” by establishing
123 the connections between its corresponding phrases and propositions, which are globally
124 organized in the macrostructure (Kintsch & van Dijk, 1978). These authors propose that
125 coherence is built at two levels: (1) a local one (the maintenance of abstract links
126 between utterances, for instance, by the use of proper pronouns to link elements), and
127 (2) a global one (the way propositions are organized to reach the global topic or goal of
128 the text, involving the connection of utterances). When global coherence is not reached
129 or maintained, the text may become incongruent, irrelevant, tangential, or repetitive
130 (Sherratt & Bryan, 2012). Finally, *macropropositions* consist of the stages through
131 which a narrative evolves, following a hierarchical structure (van Dijk, 1976, 1980). By
132 definition, macropropositions refer to the ‘global’ meaning (van Dijk, 1980) or a
133 summary representation (Wood, 2009) of propositions. Macropropositions encompass
134 some hierarchically organized categories, such as setting, complication, resolution,
135 evaluation and conclusion. Knowledge of this schematic structure of stories is important
136 and well-known in everyday communication (van Dijk, 1980).

137

138 Complementing the structural approach for analyzing discourse production, the
139 *functional approach* analyzes the ability to convey relevant and meaningful information
140 at the discourse level. *Narrativity*, which is related to the *manner* by which narratives
141 are orally produced, should be taken into consideration to reach a more complete
142 assessment. Narrativity includes the assessment of the causal relations linking the
143 sequence of events of the story, the predominance of narration (in contrast with scene
144 descriptions), the relationship between the fact narrated and the pictures, and characters’
145 recognition. As postulated by Davis et al. (1997), discourse production can be analyzed

146 as a function of the task (e.g., interview, spontaneous, picture-based) or of the type of
147 discourse elicited (e.g., narrative or expository). Furthermore, the type of analyses may
148 vary, being performed in multiple levels, from a more microstructural level to a
149 macrostructural one. Within the later, the authors suggest the inclusion of story structure
150 analysis, or what we will call *narrativity*, together with logical coherence, thematic
151 coherence and general attributes, as an important aspect to be observed in both left
152 hemisphere (LH) and right hemisphere (RH) stroke patients. Being able to detect the
153 sequence of the narrative structure, with its causal implications, is crucial for successful
154 story telling. Davis et al. (1997) postulate that the use of sequences of scenes allows the
155 clinician and the researcher to assess participants' ability to construct narrative ties
156 between the scenes, as opposed to single pictures, which tend to elicit descriptions
157 instead. Moreover, this broader structural type of analysis seems to have been less
158 studied than coherence and cohesion ties connecting sentences or parts of speech. To
159 our knowledge, no previous study investigated narrativity behaviorally nor its neural
160 correlates.

161

162 Also within a more functional approach to discourse production analyses, a few
163 different measures have been proposed to investigate the quality of a narrative in terms
164 of lexical informativeness, including lexical information units (LIUs). LIUs are content
165 and function words that are phonologically well-formed and also appropriate from a
166 grammatical and pragmatic point of view (Andreetta & Marini, 2015; Marini, Boewe, et
167 al., 2005; Marini, Carlomagno, et al., 2005; Marini, Galetto, et al., 2011). In this study,
168 an *index of lexical informativeness* was adopted to compare the groups' linguistic
169 performances and brain correlates.

170

171 The heterogeneity of the extracted variables and the various types of discourse
172 reported in discourse analysis following a stroke limits the comparison between the
173 studies and our understanding of the role of each hemisphere in discourse processing
174 (Stark et al., 2020). Lesions following a cerebrovascular accident (CVA) form a fruitful
175 context in which brain hemisphere specialization can be studied. These lesions may
176 affect each hemisphere differently and thus foster the debate on hemispheric
177 specialization in discourse at the macrolinguistic level. Some of the first studies on
178 discourse that have been conducted with patients with an RH-related lesion (Joanette &
179 Goulet, 1990; Myers, 1999) have demonstrated the relevance of RH participation in
180 comprehension and discourse production. Converging results on this topic have shown
181 that individuals with RH damage present difficulties in cohesion, coherence, and
182 consequently, in discourse organization (see Brownell & Martino, 1998; Hough, 1990;
183 Kempler, 1990; Molloy et al., 1990; Myers, 1999). Davis et al. (1997) compared
184 referential cohesion and logical coherence in an oral narrative production between eight
185 participants with an RH lesion and eight control participants. Samples from six stories
186 were obtained with tasks of cartoon-elicited story telling. Patients with a lesion in the
187 RH produced fewer predicates and their related arguments, fewer cohesive devices,
188 lower logical connection between propositions, and had difficulty in conveying the
189 theme and the structure of the narrative compared to the control group while retelling
190 the stories. More recently, Marini (2012) compared the narrative production at the
191 macrolinguistic (between sentence level) and microstructural levels (within sentence
192 level) of 15 patients with a lesion in the RH to that of 14 healthy participants. All
193 participants were asked to describe stories portrayed in a set of sequential images. In
194 comparison to healthy controls, participants with an RH lesion produced descriptions
195 with normal levels of microlinguistic elements, but they produced more tangential

196 errors and incongruent statements that reduced the levels of conveyed information.
197 Additionally, patients with frontal lesions in the RH presented more difficulties when
198 trying to organize information, which suggests that the frontal cortex in the RH would
199 have a role in the organization of information in narrative discourse.

200

201 Although most studies suggest that deficits in cohesion occur when stroke is
202 located in the RH (Marini, Carlomagno, et al., 2005; Sherratt & Bryan, 2012;
203 Stockbridge et al., 2019), others have reported cohesion impairments following a stroke
204 in the LH (Andretta et al., 2012; Barker et al., 2017; Davis et al., 1997; Ellis et al.,
205 2005; Geranmayeh et al., 2017; Marini, 2012; Stockbridge et al., 2019; Uryase et al.,
206 1991). Among the few existing longitudinal studies, Stockbridge et al. (2019) reported
207 that total cohesive markers were similarly used between LH and RH individuals in the
208 narrative samples obtained from the analyses of the Cookie theft of the Boston
209 Diagnostic Aphasia Examination (BDAE). However, when looking at the acute (< 1
210 week after stroke) and the chronic (6–12 months after stroke) stages independently,
211 fewer cohesive ties were produced in samples from LH individuals than RH individuals
212 in the acute phase. Conversely, in the chronic phase (6–12 months post-stroke), the two
213 groups seem to use different *types* of cohesive markers although the *number* of cohesive
214 markers did not differ. Barker et al. (2017) investigated cohesion together with textual
215 coherence, attention, and executive functions in non-aphasic individuals after
216 comparing LH and RH lesion. Overall, RH patients showed impaired local and global
217 coherence compared to LH and controls. Similarly, both patient groups made more
218 cohesive errors than the controls with a trend toward greater cohesion impairment in RH
219 patients. Correlations between verbal fluency and cohesion have been reported in a
220 group of older adults (Sherratt & Bryan, 2019) in patients with the behavioral variant of

221 frontotemporal dementia (Ash et al., 2006) and patients with amyotrophic lateral
222 sclerosis (Ash et al., 2014), which suggests that impairment observed in cohesion could
223 also be caused by linguistic impairment rather than by macrolinguistic impairment per
224 se (e.g. Armstrong, 1991; Huber & Gleber, 1982). However, this relation has not been
225 tested in patients who suffered from a stroke, including patients with aphasia.

226

227 Regarding the neural correlates of macrolinguistic processing, there is no
228 consensus yet on which brain regions in the LH or RH are responsible. Barker et al.
229 (2017) recently proposed a schematic representation of discourse processing based on
230 current existing models of speech production (e.g., Frederiksen & Stemmer, 1993;
231 Jakobson, 1983; Levelt, 1989, 1993; Levelt et al., 1999) involving three stages:
232 *conceptual preparation* (i.e., macrolinguistic processes), *linguistic formulation* (i.e.,
233 microlinguistic processes) and articulation. According to this model, macrolinguistic
234 processes, namely cohesion, local and global coherence as well as novelty, have been
235 traditionally associated with RH regions (e.g., Myers, 1999) whereas microlinguistic
236 processes, namely lexical retrieval, syntax, grammatical encoding and phonological
237 encoding, have been associated with the LH. Specifically regarding macrolinguistic
238 processing, the construction of a preverbal message requires the generation of ideas and
239 their organization, which are highly supported by executive functions. Indeed, non-
240 linguistic cognitive mechanisms such as executive processes and attention, but also
241 more affective aspects like social cognition and emotion are implicated in the
242 *conceptual preparation*. For instance, discourse production has been associated with
243 cognitive constructs, such as working memory (Cahana-Amitay & Jenkins, 2018) and
244 episodic memory (Seixas-Lima et al., 2020). However, the nature of this association
245 still needs to be further elicited, since most studies in stroke (and other atypical)

246 populations have focused on the assessment of linguistic features of discourse,
247 disregarding the impact of the integrity of memory types.

248

249 There is only a relatively small number of inconclusive imaging studies
250 compared to the number of behavioral studies, especially addressing the role of each
251 brain hemisphere in the discourse process (e.g., Alyahya et al., 2020; e.g. Belin et al.,
252 2008; Dal Molin et al., 2013). To date, most studies have not compared discourse
253 processing in patients who suffered from a stroke in the left and in the right hemisphere.
254 For instance, a very interesting unified model of discourse processing have been
255 recently proposed by Alyahya et al. (Alyahya et al., 2020) but their study was only
256 comparing patients with post-stroke aphasia (following a stroke in the LH) and controls.
257 Using a principal component analysis, they showed that discourse production was
258 composed of three main components, namely verbal quantity, verbal quality (i.e. the
259 component related to macrolinguistic processing) and motor speech. Using voxel-wise
260 lesion-symptom mapping, they showed that verbal quality, which refers to
261 informativeness in the present study, was associated with widespread frontal regions
262 and superior temporal lobule. These regions have previously been associated with
263 working memory (e.g., Boisgucheneuc et al., 2006) and executive functions (e.g.
264 Humphreys & Lambon Ralph, 2015), and are consistent with the model of Barker et al.
265 (2017) which suggests that the *conceptual preparation* level is supported by non-
266 linguistic cognitive factors.

267

268 The present study intended to investigate macrolinguistic variables in oral
269 production of narrative stories in middle-low to low SES adults who suffered from a
270 unilateral stroke in the LH or RH compared to participants with no brain damage. Most

271 studies on discourse processing have been conducted analyzing highly
272 educated adults, with middle-high socio-economic status. Since education
273 and SES relate to cognitive (including linguistic) performance, those studies may not be
274 generalizable for lower educated and lower SES samples. We also aimed to explore the
275 association between narrative measures and their structural correlates in the gray matter
276 (GM). More specifically, partly based on the schematic representation of connected
277 speech of Barker et al. (2017), our exploratory hypothesis is two-fold: 1) individuals
278 who suffered from a left hemisphere (LH) stroke will have a lower performance in
279 within-sentence processes, namely the index of lexical informativeness (%) as
280 compared to the other two groups, and 2) individuals who suffer from a stroke in the
281 RH will have a lower performance on the more “global” macrolinguistic variables, such
282 as cohesion, global coherence, macropropositions, and narrativity as compared to the
283 other two groups (Marini, 2012). We also have two additional exploratory hypotheses.
284 We hypothesize that 3) GM density in the left temporal and left frontal lobes will
285 correlate with lexical informativeness (i.e. within-sentence) processes (Marini & Urgesi,
286 2012). We also hypothesize that 4) right frontal areas will relate to cohesion, coherence,
287 macropropositions, and narrativity (i.e. between-sentences) based on the hypothesis that
288 the *conceptual preparation* level in the model of Barker et al. (2017) is not yet
289 linguistic and thus also relies on non-linguistic cognitive mechanisms including
290 executive processes and attention (Marini et al., 2005; Sherratt & Bryan, 2012).

291

292 **Method**

293 ***Participants***

294 Patients were recruited from a hospital that treats patients from the public health
295 system in a metropolitan area in a southern state in Brazil. Patients' inclusion criteria

296 consisted of first-ever ischemic stroke in the LH or RH and being a native speaker of
297 Brazilian Portuguese. Exclusion criteria consisted of several parameters: (1) a history of
298 major psychiatric disorder(s), (2) learning disabilities, (3) self-reported severe visual
299 and auditory perceptual deficits, (4) additional neurological diagnoses, (5) left-handed
300 or ambidextrous, (6) < 2 years of formal education or > 13 years, and/or (7)
301 bilingualism. All patients were diagnosed by a neurologist and a radiologist. The
302 language and MRI assessments took place at least four months (LH mean = 11.2 ± 5.51 ;
303 RH mean = 10.5 ± 5.1) after stroke onset.

304

305 The age- and schooling-matched control group was recruited at convenience and
306 community centers. In Brazil, recruitment of controls is very challenging, especially
307 with men. Consequently, the control group is unbalanced with both clinical groups
308 regarding the sex variable. Controls reported no history of neurological illness or
309 psychiatric history and were native speakers of Brazilian Portuguese. In addition to the
310 exclusion criteria used with the patients who suffered from a stroke, healthy participants
311 were also excluded if their score on the Mini-Mental State Examination (MMSE) was
312 lower than the age and educational specific cut-off score adapted for the Brazilian
313 population (Brucki et al., 2003). Full written consent was obtained from all subjects.
314 The study was approved by the Ethics Review Board of the Pontifical Catholic
315 University of Rio Grande do Sul (PUCRS) under CAAE # 51099415.6.0000.5336.

316

317 ***Materials and procedures***

318 *Neuropsychological assessment*

319 We administered a health conditions questionnaire with socio-demographic and socio-
320 cultural aspects adapted from Fonseca et al. (2012), the Edinburgh Handedness

321 Inventory (Oldfield, 1971), the Mini-Mental State Examination (MMSE) from Chaves
322 & Izquierdo (1992), and the Geriatric Depression Scale (GDS) from Almeida &
323 Almeida (1999) as adapted from Yesavage et al. (1982). Participants were further
324 characterized by a short neuropsychological assessment using the Digit and Word span
325 working memory tests (Instrumento de Avaliação Neuropsicológica Breve -
326 NEUPSILIN, Fonseca et al., 2009), a short naming task (Montreal-Toulouse-Brasil
327 [MTL-BRASIL], Parente et al., 2016) consisting of 12 nouns and 6 verbs (max = 2
328 points by stimuli) represented in black and white pictures, and a free (i.e., without
329 constraints) verbal fluency task (Bateria Montreal de Avaliação da Comunicação Breve
330 (MAC-Breve); Ska et al., 2014). Participants also completed a questionnaire developed
331 by the Brazilian Market Research Association (*ABEP - Associação Brasileira de*
332 *Empresas de Pesquisa*) to capture their SES. This questionnaire allows the calculation
333 of a SES score based on the education level of the head of household and other
334 household characteristics including the number of certain consumer goods and
335 amenities. Descriptive sociodemographic and neuropsychological data of each group are
336 presented in Table 1.

337

338 *Narrative discourse assessment*

339 All participants were asked to orally narrate three stories supported with
340 sequential pictures: (1) *The dog story* (Hübner et al., 2019), (2) *The car accident*
341 (Joanette et al., 1995), and (3) *The cat story* (Ulatowska et al., 1981). The three stories
342 present a sequence of six or seven scenes in black and white on a strip of paper with
343 each scene measuring 7 x 7 cm. The stories have equivalent length and narrative
344 structure (Adam, 2008) and were randomly presented to participants to balance the
345 order of presentation. Participants were instructed to carefully observe the scenes in

346 order to narrate the stories one at a time after observing that each scene represents a part
347 of the story, which has a beginning, a middle, and an end. Participants were allowed to
348 look at the pictures during narration. Narratives were audio recorded (Sony Digital
349 Flash Voice Recorder (ICD-PX312)) for further transcription and analyses.

350

351 **Transcription**

352 Audios of each discourse sample were imported and transcribed using the
353 software Transcribe by an experienced linguist and a language student. The narratives
354 were transcribed according to Cultured Linguistic Urban Norm, in Portuguese, Norma
355 Linguística Urbana Culta (NURC) standards (Castilho & Pretti, 1986) by a person who
356 was blind to the group assignment. The segmentation of the narratives into
357 propositions/utterances was made following the rules proposed by Andreetta and Marini
358 (2014). Briefly, a set of acoustic, semantic, grammatical, and phonological parameters
359 that demonstrated high reliability scores (Andreetta & Marini, 2014, p. 73) was used. To
360 be included in the count, the words had to be intelligible in the context, but they did not
361 have to be precise, relevant, or informative in relation to the stimulus. The number of
362 words was verified using the Transcribe software and revised using the statistics
363 provided by Word (Version 2005/Microsoft 365).

364

365 **Narrative analyses**

366 Two raters blinded to group assignment (RH, LH group and controls) scored the
367 participants' narrative oral productions based on these variables: (1) cohesion, (2) global
368 coherence, (3) macropropositions, (4) narrativity, and (5) index of lexical
369 informativeness. Each discourse measure was reported after combining the three stories
370 together.

371

372 *Cohesion*

373 For the analysis of the textual cohesion of the narratives produced by the participants,
374 only the narrative sequences were considered. Thus, other types of production over the
375 course of production were excluded. Cohesion was scored according to the textual
376 relations proposed by Antunes (2005): (1) references (grammatical substitution,
377 repetition, lexical substitution, and ellipse); (2) association (lexical selection), and (3)
378 connection (connector). Please see Supplemental Material 2 for examples of the
379 different cohesion relations. Interrater reliability was achieved through agreement. Two
380 experts in the field scored all variables. When a discrepancy was observed between the
381 two reviewers, a third expert resolved the conflict. Cohesion was scored by counting the
382 number of occurrences of cohesion ties. This number was divided by the number of
383 utterances (parts of the narrative produced by the participant) and multiplied by 100.

384

385 *Global coherence*

386 Global coherence (Kintsch & van Dijk, 1978) refers to the degree by which the
387 propositions/utterances are organized or structured. The global coherence was analyzed
388 through the relationship between each statement (propositions) and the global topic of
389 the presented narrative sequence. For the analysis, complete propositions related to the
390 topic were scored with a score of 1.0; incomplete propositions related to the topic were
391 scored with a score of 0.5. Global coherence was calculated by dividing the sum of
392 these points by the total number of propositions produced and then the results were
393 multiplied by 100 (adapted from Andretta et al., 2012).

394

395 *Macropropositions*

396 Each narrative was divided into macropropositions, including story setting,
397 scenario, complication, and resolution (van Dijk, 1980; van Dijk & Kintsch, 1983; see
398 Supplemental Material 1 for the list of the macropropositions used in each story). Four
399 judges participated in the identification of the macropropositions of the cat's and the car
400 accident stories. The dog story followed the division of the macropropositions presented
401 in the Bateria de Avaliação da Linguagem no Envelhecimento or BALE (Hübner et al.,
402 2019). The number of macropropositions produced by each participant was divided by
403 the total number of narrative macropropositions and multiplied by 100. The dog story
404 contained a maximum of six macropropositions, while the car accident and the cat story
405 each contained five.

406

407 *Narrativity*

408 One point, for a maximum of four points for each story, was attributed for each
409 of the following criteria (according to the norms proposed in BALE [Hübner et al.,
410 2019]) in which observance of the sequence (for example, narrative of the facts in the
411 order they occurred in the story), predominance of narration (as opposite as scene
412 descriptions), relationship of the facts narrated with the pictures (that is, inclusion of
413 intrusive or inexistent aspects), and characters' recognition. A higher narrative score
414 thus reflected a better performance.

415

416 *Index of lexical informativeness*

417 The definition, selection, and analysis of words and the index of lexical
418 informativeness were performed based on Marini et al. (2011), Nicholas and Brookshire
419 (1993), and Lira et al. (2014). Lexical informativeness refers to content and functional
420 words that are not only phonologically well-formed but also appropriate from a

421 grammatical and pragmatic point of view. Informative nouns and verbs were extracted
422 using AntConc 3.4.4w (Anthony, 2016a), a freeware which has been adapted to
423 Brazilian Portuguese. The index of lexical informativeness was calculated by dividing
424 the number of informative nouns and verbs produced by each participant by the total
425 number of words produced and multiplied by 100 (Andreetta & Marini, 2015; Marini,
426 Andreetta, et al., 2011; Marini, Carlomagno, et al., 2005).

427

428 **Inter-rater reliability**

429 Inter-rater reliability (IRR) was conducted on the transcriptions of three participants
430 (10% of the transcripts) for all three stories independently (n=12 transcriptions) by a
431 second rater. Two-way random effects intraclass correlation coefficients (ICC) were
432 calculated on the raw scores of cohesion, coherence, macropropositions and narrativity
433 to determine consistency between raters. ICCs were not calculated for the index of
434 lexical informativeness as the informative words were extracted by a freeware
435 (Anthony, 2016b). The ICC is a statistical metric commonly used to assess inter-rater
436 reliability. ICC values range from 0 to 1 and can be categorized into four levels of test-
437 retest reliability: excellent (ICC > .75), good (ICC = .60 to .74), fair (ICC = .40 to .59),
438 and poor (ICC > .40) (Fleiss et al., 2003). An excellent degree of reliability was found
439 between raters for cohesion (ICC = .907; 95% confidence interval (CI) = [.589, .979])
440 and macropropositions (ICC = .750; 95% CI = [-.108, .944]). A good degree of
441 reliability was found between raters for narrativity (ICC = .608; 95% CI = [.231, .800],
442 whereas reliability was fair for coherence (ICC = .497; 95% CI = [-1.229, .887]).

443

444 ***MRI protocol***

445 Participants underwent two meetings in two days that included an MRI scan and
446 a language assessment. The MRI protocol was acquired using a GE Healthcare 3.0T
447 HDxt MRI scanner at the Radiology Department at InsCer (Brain Institute). One high-
448 resolution three-dimensional (3D) T1-weighted scan was acquired using a
449 Magnetization Prepared Rapid Gradient Echo (MP-RAGE) sequence (TR = 6272 msec,
450 TE = 2255 msec, TI = 500 msec, voxel size = 1x1x1 mm³, matrix = 240 x 240, 196
451 slices) and an 8-channel skull coil.

452

453 ***Lesion segmentation***

454 The lesion delineation was performed using a semi-automated demarcation
455 performed with *Clusterize* SPM's toolbox (Clas et al., 2012) from
456 <http://www.medizin.uni-tuebingen.de/kinder/en/research/neuroimaging/software> and
457 verified by a fully manual method. First, *Clusterize* was used to semi-automatically
458 delineate the lesion on the T1 map of each patient. Agreement between manual
459 segmentation and the semi-automated lesion maps obtained with *Clusterize* has been
460 shown to be excellent in chronic stroke delineation (de Haan et al., 2015). *Clusterize*
461 automatically computes hypo-intensity clusters of voxels. Cluster(s)-of-interest
462 corresponding to the lesion were manually selected and adjusted to fit the lesion in each
463 slice by a team member. Finally, the entire lesion was extracted for each subject.
464 Second, each lesion file was adjusted (if needed) with MI-brain software (Imeka
465 Solutions Inc.; www.imeka.ca). The rater was blind to the behavioral scores and to the
466 severity of language impairment. Lesion volume was estimated in milliliters.

467

468 ***Voxel-based morphometry pre-processing***

469 Voxel-based morphometry (VBM) pre-processing was performed using Clinical
470 Toolbox Version 7/7/2016 running on SPM12. We used the MR segment-normalize
471 function. The template for normalization was obtained from 30 healthy subjects (mean
472 age: 61.3 years, seven men; see Rorden et al., [2012] for details). Enantiomorphic
473 normalization (6-tissue new segment), an alternative non-linear registration method that
474 corrects the signal within the lesion using information from the undamaged
475 contralesional region, has been used because it has been shown to be superior to the
476 traditional cost-masking function (Nachev et al., 2008). Lesion maps were entered into
477 the normalization step. The pre-processing of the control group followed the same
478 procedures of brain-damaged patients without including the lesion since control brains
479 were not damaged. The GM tissue images obtained from the segmentation of
480 normalized images were then smoothed with an 8-mm full-width-half-maximum
481 Gaussian filter.

482

483 *Statistical analyses*

484 *Behavioral analyses*

485 The index of lexical informativeness, cohesion, macropropositions, and global
486 coherence showed a normal distribution according to the Shapiro–Wilk normality test (p
487 > 0.05). The narrativity variable showed a non-normal distribution according to the
488 Shapiro–Wilk normality test ($p < 0.05$). Analysis of variances (ANOVAs) were
489 conducted for variables with a normal distribution with Bonferroni post-hoc
490 comparisons. A non-parametrical Kruskal–Wallis test with Bonferroni post-hoc
491 comparisons were conducted for the narrativity variable.

492 Previous studies have shown that story grammar (Mozeiko et al., 2011) and
493 global coherence (Barker et al., 2017; Wright et al., 2014) correlated with measures of

494 executive function and that cohesive ties positively correlated with verbal fluency
495 (Sherratt & Bryan, 2019). Others have reported associations between working memory
496 and discourse measures in clinical populations. Namely, spoken discourse measures at
497 the macro-level were correlated with working memory in post-stroke aphasia, whereas
498 measures at the micro-level were not (Cahana-Amitay & Jenkins, 2018). Working
499 memory was also reported to be associated with efficiency and cohesion in patients who
500 suffered from a traumatic brain injury (Hartley & Jensen, 1991). Exploratory
501 correlations were thus performed to assess the possible association between the
502 discursive variables and two lexical formal tasks (i.e., the naming and the free verbal
503 fluency tasks, which also rely on executive functions) as well as with two working
504 memory tasks (digit and word span). The naming task showed a non-normal distribution
505 according to the Shapiro–Wilk normality test ($p < 0.05$), and therefore, we used non-
506 parametric correlations with this task. The free lexical task and the working memory
507 tasks showed a normal distribution according to the Shapiro–Wilk normality test (p
508 > 0.05). Therefore, Spearman’s correlations were conducted between the free lexical
509 fluency task, digit span, word span and the index of lexical informativeness, cohesion,
510 macropropositions, and global coherence, whereas Kendall’s tau correlation was
511 conducted with the narrativity variable, which yielded a non-normal distribution. A
512 Bonferroni correction was made for multiple comparisons, resulting in an alpha level of
513 0.01 for each family of tests.

514

515 *Neuroimaging analyses*

516 A factorial analysis model was used to compare GM density at the voxel level between
517 controls, LH, and RH. Regression models were performed using the linguistic
518 discursive measures scores as dependent outcome. Age, years of education, and total

519 intra-cranial volume were considered as covariates. A family-wise error (FWE)
520 correction at $p < 0.05$ at the cluster level was applied, using an arbitrary cluster-forming
521 uncorrected threshold of $p < 0.001$. Additionally, effect sizes for significant
522 comparisons were calculated using the T-statistics (t) and the degrees of freedom (df) in
523 the formula $\sqrt{t^2/(t^2 + df)}$ (Lukic et al., 2017).

524

525

526 **Results**

527 **Participants**

528 Table 1 presents demographic information and mean neuropsychological
529 evaluation scores for both patient and control groups. One-way ANOVAs showed that
530 no significant differences in age, education, or socioeconomic status between the three
531 groups. Time of stroke onset was also comparable between the LH and RH groups. A
532 short language assessment was conducted by a speech language pathologist who
533 concluded that one participant in the LH group suffered from mild conduction aphasia.
534 This participant was included in this study since his performance was comparable to the
535 other patients of the LH group.

536

537

Insert Table 1 approximately here

538

539 **Behavioral results**

540 A significant effect of group on the cohesion score was found ($F(2,27) = 7.17, p$
541 $= 0.003$) for which the LH patients had a lower performance than healthy controls. A
542 significant effect of group on the macropropositions score was also found ($F(2,27) =$
543 $3.90; p = 0.032$), and post-hoc comparisons showed that patients with an RH stroke had

544 a lower performance than healthy controls. Similarly, a significant effect of group on
545 the global coherence score was found ($F(2,27) = 5.47, p = 0.010$) with post-hoc
546 comparisons showing that patients with an RH stroke had a lower performance than
547 healthy controls. No group effect for the index of lexical informativeness and narrativity
548 was found. Mean and standard deviations (mean \pm SD) for each group are reported in
549 Table 2 in addition to the statistical values of the tests.

550

551

552

Insert Table 2 approximately here

553

554

555 Exploratory correlations were performed to assess the possible association of the
556 discursive variables with two lexical formal tasks as well as with two working memory
557 tasks. The statistical details of the correlations are reported in Table 3. Four correlations
558 were found to be significant, and three survived the Bonferonni correction. Namely, the
559 narrativity score was significantly correlated with the naming task score ($r = 0.420; p =$
560 0.004), the digit span score ($r=.453; p=.001$) and the word span score ($r=.459; p=.001$).

561

562

563

Insert Table 3 approximately here

564

565

566 **Imaging results**

567 **Linear regression-based analysis of narratives variables**

568 Significant associations between all five discourse variables and regional GM
569 volume as measured by whole brain VBM were computed using regression-based
570 analyses after controlling for age, education, and total intracranial volume. The
571 anatomical labelings of the clusters are listed in Table 4, and the areas are shown in
572 Figure 1.

573

574 *Cohesion*

575 One significant cluster located in the right primary sensory area, precentral
576 gyrus, and the inferior frontal gyrus (IFG, *pars opercularis*) significantly and positively
577 correlated ($p = .011$) with the cohesion score.

578

579 *Global Coherence*

580 Similarly, one significant cluster located in the left superior frontal gyrus (STG)
581 and the primary sensory area was significantly positively correlated ($p = .002$) with the
582 global coherence score.

583

584 *Macropropositions*

585 GM density positively correlated with the macro-positions score mainly with
586 brain areas located in the left hemisphere. The most significant clusters were located in
587 the left cingulate ($p < .001$), the left STG ($p < .001$), the left MTG ($p = .040$), and the
588 left inferior frontal gyrus ($p = .001$). A cluster including the primary motor area, the
589 primary sensory area, and the insula in the right hemisphere ($p = .003$) also significantly
590 and positively correlated with the macropropositions score.

591

592 *Narrativity*

593 One significant cluster also located in the left primary sensory area, the left
594 insula, and the left STG significantly and positively correlated ($p = .001$) with the
595 narrative structure score.

596

597 *Index of lexical informativeness*

598 One significant cluster located in the left primary sensory area and the left insula
599 significantly and positively correlated ($p = .020$) with the lexical informativeness score.

600

601 *****

602 **Insert Table 4 approximately here**

603 *****

604

605 *****

606 **Insert Figure 1 approximately here**

607 *****

608

609 **Discussion**

610 This study was designed to explore the association between different aspects of
611 connected speech and their GM structural correlates in participants with a unilateral
612 stroke in the LH or the RH and a group of healthy controls, all having middle-low to
613 low SES. Behaviorally, individuals with a LH stroke presented impairment in cohesion,
614 whereas individuals with a RH stroke presented impairments in coherence and
615 macropropositions. The groups did not differ in terms of narrativity and lexical
616 informativeness. As hypothesized, this study demonstrated that cohesion is associated
617 with greater GM density in the RH. Surprisingly, the other more “global”

618 macrolinguistic processes (i.e., coherence, macropropositions and narrativity) were
619 associated with GM density in the LH, although macropropositions were as well
620 associated to GM density in the primary motor area and the insula in the RH. Moreover,
621 lexical informativeness, which is a more functional, but also more “local”
622 macrolinguistic process, presented neural correlates similar to those of coherence,
623 macropropositions, and narrativity. Interestingly, and consistent with our hypotheses,
624 both behavioral and imaging results were very similar between coherence and
625 macropropositional processing since both constructs are intrinsically and deeply
626 connected.

627

628 Both the LH and RH groups produced fewer proportions of cohesive ties than
629 the healthy controls, but the difference was only significant between the LH group and
630 controls. Consistent with previous findings (Uryase et al., 1991), LH participants
631 produced a lower proportion of cohesive ties per utterance than RH participants, but the
632 difference between these clinical groups was not significant considering the large score
633 range in our participants. One possible explanation for the differences between the
634 studies is the severity of linguistic impairments in patients with an LH stroke at the time
635 of testing. Barker et al. (2017) hypothesized that the impairments observed in cohesion
636 in LH individuals might be caused by linguistic impairments rather than by macro-
637 linguistic impairments per se. Consistent with this hypothesis, the number of cohesive
638 ties was moderately and positively correlated with verbal fluency in a group of older
639 adults (Sherratt & Bryan, 2019). Similarly, correlations between verbal fluency and
640 global and local connectedness have also been reported in patients with the behavioral
641 variant FTD (Ash et al., 2006) and patients with amyotrophic lateral sclerosis (Ash et
642 al., 2014). To the best of our knowledge, this relationship has not yet been tested in

643 stroke patients. Our exploratory analysis does not support this hypothesis. A weak
644 correlation between cohesion and the naming task was found, but it did not survive the
645 multiple testing corrections, and the correlation with the verbal fluency task was not
646 significant. However, one must note that in Sherratt and Bryan (2019), the *total* number
647 of cohesive ties in the picture sequence samples, similar to the samples used in the
648 present study, did not significantly correlate with the verbal fluency task. Nevertheless,
649 after examining each type of lexical ties more specifically, one of the strongest
650 correlations was between the *lexical* ties in the picture sequence samples and the verbal
651 fluency task. Considering the sample size in the present study, we decided to only look
652 at the total number of cohesive ties and not to separately investigate each type of
653 cohesion ties. Thus, the relationship between verbal fluency and cohesion still requires
654 further attention as it seems to depend on the nature of the discourse task and the type of
655 cohesive ties that were analyzed.

656

657 Consistent with previous studies conducted in different clinical populations (Ash
658 et al., 2006, 2014; Troiani et al., 2008), the present results support an association
659 between non-linguistic brain areas and discourse cohesion in which executive functions
660 play a decisive role. The cohesion score was positively associated with GM density in
661 the right primary sensory area/precentral gyrus and the *pars opercularis*. A correlation
662 between local connectedness and cortical atrophy was found significant in the right
663 frontal and anterior temporal areas in non-aphasic patients with a disorder of social
664 behavior and executive functioning (i.e., the behavioral variant of FTD) (Ash et al.,
665 2006)). Based on their results, the authors concluded that discourse impairment is
666 largely caused by language impairment which is strongly associated with poor executive
667 functioning. Similar results were obtained in patients with amyotrophic lateral sclerosis

668 who presented impaired discourse adequacy including local connectedness (i.e., a
669 measure of discourse coherence) and maintenance of the theme (Ash et al., 2014).
670 Impaired local connectedness was associated with bilateral atrophy in the inferior
671 frontal area, but also with reduced fractional anisotropy in the genu of the corpus
672 callosum and in the right uncinate, which connects the anterior temporal area to the
673 inferior frontal area. Bilateral inferior frontal activations have also been reported in
674 healthy adults in an fMRI study in which story narration was contrasted to the
675 description of unordered pictures (Troiani et al., 2008). These studies are also in line
676 with the schematic representation of discourse processing of Barker et al. (2017). In the
677 present study, correlations observed between cohesion and GM density in the right
678 primary sensory area/precentral gyrus and the *pars opercularis* could be interpreted as
679 non-linguistic functions in support of discourse cohesion (Marini, Carlomagno, et al.,
680 2005; Sherratt & Bryan, 2012). Additional work is needed to determine whether the
681 present results could be replicated in a larger group of patients who have suffered from
682 a stroke.

683

684 Global coherence is one of the most studied variables in discourse (Ellis et al.,
685 2016), but relatively few studies have compared patients with unilateral LH and RH
686 stroke individuals, especially when it comes to combine behavioral and brain imaging
687 data. Consistent with previous evidence, global coherence was significantly affected in
688 RH compared to healthy controls (Barker et al., 2017; Bartels-Tobin & Hinckley, 2005;
689 Davis et al., 1997; Marini, 2012). However, the performance in global coherence was
690 positively associated with GM density mainly in the LH, which contrasts with previous
691 findings. Nevertheless, bilateral activations in BA45 were positively correlated with
692 coherence during speech production in healthy older adults using fMRI (Hoffman,

693 2019). Behaviorally, previous findings tend to support the implication of executive
694 functions in maintaining global coherence in connected speech, which are usually
695 associated with frontal activation (Barker et al., 2017; Wright et al., 2014). Our VBM
696 results demonstrated greater GM density in the left primary sensory area/insula and
697 STG, which are not classically associated with executive functions. Thus, we could
698 hypothesize, based on the discourse representation model proposed by Barker et al.
699 (2017), that these areas could be considered as part of non-linguistic cognitive network
700 supporting macrolinguistic functions. As highlighted by Ellis et al. (2016), more
701 investigations are needed to address a comprehensive portrait of neural correlates
702 associated with global discourse coherence.

703

704 In line with the results found regarding global coherence, both the LH and RH
705 groups produced fewer macropropositions than the healthy controls did, but the
706 difference was only significant between the RH group and the control group. Although
707 considered as an important aspect of discourse (Davis et al., 1997), the assessment of
708 story structure - the macropropositions in this study – is relatively uncommon in both left
709 hemisphere (LH) and right hemisphere (RH) stroke patients. As expected, GM density
710 was associated with both coherence and macropropositions in similar areas. In addition,
711 macropropositions were positively associated with GM density in the left primary
712 sensory area/insula and STG. The left insula has been associated to articulatory
713 planning, while the primary sensory area is involved with sensory-to-motor mappings,
714 which includes the temporal cortex and other areas in the dorsal tract (Cahana-Amity
715 & Jenkins, 2018). As for the results found with coherence, we could hypothesize that
716 the areas associated with macropropositions could be considered as part of a non-
717 linguistic cognitive network as they are less traditionally associated with language

718 processing. Behavioral evidence tends to support this hypothesis. For instance, positive
719 correlations between story grammar, a variable similar to the macroproposition measure
720 used in the present study, and measures of executive functions, which are usually
721 associated with frontal activation, have been reported (Mozeiko et al., 2011).
722 Additionally, Cannizzaro and Coelho (2013) examined the relationship between
723 executive functions and story grammar in 46 neurotypical adults (18-98 years old).
724 They reported that the number of story grammar elements were negatively correlated
725 with age as well as with linguistic and non-linguistic measures of executive functions.
726 Thus, similarly to the discussion developed regarding global coherence, the relationship
727 between macroproposition processing, executive functions and a non-linguistic
728 cognitive network supporting macrolinguistic functions should be further explored.

729

730 Narrativity encompassed the assessment of the causal sequence of events in the
731 story, the predominance of narration (as opposed to description), the relationship
732 between the story scenes and the facts narrated, as well as characters' recognition. Thus,
733 it is a macrolinguistic discourse ability, which relates to story structure
734 (macropropositions), and includes crucial abilities for the construction of a globally
735 coherent narrative (van Dijk, 1980). The confluence of story structure, logical
736 coherence, thematic coherence and general attributes should be further investigated
737 comparing RH and LH stroke (Davis et al., 1997). As with coherence and
738 macropropositions – also more “macro” abilities – narrativity correlated more strongly
739 to LH areas as opposed to RH ones, namely the left insula and the STG. Moreover,
740 although no significant differences between the three groups were observed
741 behaviorally, narrativity was the only macrolinguistic measure that correlated with
742 naming (semantic memory) and working memory. Due to the novelty of this construct

743 in oral narrative production analyses, further studies should investigate the association
744 between narrativity and story planning and monitoring as executive tasks, as well as its
745 neural correlates.

746

747 The index of lexical informativeness as calculated by Marini et al. (Andretta et
748 al., 2012; Marini, 2012; Marini et al., 2007; Marini et al., 2011) did not show a
749 significant difference among the three groups. Among the few studies that compared
750 individuals with an LH and RH stroke, Agis et al. (2016) investigated the index of
751 lexical informativeness using the measure of content units (Yorkston & Beukelman,
752 1980) in the description of the Cookie Theft picture from the BDAE-3 (Goodglass et al.,
753 2001) within 48 hours of stroke onset. The two patient groups in that study did not
754 differ from each other as in the present study, but they differed from the group of
755 healthy controls. The most probable explanation for this difference is the timing of the
756 assessments. The patients recruited in the present study were in the sub-acute/chronic
757 phase of recovery, at least four months post-onset, whereas the patients in Agis et al.
758 (2016) were in the acute phase of recovery. The heterogeneity of the results (large
759 standard deviations) in both patient groups also explains the lack of statistical difference
760 with the controls. Another possible explanation for the absence of a difference between
761 the patient groups and controls could be the SES of the participants. Our participants
762 presented a middle-low to low SES, which has been associated with a reduced content
763 and discourse productivity (Snow et al., 1997; Yorkston et al., 1993) in addition to a
764 reduction in cohesive adequacy (Coelho, 2002). Similarly, Coelho (2002) reported that
765 professional and skilled workers had better scores on cohesion measures than unskilled
766 workers, but no differences were found in sentence production and story grammar
767 measures. However, participants in our sample had much lower education levels than

768 those in these previous studies (2–13 years of education in the present study versus 9–
769 14 years in the study by Coelho). Previous findings have also shown that the SES has an
770 impact on outcome after stroke (Song et al., 2017). This underlines the importance of
771 assessing SES in various language tasks, in both clinical populations and neurotypical
772 controls, in order to have a clearer idea of the impact of SES after stroke. It also
773 reinforces the need for a larger study focusing on the impact of SES in individuals with
774 a wider range of SES. The study of low SES samples brings important contributions for
775 future research and clinical outcomes since this population represents most of the people
776 in the world who are living in mainly underdeveloped countries.

777

778 Surprisingly, lexical informativeness, a more “local” process, was associated
779 with similar patterns of GM density than the processes of coherence, macropropositions,
780 and narrativity, which are generally associated with more “global” processing.
781 However, these results are consistent with previous evidence. Among the few studies
782 conducted on the neural basis of lexical informativeness, Agis et al. (2016) reported that
783 in LH stroke, total content units produced were independently associated with the
784 volume of the lesion and damage to the left inferior temporal gyrus, close to the left
785 insula, which was positively associated with lexical informativeness in the present
786 study. Similar to our results, no area was independently related to total content units
787 (CU) in RH stroke.

788

789 Some limitations of our study should be noted. First, the sample sizes of our
790 groups were relatively small, and it is therefore difficult to generalize the present results
791 to all patients who underwent LH or RH stroke. Another aspect to consider is the issue
792 of sex differences in cognition. In our study, groups were not balanced according to sex

793 due to the difficulties in recruiting participants who would fulfil all of the inclusion
794 criteria to join the behavioral and imaging data acquisition. We did not use sex as a
795 covariate in the present analysis because the use of intracranial volume significantly
796 reduces the gender differences (Pell et al., 2008). These authors also reported multi-
797 collinearity between intracranial volume and gender, and thus recommended not to use
798 gender as an additional covariate and use intracranial volume, which shows the most
799 consistent effects. Nevertheless, we acknowledge that it would have been optimal to
800 have groups matched on the sex variable. Third, inter-rater reliability for coherence was
801 found to be fair. More extensive training or refinement of coherence measurement is
802 thus required to improve the reliability of coherence. Finally, to fully understand the
803 neural basis of oral narratives, future studies should not only investigate the structural
804 correlates but also look the functional and anatomical connectivity to have a better
805 understanding of the role of the language network in discourse processing.

806

807 **Conclusion**

808 The present results underline the importance of conducting studies in both LH
809 and RH patients and of combining both cognitive and language assessments to better
810 specify the characteristics of connected speech. Our results support the assumption that
811 both hemispheres are essential in connected speech but at different macrolinguistic
812 processes. A better behavioral and neuroanatomical comprehension of the
813 macrolinguistic processes in patients with various types of communication impairment
814 will aid in the development of early detection and management protocols, particularly in
815 patients who suffered from a RH stroke. Furthermore, our study highlights the need for
816 studying middle-low SES samples, which represent the majority of older adults in

817 underdeveloped countries worldwide and of those served by the public health system in
818 many countries.

819

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841

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1146

Table 1 – Mean sociodemographic descriptive data and neuropsychological results for participants with a LH stroke, participants with a RH stroke and age-matched healthy participants.

	LH n=10			RH n=10			Controls n=10			<i>p</i> value
<i>Sociodemographic data</i>										
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	
Age (years)	67.80	7.64	57-76	67.6	9.73	50-79	66.3	8.73	52-78	H(2) = .89, p=.235†
Education (years)	7.3	3.26	2-11	7.6	2.99	3-11	6.1	3.93	2-13	F(2,27) = .52, p=.599
Sex	9M, 1F	-	-	4M, 6F	-	-	1M, 9F	-	-	-
Time Post-stroke	15.1	8.67	6-30	10.5	5.1	4-18	-	-	-	t=1.45, p=.165
Socioeconomic status (SES)	25.8	6.37	17-35	27.5	5.4	19-36	27.3	7.09	15-38	F(2,27) = .21, p=.813
<i>Neuropsychological assessment</i>										
Mini-mental state examination (/30)	23.5	3.47	16-27	25.5	3.34	23-29	28.1	1.91	25-30	H(2) = 9.57, p=.008† ^a
Geriatric Depression Scale (/15)	1.90	2.51	0-8	3.60	3.50	0-10	1.00	1.49	0-4	H(2) = 4.53, p=.104†
Naming subtest (MTL-Brasil; /30)	24.20	6.19	8-30	28.40	1.78	24-30	29.50	0.71	28-30	H(2) = 12.64, p=.002† ^a
Free verbal fluency (MAC-Breve; no maximum)	29.10	19.79	4-67	32.30	14.48	10-63	45.60	21.16	26-89	F(2,27) = 2.10, p=.142
Digitspan	10.20	3.88	3-16	8.90	2.38	6-14	9.70	2.03	7-13	F(2,27) = .52, p=.599
Wordspan	8.50	5.66	0-18	10.00	5.33	3-19	14.30	3.91	9-19	F(2,27) = 3.59, p=.042 ^a

LH= left hemisphere stroke patients; RH= Right hemisphere stroke patients; M= Male; F= Female; SES = socioeconomic status as calculated by a questionnaire developed by Associação Brasileira de Empresas de Pesquisa in 2015: Class A = 45 - 100 points, B1 = 38 – 44 points, B2 = 29 - 37 points, C1 = 23 - 28 points, C2 = 17 - 22 points, D-E = 0 – 16 points)

† Non-parametric test statistics reported because this measure showed a non-normal distribution.

^a LH significantly different from controls <.01

Table 2 – Mean behavioral results for participants with a LH stroke, participants with a RH stroke and age-matched healthy participants.

	LH n=10		RH n=10		Controls n=10		p value
Cohesion (#cohesion ties/# utterances * 100)	67.1	31.5	83.0	33.4	115.4	20.8	F(2,27) = 7.17, p=.003 ^a
Coherence (#propositions/# narrative propositions * 100)	52.8	31.2	38.0	18.3	69.6	11.5	F(2,27) = 5.47, p=.010 ^b
% Macropropositions (#macroprop./#total macroprop * 100)	48.1	33.9	41.25	24.9	71.3	11.5	F(2,27) = 3.90, p=.032 ^b
Narrativity (max. 12)	6.0	5.1	8.2	3.4	10.4	2.2	H(2) = 4.63, p=.099
% Index of lexical informativeness (IU/#words * 100)	18.0	10.9	19.2	9.2	24.8	5.1	F(2,27) = 1.73, p=.198

LH= left hemisphere stroke patients; RH= Right hemisphere stroke patients.

^a LH significantly different from controls <.005

^b RH significantly different from controls <.05

Table 3. Correlations between discursive variables and formal lexical and working memory tasks.

Variables		Cohesion	Coherence	% Macropropositions	Narrativity	% Index of lexical informativeness
Statistics						
Variables						
Naming task BNT (/30)	r	.295	.190	.262	.420	.190
	p	.034*	.172	.066	.004**	.172
	n	30	30	30	30	30
Free verbal fluency (MAC-Breve)	r	.012	.002	.005	.236	-.096
	p	.929	.986	.971	.087	.463
	n	30	30	30	30	30
Digit span (NEUPSILIN)	r	.064	.126	.053	.453	.075
	p	.736	.507	.780	.001**	.695
	n	30	30	30	30	30
Word span (NEUPSILIN)	r	.003	.152	.120	.459	.164
	p	.986	.422	.528	.001**	.387
	n	30	30	30	30	30

** p< .005; * p<.05, but did not survive the Bonferonni correction

Table 4. Stereotactic locations and Brodmann's areas (BA) of the multiple regressions with the narrative measures.

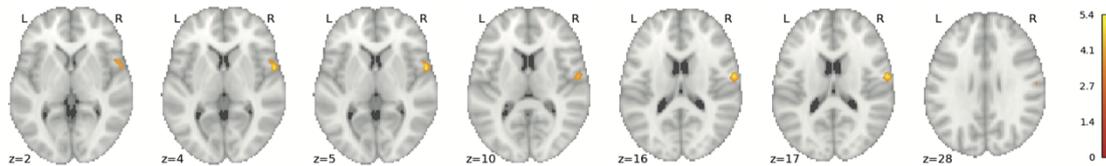
Discourse measure	Location	Cluster size (k)	MNI 152 coordinates			T	df	FWE correction	Effect size		
			x	y	z						
Cohesion	Primary sensory area	1856	62	-6	17	5.43	25	.011	.984		
	Precentral gyrus		57	4	5	5.31	25		.964		
	Inferior frontal gyrus, <i>pars opercularis</i>		52	11	1	4.22			.781		
Coherence	Superior temporal gyrus	2583	-52	-30	15	4.97	25	.002	1.042		
	Primary sensory area		-45	-14	15	4.60	25		.843		
Macropropositions	Anterior cingulate	8372	-12	-69	-34	6.64	25	.000	1.180		
	Lingual gyrus		v	-56	11	6.51	25		1.160		
	Cingulate		-9	-59	1	5.48	25		.993		
			9	-56	22	5.44	25		.986		
			5	-60	28	5.27	25		.958		
			7	-58	25	5.11	25		.931		
			18	-60	9	4.65	25		.854		
			6	-45	8	4.58	25		.842		
	Parahippocampal gyrus		14	-36	-3	5.20	25		.946		
	Cuneus		-6	-75	5	5.01	25		.915		
	Precuneus		12	-80	6	4.74	25		.869		
			14	-63	23	4.33	25		.800		
			Superior temporal gyrus	7251	-45	-15	15		6.51	25	.000
					-39	-21	12		6.15	25	1.102
	Putamen				-52	-30	15		6.06	25	1.087
	Precentral gyrus				-25	11	1		4.94	25	.903
					-55	-4	5		4.34	25	.801
	Primary sensory area				-4	-56	28		4.30	25	.794
	Insula				-37	3	9		4.24	25	.784
					-32	25	-2		4.24	25	.784
					-32	8	5		4.08	25	.757
			-29	23	0	3.90	25	.725			
			-42	-4	14	3.89	25	.724			
Primary motor area	2349	42	-7	13	6.12	25	.003	1.097			
Primary sensory area			52	-11	10	4.59	25	.844			
Insula			-39	-4	1	3.67	25	.685			
Middle temporal gyrus		1370	-55	-28	-5	5.36	25	.040	.973		
			47	-9	1	3.67	25		.685		
Inferior frontal gyrus, <i>pars opercularis</i>	2777	-42	18	5	5.30	25	.001	.963			

	Inferior frontal gyrus, <i>pars triangularis</i>		-55	-41	4	5.21	25		.948
	Superior temporal gyrus		-46	12	1	4.99	25		.911
	Fusiform gyrus	2146	-17	-39	-11	4.73	25	.005	.867
			-45	2	-10	4.52	25		.832
	Cingulate gyrus	1633	-25	-52	-10	4.90	25	.019	.896
			3	14	32	4.90	25		.896
	Precentral gyrus		-9	-21	41	4.08	25		.757
Narrativity	Primary sensory area	2675	-44	-15	15	5.67	25	.001	1.024
	Insula		-37	-21	17	5.27	25		.958
	Superior temporal gyrus		-52	-30	16	5.18	25		.943
Index of lexical informativeness	Primary sensory area	1640	-36	-23	14	4.46	25	.020	.821
	Insula		-43	-14	14	4.35	25		.800

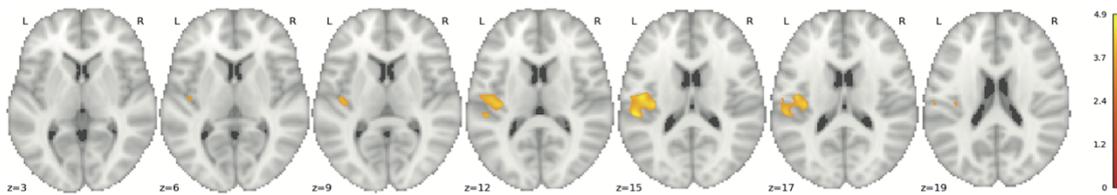
Note : Table 3 summarizes regions where GM volume was significantly associated with performance in each discourse measures. A family-wise error (FWE) correction at $p < 0.05$ at the cluster level was applied, using an arbitrary cluster-forming uncorrected threshold of $p < 0.001$. Significant peak regions are reported with corresponding MNI coordinates, T and p values, degrees of freedom, and effect sizes ($\sqrt{t^2/(t^2 + df)}$).

Figure 1. Three-dimensional surface rendering showing regions of grey matter associated with A) cohesion; B) global coherence; C) macropropositions; D) narrativity and E) index of lexical informativeness. Results are shown using a family-wise error correction at $p < 0.05$ at the cluster level, using an arbitrary cluster-forming uncorrected threshold $p < 0.001$.

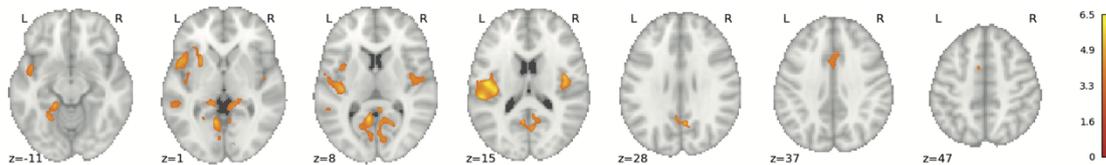
A. Cohesion



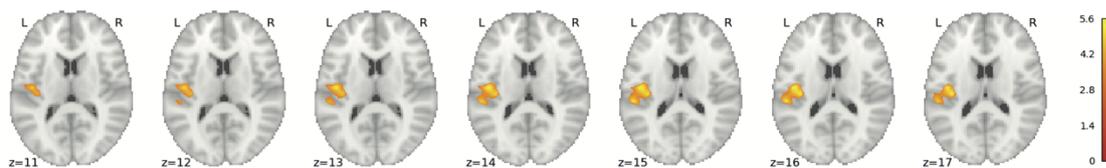
B. Global Coherence



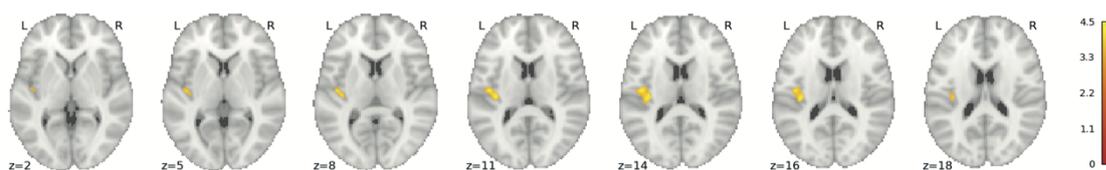
C. Macropropositions



D. Narrativity



E. Index of Lexical Informativeness



Supplementary Material 1.

Macropropositions of narratives

The dog story (Le Boeuf, 1976)	
A boy sees a dog (lost puppy) on the street / sidewalk	scenario
The boy takes (decides to take) the dog home	scenario
The boy hides the dog in the wardrobe/closet	scenario
The mother finds the dog	complication
The mother asks the boy for some explanations / The boy begs the mother to keep the dog	complication
The mother allows the boy to keep the dog / The mother helps the child/the boy builds the dog house	resolution
The car accident (Joanette et al., 1995)	
A woman/mother drives the car and takes two children/her two children	scenario
The woman/mother parks the car/goes to an establishment and leaves the two children (the two small children) in the car	scenario
The boy gets into the driver's seat and moves the steering/lever of the car	complication
The car goes down the slope and hits a lamppost	complication
The woman/mother leaves the establishment and realizes what happened	resolution
The cat story (Ulatowska, Doyel, Stern, Haynes, & North, 1983).	
A girl/a daughter cries and asks a man/father for help because a cat/his cat is stuck on the branch of a tree	scenario
The man/father climbs the tree to remove the cat	scenario
The man / father leans on the branch and reaches the cat	complication
The man/father throws the cat from the tree towards the girl (the cat jumps towards the girl)	complication
The man / father gets stuck on the branch by his jacket and a fireman comes to rescue him	resolution

Supplementary Material 2.

Cohesion Relations (Examples)			
Participant	Brazilian Portuguese	English	Explanations
RH210 (participant right hemisphere # 210)	<i>essa historinha aqui/ é de uma mãe/ é meio distraída/ saiu com as criança/ estacionou em algum lugar/ saiu pra fazer qualquer coisa/ e deixou as criança dentro do carro</i>	this story here/ is about a mother/ who is a little distracted/ she went out with the children / parked somewhere/ went out to do something and left the children in the car	This is an example of reiteration through repetition - repetition is necessary for reference, avoiding ambiguity
PLH6 (participant left hemisphere # 6)	<i>guri* achou o cachorro na rua/ Ø levou Ø para casa</i>	boy found the dog on the street/ Ø took Ø home	In this example, the symbol Ø represents an ellipsis. According to Antunes (2005), an ellipsis is a type of referencing. In Portuguese, the subject, or even the object in certain circumstances, does not have to be repeated. In this example, an English speaker would have said ' the boy took the dog home '. In Portuguese, the pronoun ele (he) would have been used in both cases and would not have resolved the ambiguity: ' ele levou ele para casa ' (in Portuguese).
PLH 7 (participant left hemisphere # 7)	<i>ele viu um cachorrinho.../ vira-lata de cachorro de rua/ ele gosta muito de cachorro</i>	<i>he saw a puppy ... / a stray dog / he likes dogs a lot</i>	In this case, the pronoun he - which refers to the boy in the story - does not have a reference. The pronoun does not have a reference, which we call a textual cohesion error.
RH205 (participant right hemisphere # 205)	<i>deve tá pedindo pra mãe deixar o cachorro dentro de casa</i>	<i>must be asking the mother to leave the dog inside the house</i>	A cohesion error is produced in this case because the subject (the boy) is missing. In other cases, the subject can be easily taken up by the context, but this was not the case in this example.

* Expression used in southern Brazil, synonymous of young boy