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Story retell and comprehension following unilateral left hemisphere stroke in Brazilian Portuguese speakers with low levels of education and socioeconomic status: A behavioral and voxel-based morphometry study

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Conflict of interest disclosure

There is no conflict of interest to declare.

Ethics Approval statement

The study was approved by the ethics review board of the university where it was conducted, under registration number 1.378.955/2015.

Abstract

Background: Little is known about story retelling and comprehension abilities in groups with lower levels of education and socioeconomic status (SES). A growing body of evidence suggests the role of an extended network supporting narrative comprehension, but few studies have been conducted in clinical populations, even less in developing countries.

Aims: The present study aims to extend our knowledge of the impact of a stroke on macrostructural aspects of discourse processes, namely main and complementary information, in individuals with middle-low to low SES and low levels of education. Relationships were tested between the performance in story retell and comprehension and reading and writing habits (RWH). Also, the associations between retelling and comprehension measures and their structural grey matter (GM) correlates were explored.

Methods & Procedures: Seventeen adults with unilateral left hemisphere (LH) chronic ischemic stroke without the presence of significant aphasia and 10 matched (age, education, and SES) healthy controls (HC) participated in the study. Retell and comprehension tasks were performed after listening or reading narrative stories. Voxel-based morphometry (VBM) analysis was conducted on a sub-group of 9 individuals with LH stroke and the 10 matched controls using structural magnetic resonance imaging (MRI).

Outcomes & Results: Retelling and comprehension abilities were not significantly different between LH and HC, nonetheless quantitively lower in LH. Exploratory correlations showed that retelling and comprehension abilities in both written and auditory modalities were correlated with naming abilities. At the neural level, written comprehension positively correlated with grey matter (GM) density of the left

hemisphere, including areas in the temporal pole, superior and middle temporal gyrus as well as the orbitofrontal cortex, precentral and postcentral gyri. Auditory narrative comprehension was associated with GM density of the lingual gyrus in the right hemisphere.

Conclusions & Implications: The present results suggest that retelling and comprehension of auditory and written narratives are relatively well-preserved in individuals with a LH stroke without significant aphasia, but poorer than in HC. The findings replicate previous studies conducted in groups with higher levels of education and SES both at the behavioral and neural levels. Considering that naming seems to be associated with narrative retell and comprehension in individuals with lower SES and education, this research provides evidence on the importance of pursuing further studies including larger samples with and without aphasia as well as with various socioeconomic status and education levels.

What is already known on this subject.

Story retell and comprehension of auditory and written discourse have been shown to be affected after stroke, but most studies have been conducted on individuals with middle to high socioeconomic status (SES) and high educational levels.

What this study adds.

The study reports on narrative retell and comprehension in both auditory and written modalities in groups of healthy controls and individuals with left-hemisphere brain damage, with low-to-middle socioeconomic status and lower levels of education.

Clinical implications of this study.

This study highlights the importance of taking into consideration the sociodemographic and reading and writing habits of patients when assessing discourse retell and comprehension in both auditory and written modalities. It also underlines the

importance of including patients without significant aphasia following LH stroke to look at the effect of both stroke and aphasia on narrative comprehension and story retelling.

Keywords: auditory narrative comprehension; written narrative comprehension; story retell; stroke; left hemisphere; brain density; low socioeconomic status.

Introduction

Auditory and written narrative comprehension are critical abilities of everyday communication. Narratives mirror and model human experience, presenting logical and semantical relationships between actions and actors (Adam 2008). Furthermore, narrative comprehension and production involve the microstructural level, which includes local information and cohesive ties, and the macrostructural level, which encompasses global comprehension, selection of important elements to macrostructure building, generalization of ideas, and construction of main ideas of a text (Van Dijk and Kintsch 1983). The selection process supports the retention of relevant information at the macrostructural level. Processes such as sentence processing at the syntactic and semantic levels, inferences management, macrostructure establishment, and microstructural details abstraction are recruited to properly achieve both comprehension and production of a narrative text (Brookshire and Nicholas 1984). Earlier studies of language comprehension following brain injury focused on words (e.g., Selnes *et al.* 1984, Bonilha *et al.* 2017, Lwi *et al.* 2021) and sentence comprehension (e.g., Dronkers *et al.* 2004, Saur *et al.* 2006, Turken and Dronkers 2011, Kristinsson *et al.* 2020). Around the mid-80s, a series of studies globally reported a weak relationship between sentence comprehension and discourse comprehension (e.g., Waller and Darley 1978, Pashek and Brookshire 1982, Brookshire and Nicholas 1984, Wegner *et al.* 1984). Discourse (including narratives) comprehension is indeed far more complex than the comprehension of individual sentences and requires consideration of the totality, but also of the interrelation between the different parts.

Linguistic and tasks variables that impact story retelling and comprehension

The difficulty in processing a narrative is leveled by variables inherited from the text itself, combined with individual differences. At the text level, structure, idea density, syntactic and semantic complexity, and text length are some of the variables that influence performance.

Story retelling constitutes one of the tasks used to assess discourse comprehension, but also production. Although story retelling first demands a good comprehension of the narrative, it requires participants to respond with a verbal production, which can be challenging for people with brain damage (Fromm *et al.* 2017). Consequently, these tasks can be used to assess both comprehension and production. For instance, Doyle et al. (2000) developed the Story Retell Procedure (SRP) to achieve valid, reliable, and economic assessment of connected speech production. Recently, people with aphasia following a left hemisphere (LH) stroke, patients without aphasia but who suffered a stroke in the LH, and neurotypical individuals were compared using this procedure (Yoo and McNeil 2019). A significant difference was found on the percentage of information units per minute (% of IU/Min) between both groups of patients who suffered from a stroke and the controls. Patients with aphasia also presented a significantly fewer % of IU/Min than the patients without aphasia. These results suggest that story retelling deficits are the effect of a combination of both aphasia and brain damage, but this needs further investigation in larger samples. Although %IU/Min seems to be a promising and efficient measure of assessing connected speech production, this measure does not account for weighting the different ideas that compose a narrative and the receptive part of the task. Main ideas or main information (MI) and complementary ideas (CI) differently impact text comprehension. Retelling main ideas is easier than retelling details of a narrative even in neurotypical individuals. In a series of studies, Nicholas and colleagues (e.g., Brookshire and

Nicholas 1984, Wegner *et al.* 1984, Nicholas and Brookshire 1995) reported that the comprehension of short stories was not significantly different between adults with aphasia and controls who were tested with yes/no questions. Although not significantly different, adults with a stroke in the LH (and aphasia) presented quantitively lower scores as compared to healthy controls. They also showed that patients with aphasia had higher scores when answering questions about MI than questions about CI. One possible explanation for the higher scores in MI as compared to CI could be related to a higher difficulty in remembering information not fundamental for the understanding of the main points or of the gist of the story.

Discourse retelling and comprehension may also be influenced by the modality of presentation (auditory versus written), which has scarcely been studied in clinical populations. Obermeyer and Edmonds (2015) have reported differences between written and auditory retelling in a group of 10 healthy individuals between 50 and 80 years old. Written retelling contained fewer words, but more content units, whereas auditory retelling contained more words but fewer content units. One potential explanation for these differences could be related to the fact that spoken discourse is more spontaneous, less organized, and thus contains more repetitions. Conversely, written discourse is usually less spontaneous, better structured, and allows the possibility to revise the written text, which could support more efficient content units retell. Differences between written and auditory retell have also been reported in patients with aphasia. One frequent compensatory strategy proposed for patients with aphasia is the use of more than one modality to enhance comprehension (i.e., Garrett *et al.* 1995), but the benefit of this strategy was not examined until recently (Brown *et al.* 2019). Using single sentences, Brown *et al.* (2019) tested whether patients with aphasia would perform better with the simultaneous presentation of auditory and written stimuli.

Results showed that not all patients with aphasia benefited from simultaneous presentation, especially the ones with severe aphasia. Despite the large heterogeneity regarding participants' profiles in this study and the relatively simple stimuli (i.e. simple active voice sentences), these results suggest that some individuals with aphasia have better auditory comprehension of narratives, whereas others have a better comprehension of written narratives (Brown *et al.* 2019). Taken together, these results highlight the importance of investigating both modalities separately as findings from auditory comprehension tasks cannot be generalized to the written modality, and vice versa.

The role of sociodemographic and sociocultural characteristics on discourse comprehension

At the individual level, knowledge of the topic (Shapiro 2004) and of discourse genre (narrative vs. expository; Clinton *et al.* 2020, Mar *et al.* 2021), literacy abilities (Mellard *et al.* 2010), level of schooling (Mackenzie 2000), age (Mackenzie 2000, Martin *et al.* 2018) and reading/writing habits (Martin *et al.* 2012) are variables that can influence discourse processing. To date, most studies on narrative comprehension have been conducted with adults from developed countries (e.g., Nicholas and Brookshire 1995, Whitney *et al.* 2009, Martin *et al.* 2018), where education levels are higher than in developing countries according to the education index of the Human Development Reports (United Nations Development Programme 2020). Since education and SES relate to cognitive (including linguistic) performance, those studies may not be generalizable for lower educated groups, and samples with lower SES. Studies in aphasia have already associated SES with the severity of linguistic and cognitive impairment and with patterns of recovery. For example, Song et al. (2017) studied the impact of SES - measured by the level of education, occupation, and income - on the functional outcome three months following an ischemic stroke. Their results suggested that people with lower SES present poorer outcomes. The multinomial logistic model analysis also showed that low educational level and manual laboring have a more significant impact on the functional outcome than does low-income level. Despite the relevance of studies on the impact of low education level and low SES, such studies investigating language abilities are still very scarce both in neurotypical adults and patients suffering from language impairments.

Earlier in life, reading and writing habits (RWH) are strongly related to the level of education (Chang *et al.* 2021). In children, RWH have generally been associated with the level of education and cognitive abilities (as measured by childhood IQ) (Sörman *et al.* 2018). During adulthood, the frequency of reading and writing practice is a measure widely used to capture information about RWH. It is important to notice that individuals with low levels of education can still have rich and frequent reading and writing activities at work or in informal settings, which has been shown to compensate for lower levels of education in cognitive and neuropsychological assessment, including language (Pawlowski *et al.* 2012, Cotrena *et al.* 2016, Malcorra, Mota, *et al.* 2022). Moreover, the number of years of education in developing countries may not reflect the quality of education as it normally does in developed countries. Pawlowski et al. (2012) developed a questionnaire that evaluates the reading frequency of different types of printed and digital materials. They demonstrated an association between the frequency of RWH and cognitive abilities, including written comprehension but not oral comprehension (Pawlowski *et al.* 2012), in a group of 489 adults from Brazil. Thus, the level of education, SES, and RWH most probably interact to shape cerebral, cultural, social, linguistic, and cognitive development and abilities (Ardila *et al.* 2010, Huettig *et* *al.* 2018, Tessaro *et al.* 2020). Furthermore, our recent results suggest that RWH are associated with macrostructural measures of spoken discourse production comparing healthy controls to unilateral stroke in left and right hemisphere (Schneider *et al.* 2022) and in healthy adults and older adults (Malcorra, Wilson, *et al.* 2022). This highlights the importance of not only investigating the role of the level of education in discourse retelling and comprehension but also including other variables which have an impact on cognitive performance such as RWH.

The relation between discourse measures and other language abilities

An increasing body of research has been exploring the relationships between lexical retrieval and discourse measures. To date, the focus has been on spoken discourse measures (i.e., discourse production). For instance, correlations have been reported between naming accuracy and informativeness in the acute (Boucher *et al.* 2020) and chronic phases (Fergadiotis and Wright 2016) of post-stroke aphasia. A correlation between naming and main concept analysis has also been reported in chronic post-stroke aphasia, but the relationship was less predictable in patients without aphasia (Richardson *et al.* 2018). Our team (Schneider *et al.* 2021, 2022) also recently reported similar correlations between naming abilities and macrostructural measures of discourse production in controls and participants who suffered from a stroke in the left hemisphere or in the right hemisphere, without significant aphasia as in the present study. As clearly summarized by Richardson et al. (2018), previous evidence tends to support a relationship between picture naming and some discourse variables, but the discourse measures used and the populations reported in the various studies limit the interpretation of this relationship. Naming abilities have also been associated with auditory comprehension at the word level (Butterworth *et al.* 1984). However, to the best of our knowledge, this has not been tested at the discourse level both with auditory and written narratives in stroke populations. The closest study was conducted in a group of Brazilian-Portuguese speakers composed of typical older adults and patients with mild and moderate Alzheimer's disease with low levels of education (Rinaldi *et al.* 2008). Using retelling of written narratives, no correlations have been found between naming and retelling abilities. Considering that naming impairments affect performance in many language tasks (e.g., picture naming, oral comprehension), including discourse tasks, the relationship between naming and narrative retell would bring evidence about the role of lexical retrieval in the ability to convey relevant information after listening to a story.

Neural correlates of discourse comprehension

Behavioral studies on narrative comprehension in post-stroke individuals with and without aphasia as a function of the type of modality (auditory versus written presentation) are scarce. Also, no previous studies have, to the best of our knowledge, investigated the neural correlates of narrative retell and comprehension regarding presentation modality in post-stroke individuals. Such studies can bring evidence on brain areas involved in cognitive (including language) processing, providing support to the development of models explaining and comparing auditory versus reading comprehension of discourse. Among the few conducted on neurotypical populations, Xu et al. (2005) examined the role of narrative context in written comprehension using functional magnetic resonance imaging. Written narrative comprehension engaged a more bilateral and dynamic network than written comprehension of unconnected sentences. More precisely, when listening to a story, the right hemisphere is more activated at the end of a story. It engages a network including extrasylvian areas such as the cerebellum, which reflects both linguistic and extralinguistic processing during narrative written comprehension. Similar results have been reported in young adults during auditory narrative comprehension, as narrative comprehension engaged regions in the classical language network and beyond (e.g., Awad *et al.* 2007, Martín-Loeches *et al.* 2008, AbdulSabur *et al.* 2014, Babajani-Feremi 2017), providing evidence that narrative comprehension is supported by an extended network. Listening to auditory narratives is the most related ability to narrative comprehension studied in post-stroke individuals. Similar to the aforementioned studies targeting narrative comprehension, Crinion et al. (2006) reported that listening to narratives engaged a bilateral temporal network when compared to listening to reversed speech, similar to what has previously been reported in neurotypical adults. However, patients with a lesion in Wernicke's area had reduced activation in the preserved left anterior superior temporal sulcus when compared to both patients without a lesion in Wernicke's area and controls. As for story retell, to our knowledge, only one study investigated the neural correlates of story retell in people with stroke (Leo *et al.* 2019). However, the focus of the study was uncovering the neural correlates of the mnemonic effect of songs; therefore, it did not provide the neural correlates of spoken story retelling.

Aims of the present study

The present study aims to extend our knowledge on the impact of brain injury following a stroke on the macrostructural aspects of discourse processing in individuals with middle-low to low SES and low levels of education. Our recent studies (Schneider *et al.* 2021, 2022) investigated the macrostructural aspects (i.e., cohesion, coherence, narrativity, macropropositions and index of lexical informativeness) of discourse production using picture-sequence description tasks. The present study focuses on two other macrostructural aspects, namely main information (MI) and complementary information (CI), in story retell and comprehension. We intend to analyze macrostructural aspects of story retell and comprehension, in both auditory and written modalities, in a sample of unilateral LH stroke patients who do not present significant persistent aphasia, since the impact of the absence of significant aphasia has not fully been addressed in the literature. The aims are threefold. First, we examine whether there are differences between LH patients and healthy controls (HC) in narrative retelling and comprehension measures, in both auditory and written modalities. Based on a series of studies from Nicholas and colleagues (e.g., Brookshire and Nicholas 1984, Wegner *et al.* 1984, Nicholas and Brookshire 1995), we hypothesized that individuals in the LH stroke group and controls would have a similar performance on both retelling and comprehension measures, but although this would not be statistically different, individuals in the stroke group would have a quantitatively lower performance. Second, we investigate whether there would be a relationship between the discursive variables and other linguistic and sociodemographic variables which have been associated with discourse in previous studies. Based on Pawlowski *et al.* 2012, we expected that RWH would be strongly related to discourse retelling and comprehension in the written modality but would also be related to a lesser extent to discourse retelling and comprehension in the auditory modality, in both groups (HC and LH). We also expected that naming would relate to retelling, in both modalities (Fergadiotis and Wright 2016, Richardson *et al.* 2018, Boucher *et al.* 2020, Schneider *et al.* 2021, 2022). Third, we explore the association between discursive measures and their structural correlates in grey matter (GM) regardless of the group considering that we are not expecting behavioral differences. Based on Crinion et al. (2006), we hypothesized that lower grey matter density in left temporal areas would relate to poorer performance in discourse comprehension, which could, in turn, impact the quality of retelling.

Methods and Procedures

Participants

Seventeen (17) individuals with a left hemisphere stroke (LH) were recruited from a public hospital in a metropolitan area in a southern state of Brazil. Demographic and clinical variables of participants with a stroke are presented in Table 1. Patients' inclusion criteria consisted of first-ever ischemic stroke in the LH at least 4 months before the study (mean=13.94 ± 7.58 months post-stroke), being a native speaker of Brazilian Portuguese and right-handed. Exclusion criteria included 1) moderate to severe language impairment (based on the SLP clinical judgment made after an interview with the individuals with a stroke and their relatives as well as with a screening assessment) which could prevent participants to complete the tasks, 2) history of major psychiatric disorders, 3) learning disabilities, 4) severe and uncorrected self-reported perceptual deficits, 5) additional neurological diagnoses, 6) left-handedness or ambidexterity which was assessed using the Edinburgh Handedness Inventory (Oldfield 1971), 7) < 2 years or > 13 years of formal education, and/or 8) bilingualism. The participants of the present study include a subset of the participants of previous studies (Schneider *et al.* 2021, 2022).

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Insert Table 1 approximately here

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Ten (10) healthy controls (Controls) were also recruited at convenience in community centers. As reported in Table 2, the control group was unbalanced with the clinical group regarding the sex variable because the recruitment of healthy men is more challenging in Brazil compared to that of women. Controls reported no history of neurological illness or psychiatric history and were native speakers of Brazilian Portuguese. In addition to the exclusion criteria used with LH patients, controls were also excluded if their score on the Mini-Mental State Examination (MMSE) was lower than the age and educational specific cut-off score adapted for the Brazilian population ((Brucki *et al.* 2003): illiterate = 20 points; 1-4 years of education = 25 points; 5-8 years of education = 26.5 points; 9-11 years of education = 28 points; ≥11years of education = 29 points). Full written consent was obtained from all participants. The study was approved by the ethics review board of the university where it was conducted, under registration number 1.378.955/2015.

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Insert Table 2 approximately here

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Materials and procedures

Participants of both groups underwent two meetings completed on two days that included magnetic resonance imaging (MRI) as well as language, cognitive and neuropsychological assessments.

Neuropsychological screening

A speech pathologist did a short interview with the patients and their companions to screen the patients' language comprehension and production abilities, as well as previous or current language treatment. Participants were characterized by a neuropsychological screening using the Mini-Mental State Examination (MMSE) adapted for the Brazilian population (Brucki *et al.* 2003), a short naming task consisting of 12 nouns and 3 verbs (maximum of 2 points per stimulus, for a total of 30), and the subtests of words and sentences repetition, words and pseudowords writing and reading (Montreal-Toulouse-Brasil [MTL-BRASIL], Parente et al., 2016) , a free (i.e., without constraints) verbal fluency task (Bateria Montreal de Avaliação da Comunicação Breve (MAC-Breve); Ska et al., 2014). Moreover, all the recorded material gathered from the oral responses given by the clinical participants was checked by the speech pathologist, which ensured they did not present any moderate to severe language impairment.

Participants were also asked to complete a SES questionnaire (*ABEP - Associação Brasileira de Empresas de Pesquisa;* https://www.abep.org/criterio-brasil). The SES score is calculated based on household characteristics, the education level of the head of household, and consumer goods and amenities. Participants were further characterized regarding their reading and writing habits (RWH) using a questionnaire (Pawlowski et al. (2012)). The questionnaire evaluates the frequency of reading different types of printed and digital material, such as magazines, newspapers, books, social media, and the frequency of writing notes, text messages, literary and/or non-literary texts, both weekly. Frequency ratings of both reading and writing habits were scored using a four-point scale for each type of material: daily (4 points); a few days a week (3 points); once a week (2 points); rarely (1 point), and never (0 points), with a maximum score of 16 points for each modality (reading and writing). For the patients, only RWH before stroke onset were considered. The examiner read the questionnaire to the controls and completed it, while in the stroke group, the participants' companions or caregivers provided the information, with the patients' confirmation.

Discourse assessment

The discourse tasks were eight narratives presented orally or visually (printed/written). Six were developed by two linguists (S.A.M.T., L.C.H.) and two are part of a language assessment battery (Parente *et al.* 2016). Briefly, stories consisted of narrative paragraphs whose structure portrayed sequential actions (Adam 2008) based on daily life situations. The narratives had the following structure: a) an initial situation (contextualization), b) a trigger node (daily problem), c) a reaction, d) a solution and e) a conclusion, with a final state. Linguistic metrics extracted from CoH-Metrix-Port software, version 2.0 (http://www.nilc.icmc.usp.br:3000/; Scarton and Aluísio 2010) were used to balance the stories in both presentation modalities (written and auditory). The software extracted the number of words and sentences, Flesch index, content word incidence, verb incidence, noun incidence, mean number of words per sentence, content word frequency (refer to Supplementary Material 1 for examples of auditory and written stories and about the statistics). A detailed description of the elaboration of the task can be found in Martins & Hübner (2020).

Main information (MI) and complementary information (CI) were then identified by the S.A.M.T. and L.C.H. for each story (refer to Supplementary Material 1 for examples). MI was considered as information essential for macrostructure comprehension, including information such as the name of the main character(s), the location, the action or the problem, and the resolution. CI consisted of details about the story, such as time shift and secondary characters involved in parallel actions. A total retelling score was calculated and consisted of the total number of MI and CI produced for the three stories combined in each modality (auditory and written). Performance in the retelling task was assessed by scoring the presence (1 point) or the absence (0 points) of preidentified MI and CI in each story. The maximum total retelling score for auditory texts is 66 and 68 for written texts. The maximum MI score for auditory texts is 35 and

38 for written stories, while the maximum CI score for auditory stories is 31 and 30 for written stories.

Similar to the Discourse Comprehension Test (Brookshire and Nicholas 1993), five questions were developed to assess the comprehension of the stories. The first two were open-ended questions while the last three were yes/no questions. Two open-ended questions and three yes/no questions were asked for each story. Open-ended questions required a short answer of one or two words and were scored on various scales (varying between 1, 2, 3 or 4-point scales) whereas yes/no questions were scored on a 1-point scale (i.e., 0 or 1). The maximum comprehension score was 19 for the written stories and 19 for the auditory stories. Examples of an auditory story and a written story are presented in Supplementary Material 1, including the original version in Brazilian Portuguese and the English translation, as well as the MIs and CIs and the structure and complexity variables of the stories.

Procedures

A training session was first completed by each participant with an oral narrative. The instructions and the questions were presented orally by the researcher. In the experimental session, before reading or listening to the first story, the participants were told that they would first read (or first listen to) three stories, followed by the other three stories (listened to or read). They were told they could read or listen to the story more than once if necessary to understand it. After each story, they should retell it in their own words with as many details as possible. Then they would be asked to answer the questions that would follow each text.

After the training, all participants completed the two tasks (retelling and five comprehension questions) related to the six narrative stories (three auditory presented and three written) in random order. Half of the participants of both groups were first presented with the oral stories, while the other half were first introduced to the written stories. Participants' retelling and answers to the questions were video, and audio recorded. Data were collected, transcribed, and scored by S.A.M.T. under the supervision and double-checked by L.C.H. Discrepancies between the two were resolved through discussion.

Auditory narratives were recorded in mp3 and m4a, in high definition, using the microphone from the recording app from an Apple iPhone 5S. All stories were recorded by a female reader, lasting from 41 to 46 seconds with a mean duration of 43s. Typical prosody of the language was used, in standard Brazilian Portuguese. Recordings were then transferred to a computer and noise removal was completed using Audacity® version 2.1.0 (Audacity team®, 1999-2021). Participants listened to the texts using a Bluetooth 4.1 version of JBL Go soundbox (180Hz-200Hz) using an audio volume compatible with typical hearing in a quiet room. Headphones were not provided. Written texts were printed in A4 white bond, landscape layout, Calibri regular font size 16, capital letters, justified, in black, and a line spacing of 1,5. Each narrative was printed on a single page.

MRI protocol

The MRI protocol was acquired using a GE Healthcare 3.0T HDxt MRI scanner. One high-resolution three-dimensional (3D) T1-weighted scan was acquired using a Magnetization Prepared Rapid Gradient Echo (MP-RAGE) sequence (TR = 6272 msec, TE = 2255 msec, TI = 500 msec, voxel size = 1x1x1 mm^3, matrix = 240 x 240, 196 slices) and an 8-channel skull coil.

Lesion segmentation

As performed recently (Schneider *et al.* 2021), the lesion delineation was performed using a semi-automated demarcation performed with *Clusterize* SPM's toolbox (Clas *et al.* 2012) from http://www.medizin.uni-tuebingen.de/kinder/en/research/neuroimaging/software and verified by a fully manual method. First, *Clusterize* was used to semi-automatically delineate the lesion on the T1 map of each patient. Excellent agreement between manual segmentation and the semi-automated lesion maps obtained with *Clusterize* have been reported in chronic stroke delineation (de Haan *et al.* 2015). *Clusterize* automatically computes hypo-intensity clusters of voxels. Cluster(s)-of-interest corresponding to the lesion were manually selected and adjusted to fit the lesion in each slice by a team member (K.M.). Finally, the entire lesion was extracted for each subject. The rater was blind to the behavioral scores.

Lesion delineation and preprocessing

Voxel-based morphometry (VBM) pre-processing was performed using the MR segment-normalize function of Clinical Toolbox Version 7/7/2016 running on SPM12. The template for normalization was obtained from 30 healthy subjects (mean age: 61.3 years, seven men; see Rorden et al., [2012] for details). Enantiomorphic normalization (6-tissue new segment) has been reported to be superior to the traditional cost-masking function (Nachev *et al.* 2008). This alternative non-linear registration method corrects the signal within the lesion using information from the undamaged contra-lesional region. Lesion maps were entered into the normalization step. The pre-processing of the control group followed the same procedures but since these participants did not have brain lesions there was no lesion included in enantiomorphic normalization. All images obtained from the segmentation of normalized images were smoothed using the full-width-half-maximum (FWHM) Gaussian kernel of 8 mm.

Statistical analyses

Behavioral analyses

All statistical analyses were done using SPSS® v25.0 and the significance level was set at $p < .05$. Independent sample *t-test*s were conducted for the variables which showed a normal distribution according to the Shapiro-Wilk normality test (p>.05) and equal variance according to the Levene's test for equality of variance (p>.05). Non-parametrical Mann-Whitney tests were conducted for variables that showed a non-normal distribution (p<.05) or unequal variance according to the Levene's test for equality of variance (p<.05). We conducted 8 group comparisons using independent samples *t*-tests (i.e., written narratives retell, auditory narratives retell, comprehension of written narratives, comprehension of auditory narratives, MI in written narratives, MI in auditory narratives, CI in written narratives and CI in auditory narratives). To avoid the inflation of Type I error rate, a Benjamini-Hochberg procedure (Benjamini and Hochberg 1995) was applied for the 8 comparisons, using a false discovery rate at 0.05.

Previous evidence reported correlations between macrostructural measures, such as measures of story grammar (Cannizzaro and Coelho 2013) and cohesive ties (Sherratt and Bryan 2019), and verbal fluency tasks. Exploratory correlations were thus performed to assess the possible association with two verbal tasks (i.e., the naming task and the free verbal fluency task). Exploratory correlations were also performed with pre-reading and writing habits. Pearson's correlations were used when both variables showed a normal distribution whereas Kendall's tau correlations were used when at least one variable showed a non-normal distribution. Considering the risk of Type I errors with exploratory correlations, the Benjamini-Hochberg method was also applied to correct the correlations for multiple comparisons, using a false discovery rate at 0.05 for each family of tests.

Neuroimaging analyses

In the first step, whole-brain statistical analyses were performed in SPM12 using the smoothed GM maps to assess whole-brain effects. Second-level general linear models were specified including the two groups (LH and controls), as well as age, years of education, and total intracranial volume as covariates of no interest. In a second step, a regression model was performed using the scores of the discursive measures as a dependent outcome as well as age, years of education, and total intracranial volume as covariates of no interest. For both analyses, a family-wise error (FWE) correction at $p < 0.05$ at the cluster level was applied, using an arbitrary cluster-forming uncorrected threshold of $p < 0.001$. Additionally, effect sizes for significant comparisons were calculated using the T-statistics (t) and the degrees of freedom (df) in the formula $\sqrt[2]{t^2/(t^2+df))}$ (Lukic *et al.* 2017).

Results

Participants

Table 2 presents demographic information and mean neuropsychological evaluation scores for both patient and control groups. A sub-group of participants with LH stroke (n=9) and the 10 participants without brain damage also underwent the MRI session. Figure 1 represents the lesion overlap of the sub-group of participants for which we had an MRI (see supplementary Table 2 for the demographic information and neuropsychological scores of the sub-group of participants who underwent MRI). Statistical analysis showed no significant differences in terms of age, education, or socioeconomic status between the two groups (which is also true when comparing the sub-group of participants who underwent MRI to the controls). Only one participant in the LH group had mild aphasia, whereas all the other 16 participants in the LH group did not have persistent language impairments. This participant was included in the study since his auditory and written comprehension abilities were comparable to those of the other patients in the LH group, his auditory language performance in the spontaneous speech was stable while presenting mild anomia and difficulty in repetition. Regarding the neuropsychological assessment, a significant difference was observed between the two groups on the MMSE ($U=147.50$, $p < .001$) and naming ($U=119.00$, $p < .001$) tasks, for which the LH patients had a lower performance than healthy controls.

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Insert Figure 1 approximately here

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Discourse comprehension and retell results

Mean and standard deviations (mean ± SD), as well as the range for each group, are reported in Table 3 in addition to the statistical values of the tests. For a matter of concision, we only report the discourse retell and comprehension scores and analysis of the complete group of participants (the results of the sub-group of participants who also completed the MRI are similar to the results of the larger group and are available in Supplementary Table 3). The distribution of the data of all groups is illustrated in Figure 2. After the Benjamini-Hochberg FDR correction, there were no inter-group differences in the retelling, comprehension, MI, and CI scores in both modalities.

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Insert Table 3 approximately here

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Insert Figure 2 approximately here

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Exploratory correlations were performed to assess the association of the discursive variables with two lexical formal tasks (i.e., naming and free verbal fluency) as well as with pre-reading and pre-writing habits. The statistical details of the correlations are reported in Table 4. All correlations computed with the naming task were found to be significant after Benjamini-Hochberg FDR correction in both the written (retelling: r =.419, adjusted p = .018; comprehension: r = .455, adjusted p = .016; MI: r = .732; adjusted p = .006; CI: r = .604, adjusted p = .008) and auditory modalities (retelling: r =.190, adjusted p = .043; comprehension: r = .401, adjusted p = .024; MI: r = .326; adjusted p = .042; CI: r = .491, p = .028). None of the correlations with the free verbal fluency task as well as reading and writing habits were found to be significant.

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Insert Table 4 approximately here

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Imaging results

Identification of grey matter density differences between groups

VBM analyses were computed to identify grey matter density differences between the groups. Age, education, and total intracranial volume were included as nuisance covariables to account for interindividual differences. Significant differences are reported in Table 5. LH stroke patients compared to healthy participants showed a reduction in grey matter density mainly in the inferior frontal gyrus bilaterally as well as in the right Rolandic operculum. The areas are represented in Supplementary Material 4.

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Insert Table 5 approximately here

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Linear regression-based analysis of discursive variables

Regression-based analyses were computed, after controlling for age, education, and total intracranial volume, between regional GM volume as measured by whole-brain VBM and the discourse measures. The anatomical labeling of the clusters is listed in Table 6, and the areas are shown in Figure 3.

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Insert Table 6 approximately here

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Insert Figure 3 approximately here

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One significant cluster located in the left hippocampus (MNI 152 coordinates -21 -31 -6; T = 4.83; k = 1203) was significantly and positively correlated with the retelling score from the written narratives. Grey matter density was also positively correlated with the comprehension score of written stories with brain areas located in the left hemisphere. Namely, written comprehension was correlated with a cluster located in the lingual gyrus (MNI 152 coordinates -5 -81 -1; T = 7.79; k = 10306) which extended towards to cerebellum as well as with a cluster located in the cingulate gyrus (MNI 152 coordinates -3 -47 31; T = 6.42, k = 1651) and two clusters located in the middle temporal gyrus (MNI 152 coordinates -49 -66 -1; T = 5.81, p = .003/MNI 152 coordinates -55 -38 3; T = 5.28, p = .011). The main information score of written narratives was also positively correlated with grey matter density in the left superior temporal pole (MNI 152 coordinates -31 15 -26; T = 8.34, .014), the left postcentral/precentral gyrus (MNI 152 coordinates -53 -15 29; T = 6.42, p = .020) and the left lingual gyrus (MNI 152 coordinates -14 -34 -5; T = 6.12; p = .002).

Regarding auditory comprehension of narratives, the comprehension score was positively correlated with grey matter density in the lingual gyrus (MNI 152 coordinates 17 -38 -13; T = 7.68, p < .001) in the right hemisphere whereas the complementary information score was positively correlated with a cluster in the left insula (MNI 152 coordinates -23 9 -20; T = 7.08, p = .021) which extended to the superior temporal pole (MNI 152 coordinates -30 14 -27). No significant grey matter area was significantly correlated with retell and main information performance in auditory narratives, nor with complementary information in written narratives.

Discussion

The present study extends the results of our previous studies (Schneider *et al.* 2021, 2022) aiming to better understand the impact of brain injury following a stroke on discourse processing in individuals with middle-low to low SES and low levels of education. Similar to our previous studies (Schneider *et al.* 2021, 2022), we investigated macrostructural processes of discourse, but while in those studies we focused on narrative production based on sequence-picture descriptions, we now focused on discourse retell and comprehension in both auditory and written modalities. Firstly, we intended to verify whether there were differences in discourse comprehension in both the auditory and the written modalities. Retelling and comprehension abilities were not significantly different between LH and HC, but quantitively lower in LH, especially in the written modality. Secondly, we aimed at determining whether there would be a relationship between the discourse measures, neuropsychological measures, and RWH. We showed a relationship between naming and macrostructural comprehension processes in comprehension and retelling of both written and auditory stories. Also, no associations were found between the comprehension nor retelling measures and RWH, even in the written modality. Thirdly, written comprehension was associated with GM density in several areas in the LH, whereas auditory comprehension was associated with GM density in the right lingual gyrus. Taken together, our results highlight the importance of investigating discourse comprehension processing in both auditory and written modalities in individuals with lower levels of education as it might differ from that of most of the studies conducted to date on post-stroke language impairments which have been conducted on English-speaking individuals (Beveridge and Bak 2011) with higher levels of SES.

Discourse Comprehension and Retell at the behavioral level

Consistent with previous evidence in participants with higher levels of education (Nicholas and Brookshire 1986, 1995), the LH and control groups presented a similar performance regarding comprehension. Nonetheless, their performance was quantitatively lower. Similar results were obtained with written narratives, but the difference was larger and almost reached the level of significance. We hypothesize that comprehension of written narratives may pose an extra load to people with lower educational levels and/or lower reading and writing habits, as compared to people with higher education and higher literacy. Reading narratives involves the interaction between low-level processes (which include decoding the print and sound units into words), high-level processes (such as syntactic and semantic processes and inferential skills), and cognitive processes (such as working memory (Safi *et al.* 2020). Lower literacy levels and lower frequency of exposure to printed material most probably increase the task demands in written narrative comprehension as compared to auditory narrative comprehension, because low-level processes might not be as automatized as in adults with higher levels of education. Formal education and the amount of reading at home, together with the number of books in the parental homes, have been identified as amongst the most important predictors of literacy in adulthood (Kyröläinen and Kuperman 2021). (Berl *et al.* 2010), and that the magnitude of activation decreases as phonological processing becomes more automatic (Church *et al.* 2008). Further studies should be conducted in larger groups of participants as we might have not detected significant differences between the two groups because of a lack of statistical power, especially regarding written narratives.

As for retelling, no differences have been found between the LH and control groups. We must note that story retell involves both comprehension and production, as one must understand what is said/read to retell the story in their own words. Although no differences have been found, the LH group produced fewer MI and CI items in both auditory and written narratives. The difference was larger with CI with the auditory narratives, which is similar to the lower performance on details in Nicholas and Brookshire (1995). Conversely, fewer (but still not significantly different) MI items were produced by the LH group with written stories. These results provide evidence of the importance of investigating both the auditory and the written modality to have a more thorough comprehension of the effect of a stroke in the LH regarding story retelling. Moreover, further studies should analyze the effect of both stroke and aphasia on narrative comprehension and story retell by comparing patients with and without aphasia following LH stroke. A recent study showed a continuum of performance when comparing patients with and without aphasia following LH stroke and controls in a story retell task (Yoo and McNeil 2019). Indeed, people with aphasia had a significantly lower performance than controls and patients with LH stroke without aphasia. Patients without aphasia had an intermediary performance and also differed significantly from controls. Although both studies used a story retell, we focused on measures targeting macrostructural and comprehension processing whereas Yoo and McNeil (2019) focused on microstructural productive measures, which could explain the conflicting results between the two studies. Interestingly, Yoo and McNeil (2019) also tested working memory as it can influence story retell. Patients with LH stroke without aphasia did not differ from controls on working memory, whereas patients with aphasia differed from both groups. Similarly, Tanridag et al. (1987) reported that impairments in short-term verbal auditory and visual memory are more frequent in patients with aphasia following a stroke in the LH than in those without aphasia. The possible relationship between working memory and auditory versus written comprehension of narratives and retelling was not the focus of this study but could be investigated in further studies considering that working memory and story retell seem to be associated (Yoo and McNeil 2019), particularly in patients with brain damage.

Correlations between comprehension and retelling from auditory narratives and naming accuracy in a naming task have been found as expected. Consistently, naming accuracy has been associated with various measures of discourse production (Fergadiotis and Wright 2016, Richardson *et al.* 2018, Boucher *et al.* 2020, Schneider *et al.* 2021, 2022), such as cohesion, coherence, narrativity, macropropositions, and informativeness. Our study contributes to these findings, by bringing evidence of the relation between naming and macrostructural processes in comprehension and retelling of auditory stories. As mentioned previously, a story retell task does not only involve production, but it requires a good comprehension of the story before retelling its important elements. Regarding the written presentation modality, correlations with naming ability has not been tested extensively in patients with stroke. Still, the relationship between naming accuracy and written stories is consistent with evidence from studies conducted on individuals with written language impairments. Namely, many studies observed that children with written language difficulties had also difficulties with object naming. Significant correlations have been reported between object naming and reading skills in children (Rubin and Liberman 1983, Katz 1986, Wolf and Goodglass 1986) and also in adults (Cantwell and Rubin 1992). The main hypothesis for this relationship is that phonological deficiencies underlie both problems and would not reflect semantic impairment. This hypothesis could explain results from a previous study (Rinaldi *et al.* 2008) conducted in a group of Brazilian-Portuguese speakers composed of typical elderly and patients with mild and moderate Alzheimer's disease, in which semantic impairments are expected. In that study, the correlation between naming and retelling of written narratives was not found significant in groups with levels of education similar to those of the present study. We did not examine the type of errors produced in the naming task to test this hypothesis, as this was not the focus of the study. Nonetheless, further studies should be conducted in groups of persons with low levels of education and socioeconomic status to see if this relationship between written story retelling and comprehension can be replicated, as to better understand the underlying processes.

The role of reading and writing habits

Based on previous work (Pawlowski *et al.* 2012), we expected that RWH would be associated with the performance in narrative comprehension, especially with written stories. Surprisingly, the comprehension of both auditory and written narratives in our sample of individuals with low to middle-to-low SES and low levels of education was not correlated with RWH. Previous studies have reported the protective effect of reading, as it engages several cognitive abilities which consequently stimulates several brain areas (Sörman *et al.* 2018). It is true that the present study only included participants with relatively low levels of RWH, which may have limited the statistical power of the analysis. Pawlowski et al. (2012) showed that RWH were related to both written and auditory comprehension in a large sample of 489 including individuals with three levels of education and two levels of RWH. The present study was smaller and only included individuals with the two lower levels of education used in their large study. Taken together, these results point to the need to further study the role of RWH and SES as potential variables to consider when studying stroke outcomes, as their influence seems to vary depending on the nature of the language tasks. Thus, it reinforces the need for further studies focusing on the impact of SES in both neurotypical and clinical populations with a wider range of SES and educational levels, using multiple language tasks and including languages other than English. Investigating the behavioral and neurobiological mechanisms in under-studied populations makes important contributions to future research and clinical outcomes because they represent most of the people in the world who are living mainly in underdeveloped countries.

Neural correlates of discourse comprehension and retell

At the brain structural level, the majority of studies conducted on clinical populations have focused on sentence comprehension (e.g., Barbieri *et al.* 2019, Lukic *et al.* 2021) or on discourse production (Gleichgerrcht *et al.* 2016, Alyahya *et al.* 2021, Schneider *et al.* 2021). Thus, the literature on narrative understanding including comprehension and retell abilities following a stroke remains scarce. Much of what we know about narrative comprehension comes from studies conducted on neurotypical individuals, and mostly on highly educated young adults. Nonetheless, there is a consensus that narrative processing requires cognitive operations very different from those required for sentence processing, and the findings found on sentence comprehension cannot be generalized to narrative processing (Xu *et al.* 2005). Taken together, their studies support the idea that language comprehension is complex and thus supported by more than one area, and more largely in the left hemisphere. Similar results were also obtained in a meta-analysis on the functional neuroanatomy of text comprehension conducted in the late 2000s based on 23 studies, but which also included studies using single sentences focusing on metaphor comprehension (Ferstl *et al.* 2008). More recently, studies conducted on neurotypical young adults also revealed activations beyond the classical language network (AbdulSabur *et al.* 2014, Babajani-Feremi 2017), adding evidence that narrative comprehension is supported by an extended language network (Ferstl *et al.* 2008). Likewise, in the present study, written comprehension of narratives was associated with several areas in the LH, such as the left lingual gyrus, the cingulate gyrus, and the left middle temporal gyrus, as well as the cerebellum. Similarly, the retelling of MI in written narratives was associated with clusters located in the superior temporal pole, the postcentral/precentral gyrus, and the left lingual gyrus in the left hemisphere. With similar sentence complexity, others have shown that written narrative comprehension engaged a more bilateral and dynamic network than written sentence comprehension, with the right hemisphere being more activated at the end of a story and including extrasylvian areas such as the cerebellum, which reflects both linguistic and extralinguistic processing during narrative comprehension (Xu *et al.* 2005). Conversely, auditory comprehension of narratives was only associated with the lingual gyrus in the right hemisphere. The lingual gyrus has been associated with semantic integration across modalities (Musz and Thompson-Schill 2015, Van de Putte *et al.* 2018), and with auditory short-term memory impairments (Dronkers *et al.* 2004), which is consistent with its relation with auditory narrative comprehension. Thus, we hypothesize that written narrative comprehension was supported by an extended network because it was more challenging than auditory comprehension for our groups of participants with lower levels of SES, education, and reduced RWH. Similar patterns have been reported in school-age children developing their reading skills for which an extended network supports written comprehension compared to auditory comprehension (Berl *et al.* 2010). Another potential explanation for the less extended network in auditory language comprehension in the present study is the lower variability in performance of auditory narrative skills which may have resulted in loss of statistical power to detect more regions. The difference between the two groups was larger with written comprehension which might explain that the regressions between the behavioral measures and grey matter density were larger.

Limitations

Some limitations should be noted. First, the sample size of each group is small, and it is, therefore, difficult to generalize the present results to adults with a stroke in the LH (Lorca-Puls *et al.* 2018). Second, we acknowledge that the present study cannot disentangle the source of the findings because we cannot determine whether the VBM results are driven by the individuals with a stroke or the controls. By combining the two groups in the VBM analysis, we cannot say whether the results reflect frank damage (i.e., due to a stroke) or grey matter loss due to other reasons such as aging. Moreover, the small sample size may have contributed to reducing statistical power, which may have led to the failure in detecting significant results across the statistical tests. The small sample has a greater impact on the VBM analysis which involves more statistical tests. The interpretation of the VBM results must therefore be taken cautiously. Also, retelling was scored by one judge, and double-checked by a second one, but the inter-rater reliability was not calculated, which would have strengthened the results. Another limitation regards the potential influence of sex differences between the two groups. We have not been able to balance the groups according to sex due to the difficulties in recruiting participants. In Brazil, the recruitment of men is very challenging. As in our previous study, we acknowledge that the study would have been more optimal with groups matched on the sex variable, considering the potential influence of sex on cognition. For instance, differences between genders in cognitive performance have been reported in a large sample of elderly individuals, suggesting that the influence of gender on cognition persists in late life (Munro *et al.* 2012). However, others have shown that the majority of sex differences are not large enough to support the hypothesis of sexual dimorphism in terms of anatomy, brain function, cognition, and behavior (Jäncke 2018). According to this review, brain and cognitive traits are modulated by several variables other than sex, including the environment, culture, and practice. We must also note that sex was not used as a covariate because the use of intracranial volume significantly reduces the gender differences (Pell *et al.* 2008). Finally, to fully understand the neural basis of narrative comprehension, future studies should not only investigate the structural correlates but also look at the functional and anatomical connectivity to reach a better understanding of the role of the language network in discourse comprehension processing.

Conclusions

This study contributes to the existing body of evidence regarding macrostructural aspects in discourse comprehension and retell by comparing adults with a chronic LH stroke to controls, corroborating the interplay between discourse and neuropsychological measures as well as the role of the LH in discourse comprehension. Moreover, this study highlights the importance of taking into consideration sociodemographic profiles of participants, such as education, SES, and RWH, as important variables influencing the performance in discourse comprehension, more specifically to what concerns both auditory and written comprehension and retell of narratives, with implications for clinicians, educators, and public health and education policymakers.

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Figure 1. Percentage lesion overlay maps, based on individual T1-weighted scans, rendered on a glass brain. The colour spectrum indicates the frequency of overlap.

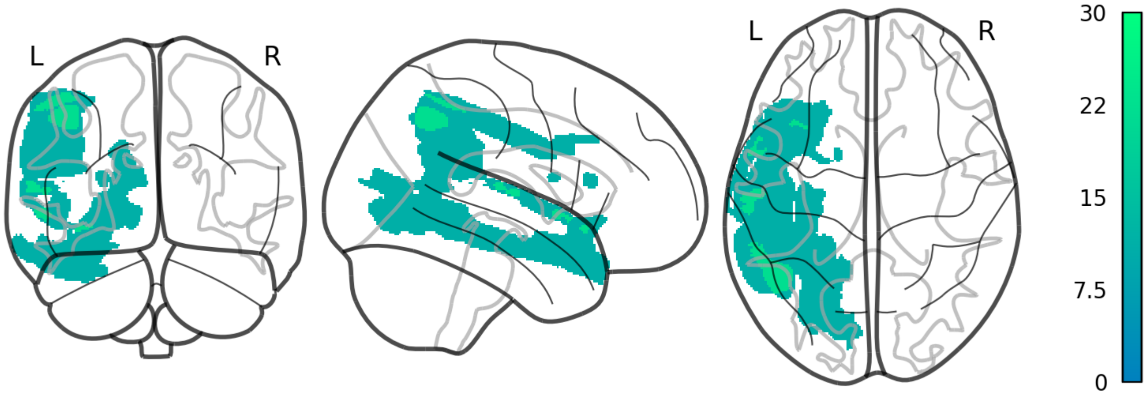
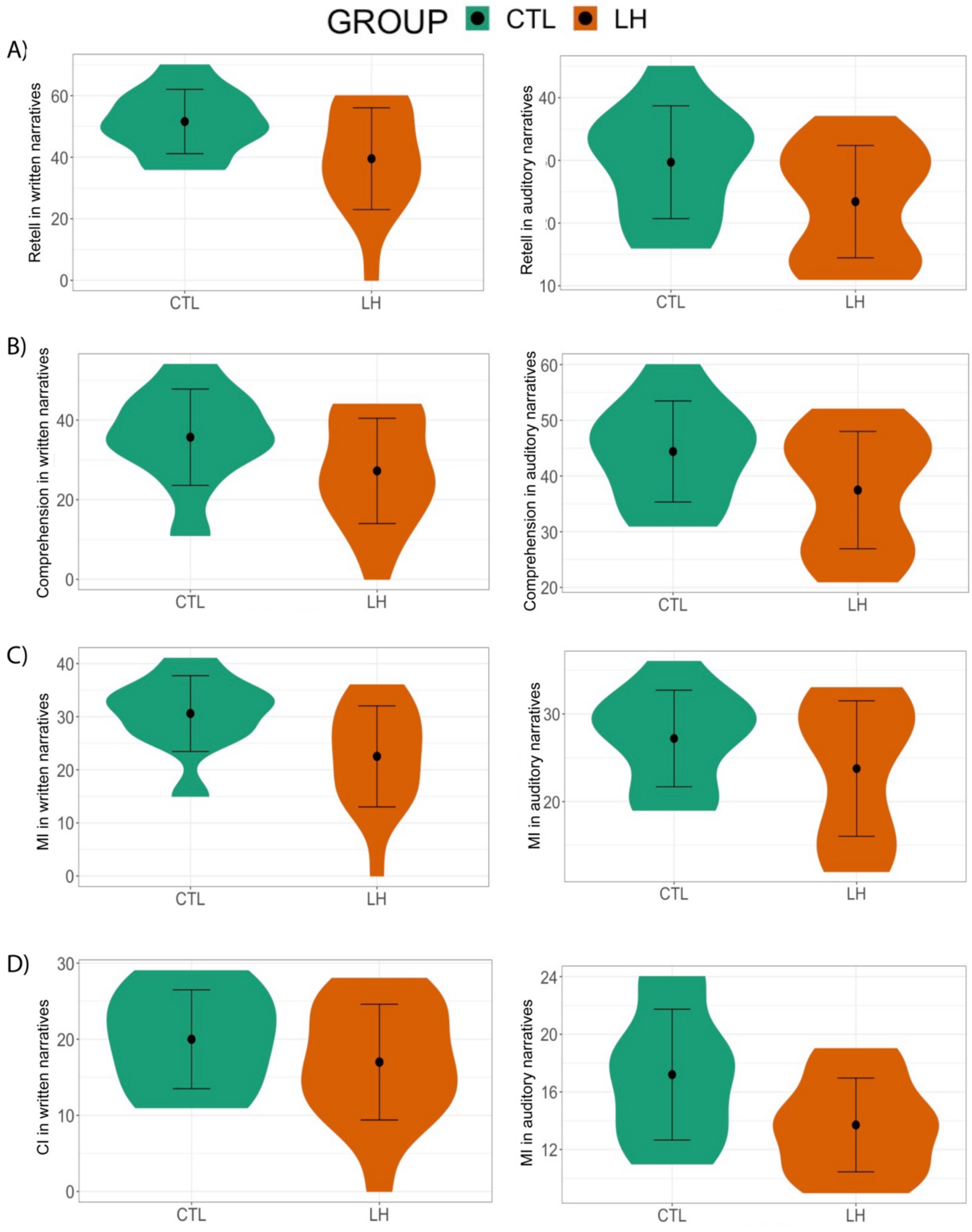


Figure 2. **Violin plots showing the distribution of the data and the probability density of the macrostructural receptive measures of written (left panel) and auditory (right panel) among the control group and the group of individuals with a left hemisphere (LH) stroke. Black dots refer to the group mean and the pointranges represents 1 SD (standard deviation)**



F1gure 3. Colour maps of significant areas in the VBM analysis. Panels (A–E) show the relationship between GM and discourse performance: (A) retelling in written narratives, (B) comprehension in written narratives, (C) comprehension in auditory narratives, (D) main informations in written narratives and (E) complementary informations in auditory informations. All voxels shown in colour survived a family-wise error correction (*p* < 0.05) at the cluster level, using an arbitrary cluster-forming uncorrected threshold (*p* < 0.001). The colour bar reflects the range of values from minimum (dark red) to maximum (yellow-white)

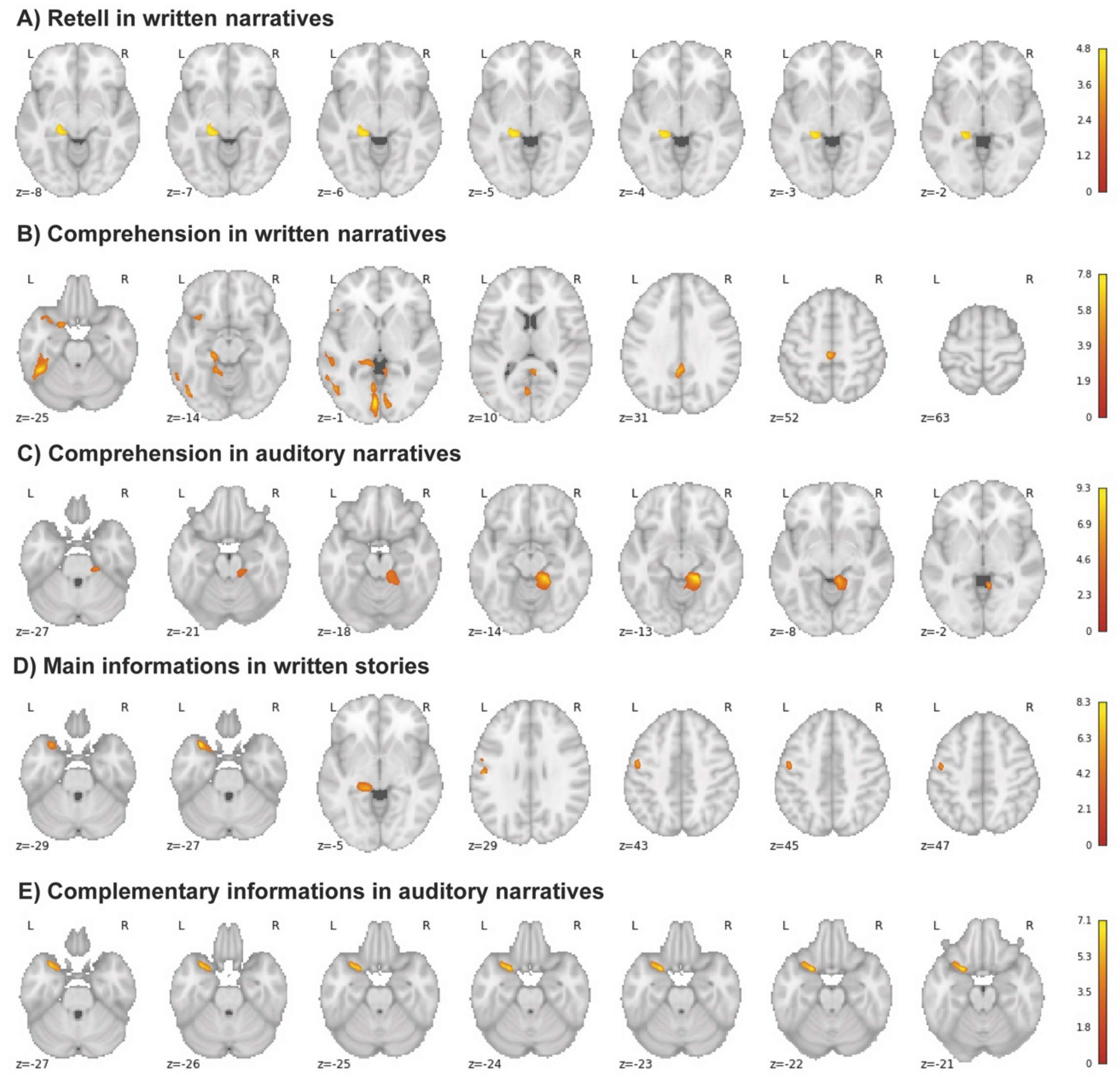


Table 1. Demographic and clinical variables of participants with a left hemisphere lesion.

Participant	Sex	Age (years)	Education (years)	Lesion location					Time post-onset (months)	Initial NIHSS score	Persistent Language Impairment
				Frontal	Temporal	Parietal	Occipital	Sub-cortical			
Patients with LH lesion											
1	M	72	7	X				X	12	7	no
2	F	76	5	X					14	5	no
3	M	59	11					X	7	5	no
4	M	76	11					X	24	11	no
5	M	65	5		X			X	11	4	no
6	M	56	10	X					11	8	no
7	M	57	11			X			14	2	no
8	M	68	8	X	X	X	X		5	6	yes

9	M	74	3					X	8	10	no
10	M	66	4				X		7	n/a	no
11	F	76	5	X					24	3	no
12	M	50	8	X		X			11	1	no
13	F	75	3			X			8	17	no
14	F	59	6			X			6	3	no
15	M	66	4			X			14	2	no
16	F	60	8			X			12	9	no
17	M	70	5	X	X				12	6	no

*For this participant, radiology service reports that there was a lesion in the territory of the medial cerebral artery.

There were no specifications regarding the more specific location of the lesion.

NIHSS= National Institute of Health Stroke Scale; F = Female; M = Male; n/a = not available

Table 2 – Mean sociodemographic descriptive data and neuropsychological results for participants with a LH stroke, and age-matched healthy participants.

	LH (whole group) n=17			Controls n=10			*p* value
Sociodemographic variables							
	Mean	**SD**	**Range**	**Mean**	**SD**	**Range**	
Age (years)	65.41	8.60	50-76	66.30	8.73	52-78	t = -.258, p=.799
Education (years)	6.76	2.91	3-12	6.90	3.93	4-11	U = 78.00, p= .749†
Sex	12M, 5F	-	-	1M, 9F	-	-	-
Time Post-stroke	13.94	7.58	5-30	-	-	-	-
Socioeconomic status (SES)*	26.81	6.65	17-35	27.30	7.07	15-38	t = -.18, p=.861
FAQ	4.29	7.72	0-26	.10	.316	0-1	U = 55.50, p= .141†
Reading (pre-stroke)	4.06	2.88	0-9	9.10	7.13	1-24	U = 122.50, p = .059†
Writing (pre-stroke)	2.29	3.06	0-9	5.40	5.016	0-12	U = 117.00, p = .115†
Neuropsychological assessment							
Mini-mental state examination (/30)	23.82	3.47	16-29	28.1	1.91	25-30	U = 147.50, p < .001†[a]
Naming subtest (MTL-Brasil; /30)**	25.08	11.64	8-30	29.50	0.71	28-30	U = 119.00, p < .001†[a]
Free verbal fluency (MAC-Breve; no maximum)**	28.62	20.21	4-67	45.60	21.16	26-89	t = -1.90, p = .071

LH = left 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); FAQ = Functional Activities Questionnaire, Brazilian version (Sanches et al., 2011)

*Data only available for 16 participants in the LH group

**Data available for 13 participants in the LH group

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

[a] LH significantly different from controls <.05

Table 3. Mean behavioral results for participants with a LH stroke and age-matched healthy participants.

	LH n=17			**Controls n=10**					
	Mean	SD	Range	Mean	SD	Range	***t-test or U-test***	***p-value***	***Corrected p-value***
Retelling (the sum of main and complementary information)									
Written narratives (max = 68)	27.24	13.23	0-44	35.70	12.09	11-54	t = -1.69	.105	.168
Auditory narratives (max = 66)	23.41	8.95	11-37	29.70	8.99	16-45	t = -1.76	.095	.190
Comprehension									
Written narratives (max = 19)	12.29	3.99	0-16	14.90	1.44	13-17	U=125	.046	.123
Auditory narratives (max = 19)	14.05	2.38	10-18	14.70	1.57	13-17	t=-.757	.456	.456
Main information									
Written narratives (max = 38)	22.52	9.51	0-36	30.60	7.13	15-41	t = -2.32	.029	.116
Auditory narratives (max = 35)	23.76	7.73	12-33	27.20	5.51	19-46	U = 105.5	.309	.353
Complementary information									
Written narratives (max = 30)	17.00	7.60	0-28	20.00	6.49	11-29	t=-1.23	.231	.308
Auditory narratives (max = 31)	13.71	3.26	9-19	17.20	4.54	11-24	t=-2.33	.028	.224

Table 4. **Correlations between discursive variables and formal lexical and working memory tasks.**

Variables	Statistics	Retelling: Written narratives	Retelling: Auditory narratives	Comprehension: Written narratives	Comprehension: Auditory narratives	Main information: Written narratives	Main information: Auditory narratives	Complementary information: Written narratives	Complementary information: Auditory narratives
Naming task BNT (/30)	r	.419	.190	.455	.401	.732	.326	.604	.491
	p	.009	.032	.006§	.015	<.001	.042§	.002	.017
	adjusted p	**.018**	**.043**	**.016**	**.024**	**.006**	**.042**	**.008**	**.028**
	n	23	23	23	23	23	23	23	23
Free verbal fluency (MAC-Breve)	r	.029	.114	.257	.259	.117	.104	-.035	.180
	p	.884§	.573§	.075§	.192§	.402§	.462§	.801§	.211§
	adjusted p	.884	.654	.600	.512	.804	.739	.915	.844
	n	27	27	27	27	27	27	27	27
Reading habits	r	.040	.040	.212	.194	.156	-.009	.081	.147
	p	.782	.782	.156§	.196	.436	.949§	.687	.322
	adjusted p	1.00	1.00	1.00	.784	.872	1.00	1.00	.859
	n	27	27	27	27	27	27	27	27
Writing habits	r	.085	-.036	.130	-.017	.102	-.096	.013	.000
	p	.567	.809	.398§	.911	.612	.522§	.930	1.00
	adjusted p	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	n	27	27	27	27	27	27	27	27

§ parametric tests have been used because both variables showed a normal distribution

Supplementary material 1.

1. Example of a narrative for auditory comprehension

Original version in Brazilian Portuguese

Na *última* (CI1) *manhã* (CI2), enquanto **Rosana** (MI1) **tomava banho** (MI2), **o chuveiro estragou** (MI3). Pelo *cheiro forte de fumaça* (CI3), Rosana logo percebeu que a **resistência do chuveiro havia queimado** (MI4). Rosana foi forçada a *parar o banho* (CI4). *Vestiu-se* (CI5) e *dirigiu-se à uma ferragem* (CI6) para comprar uma resistência nova. Ao chegar lá, como **não tinha experiência** (MI5) com o chuveiro, **pediu ajuda** (MI6) *ao atendente da ferragem* (CI7). Quando foi para casa, Rosana separou todas *as ferramentas* (CI8) de que precisava para trocar a resistência. Seguindo as *instruções do manual* (CI9) e as *dicas do atendente* (CI10), Rosana **conseguiu trocar** (MI7) a resistência do chuveiro *com segurança* (CI11). Rosana estava *orgulhosa* (CI12) de seu trabalho e quis testar o chuveiro, **recomeçando seu banho quente** (MI8).

English Translation

Last (CI1) *morning* (CI2), while **Rosana** (MI1) was **taking a shower** (MI2), **the shower broke down** (MI3). Due to the *strong smell of smoke* (CI3), Rosana soon realized that the **fuse of the shower had burned** (MI4)**.** Rosana was forced to *stop bathing* (CI4). She *got dressed* (CI5) and *went to a hardware store* (CI6) to buy a new fuse. When she got there, since she did **not have any experience with the shower** (MI5)**,** she asked the hardware attendant (CI7) **for help** (MI6)**.** When she went home, Rosana *selected all the tools* (CI8) she needed to change the fuse. Following the *instructions in the manual* (CI9) and *the attendant's tips* (CI10), Rosana was *able to safely* (CI11) **change the shower fuse** (MI7). Rosana was *proud* (CI12) of her work and wanted to test the shower, **restarting her hot bath (**MI8).

bold= **main information (MI) from the narrative (max = 8)**
italics = complementary information (CI) from the narrative (max= 12)

2. Statistics for the auditory comprehension narratives

Words: 106 (SD=4.2)
Sentences: 8
Flesch index: 52(SD=13)
Content words incidence: 608(SD=90)
Mean words per sentence: 13.2 (SD=5)
Noun incidence: 310 (SD=275)
Verb incidence: 222(SD=155)
Mean syllables per content word: 2.7(SD=2.3)

Content words frequency: 233165663.5(SD=90647869.8)

3. Example of a narrative for written comprehension

Original version in Brazilian Portuguese

Na *última sexta-feira* (CI1), o **cartão de crédito** (MI1) de **Luciana** (MI2) foi **recusado** (MI3) por uma **loja** *(*MI4). Luciana queria **comprar** (MI5) **chocolates** (MI6) para **o aniversário** (MI7) da **neta** (MI8). *Era comum* (CI2) Luciana pagar as compras no cartão com facilidade. Ao ver Luciana tão *chateada* (CI3), a *loja* (CI4) *ligou* (CI5) para o *banco* (CI6). Depois de consultar o sistema, o **gerente do banco** (MI9) **informou** (MI10) que o cartão tinha sido **clonado** (MI11). *Luciana* (CI7) *foi* até o *banco* (CI8) para *conversar com o gerente* (CI9) e *resolver o problema* (CI10). No *final da tarde* (CI11), Luciana ainda **não tinha comprado** (MI12) **os chocolates** (MI13) para a festa da neta, mas estava **aliviada** (MI14) por ter *evitado um prejuízo* (CI12) na sua *conta bancária* (CI13).

English translation

Last Friday (CI1), **Luciana's** (MI1) **credit card** (MI2) **was refused** (MI3) by a **store** (MI4). Luciana wanted **to buy** (MI5) **chocolates** (MI6) for her **granddaughter's** (MI7) **birthday** (MI8). *It was common* (CI2) Luciana to easily pay for purchases on the card. Seeing Luciana so *upse*t (CI3), the *store* (CI4) *called* (CI5) the *bank* (CI6). After consulting the system, the **bank manager** (MI9) **informed** (MI10) that the card had been **cloned** (MI11). *Luciana* (CI7) *went to the bank* (CI8) to *talk to the manager* (CI9) and *solve the problem* (CI10). At the *end of the afternoon* (CI11), Luciana **still hadn't bought** (MI12) the **chocolates** (MI13) for her granddaughter's party, but she was **relieved** (MI14) for having *avoided a loss* (CI12) in *her bank account* (CI13).

bold= **main information (MI) from the narrative (max = 14)**
italics = complementary information (CI) from the narrative (max= 13)

4. Statistics for the written comprehension narratives

Words: 106.5 (SD=6.3)
Sentences: 7
Flesch index: 51.6(SD=11)
Content words incidence: 601(SD=93)
Mean words per sentence: 15.2 (SD=9)
Noun incidence: 310 (SD=185)
Verb incidence: 214(SD=374)
Mean syllables per content word: 2.8(SD=1.1)
Content words frequency: 45150040.4(SD=311332866.3)

5. **Instructions for story retell** (part 1)

Instructions in Brazilian Portuguese for oral narratives

Você ouvirá **3** textos e responderá a perguntas sobre eles. Você poderá ouvir cada texto quantas vezes achar necessário para entendê-lo. Quando achar que entendeu o texto, vou lhe pedir que conte a história com o máximo de detalhes que lembrar. Vou iniciar o áudio agora. Você está pronto(a)?

English translation

You will listen to 3 texts and answer questions about them. You will be allowed to listen to the audio of the text as many times as you wish in order to understand it. When you think you have understood the text, I will ask you to tell me the story in as many details as you can remember. I will play the audio now. Are you ready?

Instructions in Brazilian Portuguese for written narratives

Você lerá 3 textos e responderá a perguntas sobre eles. Você poderá ler esse texto quantas vezes achar necessário para entendê-lo. Quando achar que entendeu o texto, vou lhe pedir que conte a história com o máximo de detalhes que lembrar. Você está pronto(a)? Pode ler o texto agora.

English translation

You will read 3 texts and answer questions about them. You will be allowed to read each text as many times as you wish in order to understand it. When you think you have understood the text, I will ask you to tell me the story in as many details as you can remember. Are you ready? You can read the text now.

6. Examples of questions assessing the comprehension of the story (part 2)

Original questions in Brazilian Portuguese for oral narratives

1. O que estragou na casa de Rosana?
   Resposta: resistência, chuveiro. (Scoring: (0) (1) (2))

2. Como Rosana notou que o chuveiro tinha queimado?
   Resposta: cheiro, fumaça. (Scoring: (0) (1) (2))

3. Rosana tinha experiência em arrumar chuveiros?
   Resposta: **não**/sim. (Scoring (0) (1))

4. Rosana levou um choque?
   Resposta: **não**/sim. (Scoring (0) (1))

5. Rosana conseguiu terminar seu banho no final?
   Resposta: não/**sim**. (Scoring (0) (1))

English translation

1. What broke down at Rosana's house?
   Answer: shower fuse, shower. (Scoring: (0) (1) (2))

2. How did Rosana notice the fuse has blown?
   Answer: smell, smoke. (Scoring: (0) (1) (2))

3. Rosana had experience with shower fuse?
   Answer: **no**/yes. (Scoring (0) (1))

4. Rosana got a shock?
   Answer: **no**/yes. (Scoring (0) (1))

5. Did Rosana finish her bath at the end?
   Answer: no/**yes**. (Scoring (0) (1))

Original questions in Brazilian Portuguese for written narratives

1. O que Luciana ia comprar?
   Resposta: chocolates. (Scoring: (0) (1))

2. Para quem eram os chocolates?
   Resposta: neta. (Scoring: (0) (1))

3. Luciana ia pagar os chocolates em dinheiro?
   Resposta: **não**/sim. (Scoring (0) (1))

4. O gerente do banco resolveu o problema de Luciana?
   Resposta: não/**sim**. (Scoring (0) (1))

5. Luciana levou os chocolates da loja sem pagar?
   Resposta: **não**/sim. (Scoring (0) (1))

English translation

1. What was Luciana going to buy?
   Answer: chocolate. (Scoring: (0) (1))

2. Who were the chocolates for?
   Answer: granddaughter. (Scoring: (0) (1))

3. Was Luciana going to pay cash for the chocolates?
   Answer: **no**/yes. (Scoring (0) (1))

4. Did the bank manager solve Luciana's problem?
   Answer: no/**yes**. (Scoring (0) (1))

5. Did Luciana take the chocolates from the store without paying?
   Answer: **no**/yes. (Scoring (0) (1))

7. Statistics for three written texts and three auditory texts

	W1	W2	W3	A1	A2	A3
Number of words	111	102	108	109	103	104
Number of sentences	7	7	7	8	8	6
Flesch index	43.72	54.06	45.96	42.52	61.64	61.87
Content word incidence	594.560	607.84	546.30	614.68	601.94	552.38
Mean words per sentence	15.86	14.57	15.43	13.63	12.88	17.50
Noun incidence	297.30	323.53	268.52	330.28	291.26	276.19
Verb incidence	216.22	215.69	203.70	211.01	233.01	190.48
Mean syllables per content word	2.92	2.76	3.00	2.91	2.58	2.60
Content words frequency	671645.99	231354.82	187321.10	169067.94	297263.39	232836.74

Subtitles: W: Written texts; A: Auditory texts

All statistics variables were extracted trough CoH-Metrix-Port software, version 2.0 (http://www.nilc.icmc.usp.br:3000/; Scarton and Aluísio 2010)

Supplementary Table 2. Mean sociodemographic descriptive data and neuropsychological results for the subgroup of participants who underwent MRI with a LH stroke and age-matched healthy participants.

	LH (MRI subgroup) n=9			Controls n=10			*p* value
Sociodemographic variables							
	Mean	**SD**	**Range**	**Mean**	**SD**	**Range**	
Age (years)	67.11	8.22	56-76	66.30	8.73	52-78	t =.21, p=.838
Education (years)	8.00	3.20	3-12	6.9	3.93	4-11	U = 44.0, p= .684†
Sex	8M, 1F	-	-	1M, 9F	-	-	-
Time Post-stroke	15.89	8.81	5-30	-	-	-	-
Socioeconomic status (SES)	27.22	5.74	22-37	27.30	7.07	15-38	t = -.03, p=.979
FAQ	7.50	9.45	0-18	.10	.316	0-1	U = 17.0, p= .022†[a]
Reading (pre-stroke)	4.00	3.62	0-9	9.10	7.13	1-24	U = 62.5, p = .156†
Writing (pre-stroke)	1.90	3.00	0-9	5.40	5.016	0-12	U = 63.0, p = .156†
Neuropsychological assessment							
Mini-mental state examination (/30)	23.11	3.66	16-29	28.1	1.91	25-30	U = 81.5, p=.001†[a]
Naming subtest (MTL-Brasil; /30)	24.56	6.56	8-30	29.50	0.71	28-30	U = 82.0, p = .001†[a]
Free verbal fluency (MAC-Breve; no maximum)	29.00	22.11	4-67	45.60	21.16	26-89	t = -1.62, p = .125

LH= left hemisphere stroke patients; M= Male; F= Female; SES = socioeconomic status as calculated by a questionnaire developped 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); FAQ = FAQ = Functional Activities Questionnaire, Brazilian version (Sanches et al., 2011)

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

[a] LH significantly different from controls <.05

Supplementary Table 3. Mean behavioral results for the sub-group of participants who underwent MRI with a LH stroke and age-matched healthy participants.

	LH n=9			**Controls n=10**					
	Mean	SD	Range	Mean	SD	Range	***t-test or U-test***	***p* value**	**Corrected *p* value**
Retelling									
Written narratives (max = 68)	23.10	17.24	0-44	35.70	12.09	11-54	t = -1.89	.075	.200
Auditory narratives (max = 66)	22.70	10.38	13-33	29.70	8.99	16-45	t = -1.61	.124	.198
Comprehension									
Written narratives (max = 19)	11.66	4.82	0-16	14.90	1.45	13-17	t=-2.03	.059	.236
Auditory narratives (max = 19)	14.11	2.66	10-18	14.70	1.57	13-17	t=-.60	.560	.560
Main information									
Written narratives (max = 38)	20.78	11.21	0-35	30.60	7.13	15-41	t = -2.30	.034	.272
Auditory narratives (max = 35)	24.00	8.83	12-33	27.20	5.51	19-46	t=-.96	.351	.468
Complementary information									
Written narratives (max = 30)	16.56	9.12	0-27	20.00	6.49	11-29	t=-.96	.353	.403
Auditory narratives (max = 31)	13.67	3.74	9-19	17.20	4.54	11-24	t=-1.84	.084	.168

Supplementary materiel 4.

Glass brain rendering showing regions of grey matter loss A) in the patients with a lesion in the left hemisphere compared with controls. All voxels shown in color survived a family-wise error correction ($p < 0.05$) at the cluster level, using an arbitrary cluster-forming uncorrected threshold ($p < 0.001$). The color bar reflects the range of *t* values from minimum (blue) to maximum (green).