Inner speech in post-stroke motor aphasia

Vanja Kljajevic (vanja.kljajevic@gmail.com)
University of the Basque Country (UPV/EHU), Vitoria &
IKERBASQUE, Basque Foundation for Science, Bilbao, Spain

Estibaliz Ugarte Gómez (estibaliz.ugarte@atecearaba.org)
Asociación de traumatismo cráneo-encefálico y daño cerebral adquirido de Álava (ATeCe), Vitoria, Spain

Cristina López (cristina.lopez@atecearaba.org)
ATeCe, Vitoria, Spain

Yolanda Balboa Bandeira (yolibalboa_b@yahoo.es)
ATeCe, Vitoria, Spain

Agustin Vicente (agustin.vicente@ehu.eus)
University of the Basque Country (UPV/EHU), Vitoria &
IKERBASQUE, Basque Foundation for Science, Bilbao, Spain

Abstract

The goal of the present study was to determine whether chronic post-stroke patients with motor aphasia have impaired inner speech abilities and whether they use inner speech in everyday life. To answer these questions, we recruited eight chronic post-stroke aphasic patients and 13 cognitively healthy adults, who underwent testing on a range of evaluative tests and four experiments specifically designed for the purposes of this study. The experimental results suggest that post-stroke patients with motor aphasia have impaired inner speech. However, patients' subjective reports indicate that they use various types of inner speech, despite the observed deficit. Taken together, our data suggest that impairment of certain aspects of inner speech may still allow a degree of use of other aspects of inner speech, emphasizing a need to extend research on inner speech in aphasia to the variety of its forms.

Keywords: aphasia; inner speech; anomia; working memory.

Introduction

Inner speech has been traditionally recognized as an important component of human mental life, and in particular its role in the relationship between language and thought has been debated (Kinsbourne, 2000). The interest in inner speech has been renewed recently, partly due to new perspectives on how language contributes to consciousness and whether conscious thought is possible without inner speech (de Guerrero, 2005, Martínez-Manrique & Vicente, 2010), and partly due to recent developments in speech production theories (e.g., Indefrey & Levelt, 2004) that propose that inner speech is a stage in speech production that precedes articulation (Levelt, 1995). Inner speech is often defined as silently talking to oneself or speech-for-oneself (Vygotsky, 1986), "the little voice in the head" (Perrone-Bertolloti et al., 2014), an internalized verbal thought that can be consciously explored (Marverl & Desmond, 2012), "the subjective experience of language in the absence of overt and audible articulation" (Alderson-Day & Fernyhough, 2015, p. 931) or more generally as a form of mental imagery (Oppenheim & Dell, 2008).

The unique cognitive status of inner speech is reflected in its pervasive role in a variety of functions. It is involved not only in language, but also in working memory (e.g., in subvocal rehearsal) (Paulesu et al., 1993; Baddeley & Loggie, 1999), complex reasoning (Baldo et al., 2015), self-regulation (Vygotsky, 1986), meta-cognition (Bermúdez, 2003), and self-awareness (Morin, 2009; Morin & Michaud, 2007). For example, impairment of inner speech has been associated with the impairment of global self-awareness, self-related memories and emotional awareness, along with impaired "sense of individuality" and corporeal awareness (Morin, 2009). It also contributes to auditory verbal hallucinations in schizophrenia (Frith, 1992). In addition to establishing that inner speech is implicated in a variety of cognitive functions in healthy and impaired brains, research so far has discerned various forms of inner speech, such as condensed, dialogic, self-referent, involving others (Alderson-Day & Fernyhough, 2015), with the evidence indicating that these different forms of inner speech may require support of different brain areas (Alderson-Day et al., 2015).

However, investigating directly and objectively the highly subjective and elusive psychological processes that support inner speech represents a methodological challenge (Vygotsky, 1986; De Bleser & Marshall, 2005). The attempts to determine the elusive nature of inner speech fall roughly into two types: the accounts that try to view inner speech in its entirety and emphasize its subjective character, and accounts that focus on a specific aspect of inner speech that can be objectively tested. Thus, the hypotheses generated by the first type of accounts cannot be objectively tested, and the explanations based on the second type of accounts do not exhaust the concept of inner speech.

As an example, Vygotsky's (1986) concept of inner speech is characterized by a highly subjective meaning, predicative nature, and a reduced syntactic form. In contrast, an often studied proxy of inner speech in contemporary research is phonological representation of a word, which is tested via a person's ability to silently judge whether two words rhyme, whether one word is longer than the other, or whether two words are homophones (Levine et al., 1982; Feinberg et al., 1986). Making silent judgments in such tasks requires the use of inner speech.

Another way of distinguishing between the two types of approaches to studying inner speech is in terms of abstract and concrete inner speech, where the former refers to inner speech as relating language and thought, and the latter considers inner speech a stage in speech production, i.e., phonological and/or phonetic level of inner speech (Levelt, 1995).

One interesting and still not well explored issue pertains to inner speech abilities in persons with impaired overt speech due to brain damage, such as post-stroke patients with motor aphasia.

The available evidence suggests a great variability in inner speech abilities in persons with post-stroke aphasia, with patterns of partial as well as complete deficit in inner speech (Levine et al., 1982; Feinberg et al., 1986; Langland-Hassan et al., 2015). Furthermore, the degree of inner speech deficit in these patients typically coincides with a degree of overt speech impairment, although cases of aphasia with discrepant overt-covert speech abilities were also reported (Geva et al., 2011a).

In the present study, we investigated inner speech abilities in chronic post-stroke patients with motor aphasia. The goal was to determine whether these patients had impaired inner speech abilities and how they used inner speech in everyday life. To answer these questions, we tested chronic post-stroke aphasic patients on a variety of evaluative tests and four experiments specifically designed to assess their inner speech abilities.

Methods

Participants

Eight post-stroke aphasic speakers (two males) were recruited at a local rehabilitation center (Asociación de traumatismo cráneo-encefálico y daño cerebral adquirido de Álava, henceforth ATeCe). All patients were at the chronic stage, with more than one year post-onset time. They all had suffered a single stroke in the left hemisphere, affecting the prefrontal or fronto-temporal areas, except one person, who had a lesion in the left basal ganglia (A07). Seven patients had motor aphasia, while one person's aphasia was characterized as mixed aphasia (A02). This person's aphasia was of a predominantly motor type, with a strong anomic component it was labeled as "mixed" aphasia by the speech pathologist (C.L.) on the basis of multiple extensive tests, subjective observations and neurological reports. Severity of patients' aphasia ranged from moderate to severe. They were all right-handed before the illness, except one patient who was left-handed (A03). They had no other significant neurological or psychiatric conditions.

Thirteen cognitively healthy adults for the control group (four males) were recruited from the community. The participants in the control group had no history of neurological or psychiatric disease, drug abuse, and at the time of testing they were not using any medications that could affect cognition.

All participants had normal hearing and normal or correct-to-normal vision.

Evaluative measures

To obtain more general information on patients' cognitive abilities relevant for the present study, we administered the following evaluative measures: Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005) to assess participants' general cognitive status, Boston Diagnostic Aphasia Examination (Goodglass & Kaplan, 1983) - the Spanish version (García-Albea et al., 1996), Boston naming test (Kaplan et al., 1983), phonological discrimination test (Ardila et al., 1994), the Edinburgh handedness inventory (Oldfield, 1971), the Month ordering test (Almor et al., 2001) to test their verbal working memory, Raven's Progressive Color Matrices (Raven et al., 1990) to test their nonverbal intelligence, Beck depression inventory (Beck et al., 1961) to exclude severe depression, and the Varieties of Inner Speech Questionnaire (McCarthy-Jones & Fernyhough, 2011) to obtain an insight into each patient's awareness of their use of different forms of inner speech in everyday life.

Unlike other types of inner speech questionnaires, the VISQ addresses important aspects of inner speech, such as condensation and dialogicality. The condensed form, which has by definition reduced syntax, and dialogic inner speech, which is exchange among different internalized perspectives, are of particular importance in studying inner speech of patients with motor speech disorders. Thus, the Questionnaire assesses four types of inner speech: dialogic, condensed, other people in inner speech, and evaluative/ motivational inner speech Examples of stimuli for each form are given in (1-4):

(1) My thinking in words is more like a dialog with myself rather than my own thoughts in a monologue. - Dialogic
(2) I think to myself in words using brief phrases and single words rather than full sentences. - Condensed
(3) I hear other people's voice nagging me in my head. - Other people in inner speech
(4) I talk silently to myself telling myself to do things. - Evaluative/motivational inner speech (McCarthy-Jones & Fernyhough, 2011).

Healthy controls (HCs) underwent MoCA and completed the Varieties of Inner Speech Questionnaire. All tests were administered in Spanish, which was the first language of all participants.

Experimental measures

All participants were tested in four tasks, which require inner speech for correct completion: silent judgments of rhyming (experiment 1), syllable discrimination (experiment 2), identification of words in compounds (experiment 3) and identification of words in names for numbers (experiment 4).

Experiment 1: The rhyming task in our study required silent rhyming judgments of pairs of words associated with pairs of drawings. The silent rhyming judgments paradigm has been successfully used in previous studies on inner speech in other languages (Langland-Hassan et al., 2015). This paradigm is more appropriate for the Spanish language than the classical paradigm, in which rhyming of written words is judged, because judging whether Spanish written words rhyme can be done visually, on the basis of words' orthography and without evoking inner speech (e.g., avión-camión). There were 40 pairs of drawings in this experiment, with 20 pairs representing objects whose names rhyme in Spanish and 20 pairs representing objects whose names do not rhyme in Spanish. The drawings were selected from Snodgrass & Vanderwart (1980), based on a standardization for Spanish (Sanfeliu & Fernandez, 1996), considering name agreement, image agreement, familiarity, and visual complexity. The stimuli were created from the drawings with the highest ratings in Spanish-speakers.

Using the same pairs of words from this experiment, we tested participants' overt rhyming abilities at the end of experimental session. In this overt rhyming judgment task, the experimenter read aloud pairs of words and participants' task was to judge if the words within each pair rhymed.

Experiment 2: The syllable discrimination task required a silent discrimination of syllables in verbally presented words (n=40). The stimuli consisted of sets of randomized 2-syllable (n=13), 3-syllable (n=15), and 4-syllable (n=12) highly frequent Spanish words, such as *bueno*. The experimenter read words and the participants were required to determine the number of syllables in each word.

Experiment 3: The following test required silently discerning words in compounds. The stimuli consisted of compounds (n=20) and simple words (n=20). Like in previous experiments, the stimuli included only highly frequent Spanish words, such as *girasol* and were presented in a randomized order. The experimenter read words and the participants were required to determine the number of words in each compound.

Experiment 4: The final test required silently discerning words in names for numbers. The stimuli (n=20) included trials that allowed 1, 2, 3, or 4 words to be discerned. For example, eight contains only one word, whereas in fifty-six two additional words can be discerned: fifty, six. The experimenter read number words and the participants were required to determine the number of words in each.

Except for the silent rhyming task, the stimuli in the experiments were presented verbally.

Procedures

Before evaluation began, each participant signed informed consent. Prior to each experiment, participants completed two to four practice trials. They were instructed to avoid using strategies, moving the mouth or tongue, and to use inner speech in all tests. The experimenter would read the stimuli, except in Experiment 1 in which the stimuli were presented visually, and participants were required to respond as accurately as they could. There was no time limit for answers. Participants' responses for each experiment were recorded manually on a separate response form and later scored for accuracy. No feedback was provided during testing.

Testing was carried out individually with each participant in a quiet room, at ATeCe (patients) and at their homes (HCs). Each patient was assessed in 3 sessions. The first two sessions were devoted to evaluative measures (one session with the certified speech pathologist, C.L., one session with the neuropsychologist, E.U.G.) and the last session was devoted to the experiments. Each session lasted approximately 1 hour. HCs were tested in a single session.

The study was approved by the Basque Ethics Committee for Clinical Research as well as by the ethics committee of the University of the Basque Country. The study was conducted in accordance with the Helsinki Declaration guidelines on studies involving human subjects

Statistical analyses

We performed Mann-Whitney test for group comparisons in experimental tasks and the modified –t-test (Crawford & Howell, 1998) to compare performance in experimental tasks of the patient with mixed aphasia to the mean scores of the HCs group; the latter tests were one-tailed, as recommended (Crawford & Howell, 1998), with α set at .05. All statistical analyses were carried out in SPSS 22, except for the modified t-test which was performed using the SINGLIMS program (Crawford & Howell, 1998).

Results

The two groups did not differ considerably in age (t (19) = -1.433, p = .168) or in years of formal education (t (19) = -.560, p = .582). However, they differed in general cognitive status (t (19) = -7.213, p < .005), with the aphasic group having achieved a mean score of 17.8 (±2.5) on MoCA and HCs having a mean of 25.1 (±2.1).

Each patient achieved 100% correct scores on the phoneme discrimination task. Their performance on Raven Progressive Color Matrices (RPCM) and verbal working memory (vWM) test varied, revealing different degrees of deficit in non-verbal intelligence and vWM capacity respectively across patients. The results of these tests are summarized in Figure 1.

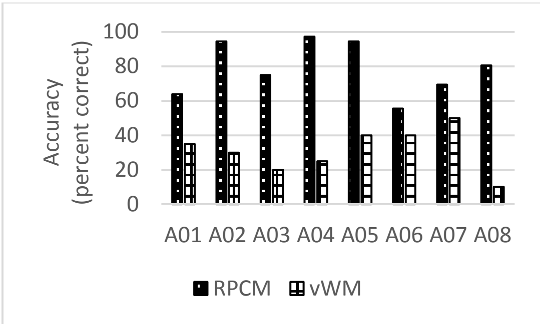

Fig 1. Aphasic speakers' performance on RPCM and vWM.

Furthermore, patients' performance on the Varieties of Inner Speech Questionnaire revealed different degrees of use of the four types of inner speech (Fig. 2). The condensed inner speech featured prominently, while inner speech involving others was less present in their everyday spontaneous use of inner speech.

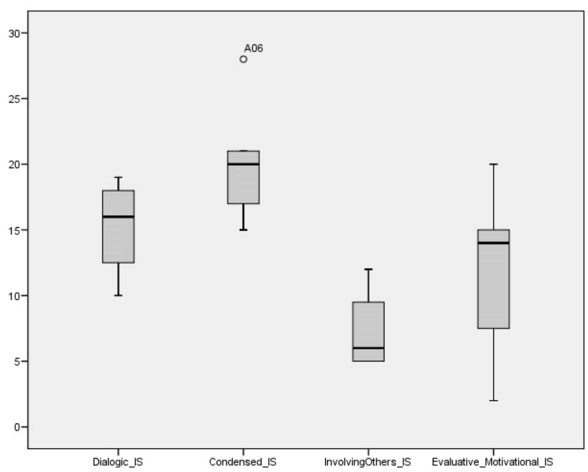

Fig 2. Aphasic speakers' use of four types of inner speech in everyday life.

Looking at the results from experimental measures, we found that, compared to HCs, the aphasic group performed considerably worse on both rhyming tests (silent and overt), and on the test of discrimination of syllables within words (Table 1).Their ability to discern numbers and words in compounds was comparable to that of HCs.

Table 1: Group differences across the experimental tasks.

	U	*Z*	*p*
Silent rhyming	4.500	-3.475	.001*
Overt rhyming	1.500	-3.701	.005*
Syllables	25.500	-1.985	.047*
Compounds	32.000	-1.513	.13/ .05*
Numbers	43.500	-.631	.53

However, since the modified t-test has shown that the person with mixed aphasia, A02, performed well in all tasks relative to HCs (silent rhyming, *p* = .16; overt rhyming, *p* =.07; syllables, *p* =.33; compounds, *p* = .18; numbers, *p* =.5), we repeated analyses excluding this patient from the aphasic group.

The overall pattern of results remained unchanged, except that the *p* value obtained in testing for differences in distinguishing words in compounds reached statistical significance (*U* = 22.000, *Z* = -1.93, *p* = .05). Thus, our experimental data indicate that the persons with motor aphasia had overall impaired inner speech, except when inner speech involved words for numbers.

Discussion

The goal of the present study was to assess whether post-stroke patients with motor aphasia have deficits in inner speech. To answer this question, we tested eight patients with chronic aphasia using four tests of inner speech, including the traditional tests such as silent rhyming judgments and syllable discrimination, together with the tests of word and number discrimination. The main finding of the present study is that post-stroke patients with motor aphasia have impaired inner speech. An additional, unexpected finding is their preserved ability to silently discern numbers in number words. The two findings are discussed in turn.

Since all the aphasic patients achieved 100% correct on the phoneme discrimination task (see Results), the deficit in silent rhyme judgments cannot be due to impaired ability for phonological discrimination. Instead of being solely due to inner speech impairment, the silent rhyme judgments impairment could be related to anomia, i.e. word finding difficulty which to some extent characterizes all types of aphasia (Benson & Ardila, 1996). A deficit in retrieval of words referring to the presented images would preclude making judgments on whether a pair of words referring to a pair of drawings rhyme or not. Alternatively, a relatively high working memory load in the silent rhyming task could explain the deficit: the task requires interpreting pairs of drawings, keeping track of semantic information derived from the drawings, retrieving appropriate words, and maintaining the retrieved words in working memory, while judging whether the words rhyme.

Furthermore, the aphasic group had low scores in overt rhyme judgments, a task in which the experimenter read aloud pairs of words. Although this task imposes a smaller cognitive load compared to the silent rhyme judgment task, it still requires a certain amount of working memory capacity, a cognitive resource that appears to be deficient in the aphasic group (Fig. 1). Taken together, these results indicate that the aphasic group's deficit in judging rhymes both covertly and overtly may be due to the verbal working memory impairment. This explanation is compatible with the aphasic group's low scores on the subtests of MoCA related to language and/or memory for language, including repetition of sentences and verbal fluency. However, although limited vWM capacity may have affected silent rhyming in the aphasic group, it does not explain their overall poor scores on inner speech tasks, involving also impaired discrimination of syllables in words and impaired discrimination of words in compounds. These scores indicate an impairment of inner speech, which could have been further exacerbated by an increased verbal WM load and anomia in the silent rhyming task.

The unexpected finding that the aphasic group was successful in discerning numbers in number words is not only interesting in itself, but it also has implications for the theories on number processing. It suggests that the aphasic speakers relied on a nonverbal, digital representation of numbers (e.g. "57") and not on spoken numerals representations ("fifty-seven"). This explanation is compatible with the proposals suggesting that number processing is mediated by modality-specific processes, e.g., verbal code vs. digits (Kadosh & Walsh, 2009). While the neural substrates supporting the two types of processing differ, it remains unclear whether the differences pertain to these representations supporting inner speech as well.

Wernicke originally proposed that the left superior temporal gyrus (STG) supported auditory word-form recognition, monitoring of speech output generated by frontal regions as well as inner speech, while contemporary models suggest a functional distinction between the anterior STG, which supports auditory word-form recognition, and posterior STG, which regulates speech production, including inner speech (DeWitt & Rauschecker, 2013). Neuroimaging studies have associated inner speech with a range of brain areas, including the left supramarginal gyrus, posterior STG, middle temporal gyrus and the inferior frontal gyrus (Paulesu et al., 1993; Indefrey & Levelt, 2004; Geva et al., 2011b; Fama et al., 2017). A recent voxel-based lesion-symptom mapping study involving 40 left-hemisphere post-stroke patients indicates that inner speech, at the phonological access stage of speech production, is supported by the posterior STG and adjacent areas (Pillay et al., 2014), and that the left inferior frontal gyrus in fact supports working memory and control processes associated with inner speech. Our data appear to support this model, although we would interpret the working memory deficit in our aphasic group in terms of affected network connectivity (Kljajevic, 2014), because all the patients had deficient vWM, regardless of each case's specific site of lesion.

As pointed out in the Introduction, studying phonological word form as a proxy of inner speech provides only a part of the answer to the question of whether inner speech is impaired in motor aphasia. A quick look at the patients' subjective reports on their use of inner speech in everyday life (Fig. 2) suggests a rather complex picture. It suggests that, as in impaired overt speech – where some degree of communication may take place despite the deficit-, impairment of certain aspects of inner speech may still allow use of its other forms. It is not surprising that aphasic speakers in our study showed the most use of the condensed type of inner speech in everyday life. The condensed form is closest to the type of inner speech originally described by Vygotsky (1986): compressed, and not necessarily resembling overt speech.

In conclusion, our data indicate a degree of inner speech impairment in post-stroke patients with motor aphasia, regardless of lesion distribution (frontal, fronto-temporal, deep grey matter structures). Like their overt speech, their inner speech appears to be affected by difficulties in word retrieval and reduced verbal WM capacity.

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