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Complete List of Authors:	Stark, Brielle; University of Cambridge, Clinical Neurosciences Geva, Sharon; University College London, UCL Institute of Child Health Warburton, Elizabeth; University of Cambridge, Clinical Neurosciences
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BC Stark[1], S Geva[2], EA Warburton[1]

[1]University of Cambridge, [2]University College London

Corresponding author:

BC Stark

University of South Carolina

Office 211 915 Greene St

Columbia SC 29205

stark2@mailbox.sc.edu or brielle.stark@gmail.com

(803) 777 9240

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Abstract

Purpose

Preserved inner speech alongside relatively poor overt speech has been documented in some persons with aphasia (PWA) but the relationship of overt speech with inner speech is still largely unclear, as few studies have directly investigated these factors. The present study investigates the relationship of preserved inner speech in aphasia with selected measures of language and cognition.

Method

38 chronic PWA (11 F, average age 64.53 ± 13.29 years, time since stroke 8-111 months), were classified as having preserved inner and overt speech (N=21), preserved inner speech with poor overt speech (N=8) or not classified due to insufficient measurements of inner and/or overt speech (N=9). Inner speech scores (by group) were correlated with selected measures of language and cognition from the Comprehensive Aphasia Test.

Results

The group with relatively poor overt speech showed a significant relationship of inner speech with overt naming (r=0.95, p<0.01) and with mean length of utterance produced during a written picture description (r=0.96, p<0.01). Correlations between inner speech and language and cognition factors were not significant for the group with relatively good overt speech.

Conclusion

Like previous research, we show that preserved inner speech is found alongside otherwise severe production deficits in PWA. PWA with relatively poor overt speech may rely more on preserved inner speech for overt picture naming (perhaps due to shared resources with verbal working memory) and for written picture description, perhaps owing to reliance on inner speech due to perceived task difficulty. Assessments of inner speech may be useful as a standard component of

aphasia screening, and therapy focused on improving and utilizing inner speech may prove clinically worthwhile.

Introduction

At least one million people in the USA are currently living with aphasia, the loss of language most often resulting from stroke (National Aphasia Association, 2016). A phenomenon that has been observed in some persons with aphasia (PWA) is that their internal monologue, or inner speech, is preserved despite poor language production (Fama et al., 2017; Geva et al., 2011a; Hayward et al., 2016; Langland-Hassan et al., 2015).

The awareness of an internal monologue/inner speech found its roots early in psychological research (Vygotsky, 1962) and has been diversely defined. Inner speech has been described as abstract ‘language of the mind’ (reviewed in Sokolov, 1972), as dialogic or conversational (Alderson-Day et al., 2016) and as phonologically or phonetically concrete (Oppenheim & Dell, 2010a; Vigliocco & Hartsuiker, 2002). Inner speech has played a role in schizophrenia research regarding auditory hallucinations (Agnati et al., 2012; Girbau, 2007; Langdon et al., 2009) but less of a role in aphasia research. Geva et al., (2011a) define inner speech “as the ability to create an internal representation of the auditory word form, and to apply computations or manipulations to this representation” and we will employ this definition when referring to inner speech.

The cognitive mechanisms of inner speech are potentially diverse. Inner speech has been associated with pre-speech articulation (i.e., Geva et al., 2011b; Owen et al., 2004) and, especially in the case of rhyme judgment using inner speech, with phonological working memory (Baddeley & Hitch, 1974; Durisko, 2002; Geva et al., 2011a; Howard & Franklin, 1990; Martin & Saffran, 1997; Marvel & Desmond, 2012). Inner speech has also been described as an internal monitoring mechanism in the language system (i.e., Dell, 1986; Levelt, 1983) and has been proposed as a potential buffer for detection of pre-speech errors (Corley et al., 2011; Dell &

Repka, 1992; Hartsuiker & Kolk, 2001; Nooteboom, 2005; Oppenheim & Dell, 2010b; Postma, 2000; Slevc & Ferreira, 2006).

Studies evaluating the relationship of inner speech to overt speech in PWA are relatively rare, and they have shown conflicting results (i.e., Fama et al., 2017; Geva, Bennett, et al., 2011; Langland-Hassan et al., 2015). A recent study, using self-report of inner speech ability, showed that subjective judgment of good inner speech correlated with aphasia severity and lexicality effect (Fama et al., 2017), suggesting that there was preserved inner speech alongside deficits in phonological output processes. However, while this study suggests that there may be a strong relationship between inner speech and overt speech in aphasia, a study by Langland-Hassan and colleagues (2015) did not find a relationship between inner speech and aphasia severity, as measured by components of language processing (both production and comprehension) from the Western Aphasia Battery, or a relationship of inner speech with various aspects of cognition. It is likewise unclear how many, within the population of PWA, show this pattern of preserved inner speech alongside poor overt speech. In the present study, we will evaluate, in a relatively large group of PWA (chronic), the relationship of preserved inner speech with particular measures of language and cognition, specifically evaluating the relationship of these factors to preserved inner speech when overt speech is relatively poor.

Methods

Participants

Thirty-eight chronic PWA (11 females), following left hemisphere middle cerebral artery (MCA) territory stroke, age-at-testing 21-87 years (M=63.53, SD=13.29), 8-111 months' post-stroke (M=30.03, SD=24.39), and 6-20 years of education (M=13.76, SD=3.23) participated in the study. The study was approved by the Cambridge Research Ethics Committee (2007) and East of England Ethics Committee (2013). All participants gave informed consent following receipt of information sheet and task instructions.

Participants showed first language competence in British English. Participants did not have any known degenerative neurological conditions and no known history of other neurological or psychiatric disorders. The diagnosis of aphasia was based on the convergence of clinical consensus and the results of a standardized aphasia examination, the Comprehensive Aphasia Test (CAT) (Swinburn et al., 2004). All PWA had some level of language production impairment at initial presentation with relatively intact comprehension. Full participant demographics are found in Supplementary Table 1.

In this study, we were interested in particular measurements of language and cognition; these will be detailed in *'Outcome Measures*.'

Procedure For Testing Inner Speech

Two tests were employed for assessing inner speech. Patients were asked to perform a yes/no task on whether two words rhymed or were homophones without pronouncing the words aloud and without moving any part of the mouth, including lips or tongue. The words were presented to the participant side-by-side on pieces of paper by the experimenter (author BS or author SG). Participants pointed to 'yes' or to 'no' on a piece of a paper or said the word 'yes' or 'no' to indicate their answer. Participants were monitored during the task by the experimenter to make sure these instructions were followed. The visually-presented words which were used to test inner speech and overt speech were partially derived from the PALPA subtests 36 (non-word reading) and 15 (written rhyme judgment) (Kay et al., 1996) and ensured to match British pronunciation (Geva, Bennett, et al., 2011a). Variations of this test have been used to assess inner speech in aphasia previously (Geva et al., 2011a; Kay et al., 1996; Langland-Hassan et al., 2015; Stark, 2016) and further details of test administration and scoring can be found in Geva et al (2011a).

To test inner speech using rhyme judgment, participants were tested with 60 pairs of potential rhyming words with varying orthography, the majority of which were single syllable words. Some words had similar orthography and rhymed ('tweak' and 'freak'); similar orthography but did not rhyme ('tint' and 'pint'); dissimilar orthography and rhymed ('quay' and 'sea'); or dissimilar orthography but did not rhyme ('chew' and 'hoe'). In this way, participants could not determine whether or not a word rhymed based on orthography alone. The 60 pairs of words were split into two lists of 30 word pairs each, and each list presentation was counterbalanced across participants. Lists of words can be found in Supplementary Table 3.

To test inner speech using homophone judgment, participants were shown 60 pairs of potential homophones, with 20 of them being non-words such as 'quib' and 'kwib.' Since the number of pairs of non-words from the PALPA was small, 40 additional pairs of non-words were developed by authors SG and BS. As in the rhyme judgment procedure, the 60 pairs of words were split into two lists of 30 word pairs each, and each list presentation was counterbalanced across participants. Lists of words can be found in Supplementary Table 3.

To measure overt speech, PWA were asked to read the same visually-presented words aloud for both the rhymes and the homophones. The overt speech score had two scoring segments: correct pronunciation of the words and correct indication as to whether the words rhymed or were homophones. The pronunciation of the words was based on a British-English rhyming dictionary. To ensure the validity of the results from these two tasks, we correlated the overt speech measure from the PALPA with the reading aloud component from the CAT, finding that they showed significant agreement (r_s=0.76, p<0.001).

For both inner and overt speech, we used the raw accuracy score. In this study, 'relatively preserved' inner and overt speech function is defined as scoring greater than 50% on the rhyme and homophone test. However, it should be noted that persons in this study are still considered to have aphasia based on their CAT scores. Therefore, 'preserved' overt speech means relatively good production for a person diagnosed with aphasia.

Some participants did not complete inner and overt speech assessments due to difficulty; they are noted in the results.

Outcome Measurements

Conflicting results have arisen from previous studies attempting to associate inner speech with phonological working memory (Geva, Bennett, et al., 2011) as well as with measures of generative speech and confrontational naming (Fama et al., 2017; Langland-Hassan et al., 2015) and non-linguistic cognition (Langland-Hassan et al., 2015). In an attempt to resolve this conflict in a relatively large cohort of PWA, we chose measurements from the CAT that targeted aspects of non-linguistic cognition, phonological working memory, confrontational naming and generative speech. These tests are described in more detail below. Refer to Figure 1 for a graphic explanation of the proposed correlations.

Measures of language and cognition from the CAT.

Seven subtests from the CAT were used as outcome measures: non-word repetition and sentence repetition; overt picture naming; written and spoken picture description; semantic memory and mental arithmetic.

(1) Non-word repetition and sentence repetition subtests examined the ability to repeat non-words and sentences of varying lengths, targeting both speech repetition and phonological working memory.

(2) Overt picture naming subtest involved confrontational, overt naming of pictures. We used this measure to evaluate inner speech's relationship with components of confrontational naming.

(3) Written and spoken picture description subtests involved generative writing and speaking about a picture for an unspecified amount of time. In the spoken picture description (SPD) subtest, PWA were asked to describe a picture aloud, and in the written picture description (WPD) subtest, were asked to describe the same picture with writing. The tasks used the same picture (Cookie Theft). There was no time limit for completing either task and SPD was always administered first. We used these tests to provide a measure of spontaneous or generative language; that is, having the potential to incorporate grammatical and syntactic complexity into written and spoken language. For the purposes of this paper, we used mean length of utterance (MLU) as the score for SPD and WPD. MLUs are a standard measure of grammatical complexity in the literature (for example, in Expression, Reception and Recall of Narrative Instrument (ERRNI) (Bishop, 2004) and have been used in aphasia literature (Martinez-Ferreiro

et al., 2015; Thompson et al., 2010; Thompson & Shapiro, 2007). MLUs were scored according to the protocol used by ERRNI, where the MLU for each PWA was obtained by calculating the average number of words per utterance (Bishop, 2004).

(4) Two components from the cognitive screen of the CAT were used to probe general memory and cognition: semantic memory and mental arithmetic. In the test of semantic memory, PWA were shown a set of four pictures and a target picture. They were asked to point to the picture that was most related to the target picture. In the mental arithmetic test, PWA were given a set of ten mathematical problems of increasing difficulty. There were five multiple choice answers from which they could choose to solve the problem. They were asked to complete the task entirely in their head. We used these measures of cognition to investigate whether cognitive (less linguistic) factors might show a relationship with preserved inner speech.

Preserved Inner Speech Groups

We were interested in two groups of participants: those with preserved inner speech alongside relatively preserved overt speech (GOS) and those with preserved inner speech alongside relatively poor overt speech (POS).

First, we qualitatively separated participants into groups based on their average inner and overt speech scores. Participants who successfully completed both the rhyme and homophone section of both inner speech and overt speech were assessed. Seven participants were not classified into groups because they were missing data from a rhyme or homophone section for inner and/or overt speech. Of the included participants, those scoring >50% on both the inner and overt speech tasks were classified into the GOS group, while participants scoring >50% on inner speech and ≤50% on overt speech tasks were classified into POS group. We were interested in relatively preserved inner speech, and therefore two participants were not classified into the groups because they showed overall poor inner and overt speech scores (≤50% accuracy).

Then, we compared inner and overt speech scores of the GOS and POS groups to our 50% benchmark, to verify that the GOS group as a whole showed relatively preserved inner and overt speech and that the POS group showed relatively preserved inner speech but relatively poor overt speech. GOS group demonstrated average inner and overt speech scores significantly greater than 50% as tested by the one-sample Wilcoxon Signed Rank test (inner speech: W=3.92, p<0.001; overt speech: W=3.93, p<0.001). POS group demonstrated inner speech scores significantly greater than 50% (W=2.24, p=0.03) and overt speech scores significantly less than 50% (W=2.53, p=0.01). The GOS group comprised 21 participants and the POS group comprised eight participants; descriptive statistics are shown in Table 2.

We were most interested in the ratio of inner speech to overt speech within these groups, as we wanted to verify that the POS group showed relatively preserved inner speech as compared to their overt speech. This was indeed the case. Within the POS group, average inner speech score was significantly greater than average overt speech score (W=2.52, p=0.01). As expected, the GOS group did not show significantly different inner speech and overt speech scores (W=1.85, p=0.06).

Demographically, GOS and POS were not significantly different in age (U=1.41, p=0.17), years of education (U=0.54, p=0.60) or time since stroke (U=1.63, p=0.10). GOS group showed significantly higher scores on the total production score (naming, reading, repetition, writing) from the CAT (U=3.61, p<0.001) and total comprehension score (auditory and reading) from the CAT (U=3.23, p=0.001). GOS group showed significantly better scores on inner speech rhyme (U=2.48, p=0.01), inner speech homophone (U=2.74, p=0.01), overt rhyme (U=4.16, p<0.001) and overt homophone (U=4.01, p<0.001) (Figure 2).

Statistical analysis.

The subtests of the CAT each contained a different amount of items/stimuli. To standardize these measures, we transformed each subtest score as a function of the subtest's aphasia-cut off, a score above which is considered non-aphasic for that subtest. The various CAT subtests have different aphasia cut-off scores. For example, see Table 1, which shows the repetition subtest of the CAT, which comprises five subcomponents all of which have different aphasia cut-off scores according to their total possible score. Two of these measures (non-word and sentence repetition) were used as outcome measures. Row four of Table 1 shows the transformed score, dividing the raw scores by the aphasia cut-off. Raw scores from the CAT were standardized in this way. We believe this standardization also provide an easily accessible interpretation of the participant's score on the subtest (for more detailed description, see: Stark & Warburton, 2016). For example, Table 1 shows that the example participant exhibited a 0.96 score for total repetition, indicating that they score as aphasic on this particular task. A score of 1.0 signifies that the person's score is equivalent to aphasia cut-off, and a score higher than 1.0 suggests they are not considered aphasic on the task.

To establish inter-rater reliability of MLU scoring on the picture description subtests, six randomly selected transcripts from the WPD subtest and 13 randomly selected transcripts from the SPD subtest were scored independently by two of the authors (BS and SG). Using Cronbach's alpha at 95% confidence to assess inter-rater reliability in SPSS 23, both WPD MLUs (α=0.99) and SPD MLUs (α=0.94) showed high inter-rater agreement. Due to high agreement, MLU scores by author BS were used in the analysis.

SPSS 23 was used for all statistical analyses. Nonparametric tests were used if data did not satisfy the normality assumptions of the Shapiro-Wilk normality test. For the purposes of using the Fisher r-to-z transformation, Pearson product moment correlations were used; however, if data was not normal, the Spearman rho correlation was also presented. The stringent Bonferroni correction for multiple comparisons was used for correlation comparison.

Results

The POS group showed a significant correlation (with multiple comparison correction) between inner speech rhyme and naming (r=0.95, p<0.001) and between inner speech homophone and written MLUs (r=0.96, p<0.001) (Table 3). Without multiple comparison correction, the GOS group showed relationships of non-word repetition (r=0.49), sentence repetition (r=0.54) and spoken MLUs (r=0.63) with inner speech rhyme and the POS group showed an additional relationship of sentence repetition with inner speech rhyme (r=0.76).

Fisher r-to-z transformation (using Pearson's *r)* indicated that the POS group showed significantly greater correlation of inner speech rhyme with naming (p=0.006) and inner speech homophone with written MLUs (p=0.004) than the GOS group (Table 4). The relationship of inner speech rhyme to naming for both groups is shown in Figure 3.

Discussion

In this study we investigated the relationship between preserved inner speech and selected measures of language and cognition, specifically interested in whether there was a different relationship with these factors in people with preserved inner speech alongside poor overt speech as compared to those with relatively good overt speech. Further, while the relationship of inner speech and overt speech has been investigated in few studies (Fama et al., 2017; Geva, Bennett, et al., 2011; Hayward et al., 2014, 2016; Stark, 2016), there has not been agreement as to whether inner speech and overt speech are dissociable in aphasia.

This study was able to differentiate a cohort of 29 out of 38 PWA into two groups: a group of good overt and inner speech (GOS) and a group of poor overt and good inner speech (POS). While the POS group was much smaller than the GOS group, the groups were not significantly different in age, years of education or time since stroke. As members of the POS group were chosen because of their poor overt speech, it is not surprising that the GOS group presented with less severe scores on language production. However, the POS group was likewise more severe on measurements of language comprehension, inner speech and overt speech. This finding reveals two things. The first is that persons in the POS group presented with the most severe aphasia symptoms. Second, that despite presenting with severe production deficits, members of the POS group demonstrated relatively preserved inner speech in comparison to their overt speech, suggesting a dissociation between inner and overt speech. Nine participants from the original cohort were not assigned to groups, either due to overall poor scores in both inner and overt speech or missing scores on these measures. Therefore, there are also individuals in which both inner speech and overt speech are equally poor, but this study did not specifically investigate the relationship of inner and overt speech in these individuals.

The proportion of PWA who show relatively preserved inner speech alongside relatively poor overt speech in the population of PWA in general, is unclear. Geva et al., (2011a) investigated rhyme and homophone judgments using inner and overt speech (some participants which are included in the present study were included in this 2011 study). Of the 29 participants included in the 2011 study, six showed relatively preserved inner speech alongside poor overt speech for homophone judgment and four participants showed relatively preserved inner speech alongside poor overt speech for rhyme judgment. This finding suggests that, in a sample of nearly thirty participants, one-sixth showed relatively preserved inner speech alongside poor overt speech. Another fairly large study, examining subjective experiences of overt anomia ("*I can't say it out loud, but I can say it in my head and it sounds right*"), found relatively intact inner speech in 78.4% of participants (N=29) from a cohort of 37 participants (34 with diagnosed aphasia from the Western Aphasia Battery) (Fama et al., 2017). It is unclear how many participants in the Fama et al. (2017) study showed poor overt speech in the same way that we have classified here, but Fama et al.'s study does suggest that, in more than half of their participants, an intact experience of inner speech was associated with overt anomia. In the current study, we found 21% of participants (N=8) with relatively preserved inner speech and relatively poor overt speech and 55% (N=21) showed relatively preserved inner alongside relatively preserved overt speech (5.2% (N=2) showed poor inner and overt speech and 18.42% (N=7) were not able to be classified). Altogether, these studies suggest that problems with overt speech alongside preserved inner speech are present in the aphasia population, albeit in a smaller proportion than those with preserved inner and overt speech, and give credence to a dissociation of the cognitive mechanisms generating inner and overt speech.

The relationship of preserved inner speech with selected measures of language and cognition was evaluated. We believe that this evaluation has important implications for understanding the cognitive processes associated with inner speech, such as pre-articulation and phonological working memory, and whether there is a difference in the relationship of inner speech with these measures of language and cognition when overt speech is particularly poor or aphasia symptoms are severe.

We found that persons with preserved inner speech alongside poor overt speech showed a significant positive correlation of inner speech rhyming with overt naming, and this correlation was significantly greater than the same comparison for persons with relatively good overt speech. Inner speech rhyme has been shown to associate with phonological working memory (Howard & Franklin, 1990; Geva et al., 2011a). Within Baddeley and Hitch's 1974 model of working memory is the phonological loop, made up of two parts: a phonological store and an articulatory control process (Baddeley & Hitch, 1974). The phonological store holds verbal information for short periods of time, whilst the articulatory control process allows the manipulation of this information, such as rehearsal (Baddeley & Hitch, 1974). This original working memory model did not implicate the language system, but evidence has shown that parts of the language system and parts of the working memory system share a common mechanism (Fedorenko, Duncan, & Kanwisher, 2012; Hulme & Roodenrys, 1997; Martin & Saffran, 1996; Marvel & Desmond, 2012; Saffran, 1997).

The empirical evidence of phonological working memory playing a part in inner speech has been varied. Baddeley and Wilson (1985) demonstrated that the processes of sub-vocal rehearsal were not dependent on the capacity for overt articulation: dysarthric patients (who lost the capacity to articulate) showed evidence of sub-vocal rehearsal as reflected in the word length effect or an effect of acoustic similarity with visually presented items (Baddeley & Wilson, 1985). Dyspraxic patients (whose problems stem from a loss of capacity to assemble speech-motor control programs) did not show a sign of rehearsal (Caplan & Waters, 1995). However, it is difficult to fully disentangle repetition from working memory, as clinical tests often employ only repetition to test working memory. While our study did not explicitly evaluate phonological working memory as a factor, a more exhaustive study utilizing specific phonological working memory assessments (i.e. varying difficulties of word span) alongside inner speech rhyme would more clearly demonstrate the relationship between these two closely related internal mechanisms.

While the significant association of phonological working memory with inner speech rhyme may explain some of the relationship with overt naming in persons with relatively poor overt speech, the strength of this relationship may also be due to the role of inner speech in pre-articulation processes (De Bleser & Marshall, 2005; Goldstein, 1948; Marvel & Desmond, 2012; Sokolov, 1972). Inner speech in PWA has been shown to associate with neural components linked with articulatory features pre-speech, such as the premotor cortex (Calvert et al., 2000; Geva et al., 2011b; Owen et al., 2004). Therefore, in persons with relatively poor overt speech alongside preserved inner speech, the contribution of inner speech to pre-articulation may be emphasized.

Subjective inner speech has been shown to significantly correlate with objective measurements of overt anomia and post-lexical output processes (Fama et al., 2017). While Fama and colleagues (2017) did not detail the participants who showed particularly impaired overt speech, they did indicate that a large proportion of participants (78.4%) reported intact inner speech alongside overt anomia, so a portion of their cohort appear to resemble members of the POS group in our study. Together with Fama et al. (2017), our findings suggest that, when overt speech is relatively poor, inner speech may play a significant role in successful overt naming.

Alongside a relationship of inner speech rhyme with overt naming, persons with relatively poor overt speech also showed a significant correlation of inner speech homophone with greater MLU produced on the writing picture description task. There are few studies evaluating inner speech's role in writing, or indeed generative writing. Since writing is produced letter-by-letter, it is believed that the ability to sound out words or produce a phonological representation plays an important and perhaps essential role in the ability of people to write. Agraphia, or problems with writing, can accompany aphasia, and this has been considered by some to be a manifestation of the dependence of writing on inner speech (Friederici et al., 1981), especially for more difficult writing tasks (Levine et al., 1982).

Unlike inner speech rhyme, inner speech homophone is not thought to associate strongly with phonological working memory (Howard & Franklin, 1990). We propose that one role of inner speech homophone during a generative writing task in persons with relatively poor overt speech may be as an error buffer. Inner speech as an error monitoring system has been hypothesized as part of the language system (Bredart, 1991; G. S. Dell & Repka, 1992; Hartsuiker & Kolk, 2001; MacKay, 1992; Motley, Camden, & Baars, 1982; Runnqvist et al., 2016; van Wijk & Kempen, 1987; Vigliocco & Hartsuiker, 2002). Inner speech, in these models, serves as an internal 'buffer' for possible language errors. Therefore, greater MLUs during a generative writing task associating with inner speech homophone in persons with relatively poor overt speech might reflect the fact that these participants have an opportunity for revising and correcting their errors during completion of the written picture description task. Indeed, in some examples from this study, participants scratched out incorrect words or restarted sentences.

However, persons with relatively preserved overt speech also edited their writing samples. Why, then, do we see a significant correlation of written MLUs with inner speech only for the POS group? This relationship is not fully explained by inner speech as an error buffer. Another reason for inner speech's involvement in writing for the POS group may be due to perceived task difficulty. Non-aphasic people have been shown to invoke an internal monologue when reading, with more difficult texts showing a heavier reliance on inner speech (Alexander & Nygaard, 2008). It might be the case that persons with relatively poor overt speech, who also show more severe language deficits than those with relatively preserved overt speech, perceived the writing task to be more difficult and therefore relied more heavily on inner speech for aid in processing.

Notably, inner speech (rhyme or homophone) did not show a significant relationship with the selected measures of language and cognition in persons with relatively preserved overt speech. Langland-Hassan and colleagues (2015), whose participants' competency on an overt rhyme task largely resembled those persons included in the GOS group in our study, likewise did not show a significant relationship between inner speech and a battery of language production, nor with measures of linguistic cognition.

Clinical Implications

The present study suggested that, in those people presenting with preserved inner speech alongside poor overt speech, there was a positive relationship between inner speech ability and overt naming and written MLUs. Therefore, we found that deficits in overt speech are not necessarily accompanied by deficits in inner speech, and, in the case of overt naming and written picture description, inner speech in some PWA with particularly poor overt speech may show an augmented relationship with overt speech.

On one hand, assessments of inner speech may be useful as a standard component of aphasia screening, illustrating whether an internal monologue is indeed preserved in persons who show particularly severe overt speech deficits. Further, it was shown that members of the POS group demonstrated relatively intact inner speech compared to their overt speech but it was also demonstrated that their inner speech was significantly worse than the inner speech shown by the GOS group. If indeed persons with severe overt speech deficits must rely on their internal monologue to complete some overt tasks, specializing therapy to improve and more often utilize their internal monologue may prove clinically worthwhile.

Training phonological working memory may be particularly useful for improving overt naming, as phonological working memory associates with inner speech. A large meta-analysis (Park & Ingles, 2001) showed that cognitive rehabilitation is used more often in traumatic brain injury and has been shown to have a large effect on working memory (though not necessarily phonological working memory), so it may be the case that training phonological working memory, or other aspects of higher cognition, will feed forward into improved inner speech and perhaps improved overt speech.

Training inner speech may have other ramifications not investigated in the present study. For example, it has been hypothesized that inner speech may have a role in self-cueing in aphasia, where an internal mechanism such as inner speech, involved in choosing correct phonological and lexical word forms, is necessary for successful self-cueing (Fama et al., 2017; Tompkins et al., 2006).

Conclusion

In a cohort of 38 persons with aphasia, we investigated the relationship of preserved inner speech to selected measures of language and cognition. We were chiefly interested in the relationship of inner speech to these measures when overt speech was particularly poor. In our cohort, 21 participants showed relatively preserved inner and overt speech, eight showed relatively preserved inner speech alongside poor overt speech and nine did not fit either classification. Those with preserved inner speech alongside relatively poor overt speech also demonstrated significantly more severe aphasia, but were similar in biographical factors to those with relatively good overt speech. Therefore, some persons with aphasia may indeed demonstrate preserved inner speech alongside severe deficits of overt speech. Overt naming and a generative writing task were found to significantly, positively correlate with inner speech but only in persons with relatively poor overt speech and not in persons with relatively preserved overt speech, suggesting an exceptional role for inner speech when there is a severe impairment in overt speech. Assessing and treating inner speech in PWA may improve their inner speech, which in turn may feed into overt speech improvement.

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Table 1: Example of scoring transformation for Repetition subtest

	Words	Complex Words	**Non-Words**	Digits	**Sentences**	**Total**
Total possible score	32	6	10	14	12	**60**
Aphasia cut-off	29	5	5	8	10	**49**
Example Raw Score	20	3	5	9	10	**47**
Example Transformed Score	(20/29=)0.69	(3/5=) 0.60	(5/5=)1	1.13	1	**0.96**

Table 2: Descriptive statistics for the POS and GOS groups

	POS Group		GOS Group	
	Mean	*SD*	*Mean*	*SD*
N	8		21	
Age	70.13	10.83	62.92	14.48
Years of Education	13.50	2.73	14.08	3.49
Time Since Stroke (mos)	46.00	32.59	22.56	16.89
Inner Speech (Average)	0.64	0.13	0.84	0.11
Overt Speech (Average)	0.07	0.17	0.89	0.12

*Table 3: Table of Pearson's r-values (Spearman's rho in parentheses for non-parametric correlations) for both groups showing relationship of inner speech with overt language and working memory; * indicates significant with multiple comparison correction using Bonferroni correction of p<0.01 and ^ indicates significant without multiple comparison correction at p<0.05*

	GOS Group		POS Group	
	Inner Rhyme	Inner Homophone	Inner Rhyme	Inner Homophone
Non-word Repetition	0.49^ (0.53^)	-0.04 (0.09)	0.24	-0.1
Sentence Repetition	0.54^ (0.56^)	0.28 (0.17)	0.76^	0.47
Semantic Memory	-0.25 (-0.24)	-0.15 (-0.08)	0.54 (0.49)	-0.03 (0.28)
Arithmetic	0.38 (0.45^)	0.29 (0.41)	0.51 (0.56)	-0.21 (-0.14)
Naming	0.41 (0.43)	0.20 (0.23)	**0.95***	0.5
Spoken MLUs	0.63^ (0.51^)	0.10 (-0.02)	-0.09	-0.49
Written MLUs	0.14 (0.11)	0.03 (0.13)	0.70 (0.59)	**0.96*** (0.65)

*Table 4: Fisher r-to-z transformation table of two-tailed p-values comparing POS and GOS groups, Bonferroni multiple comparison correction p<0.007 used (signified by *)*

	Inner Rhyme	Inner Homophone
Non-word Repetition	0.56	0.91
Sentence Repetition	0.44	0.66
Semantic Memory	0.09	0.81
Arithmetic	0.75	0.31
Naming	**0.006***	0.49
Spoken MLUs	0.14	0.25
Written MLUs	0.19	**0.004***

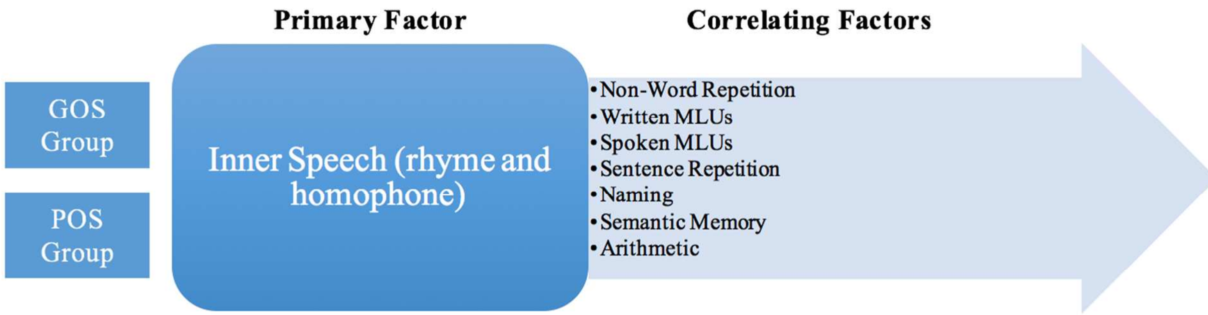

Figure 1: Outcome measures; GOS=good overt speech and preserved inner speech, POS=poor overt speech and preserved inner speech

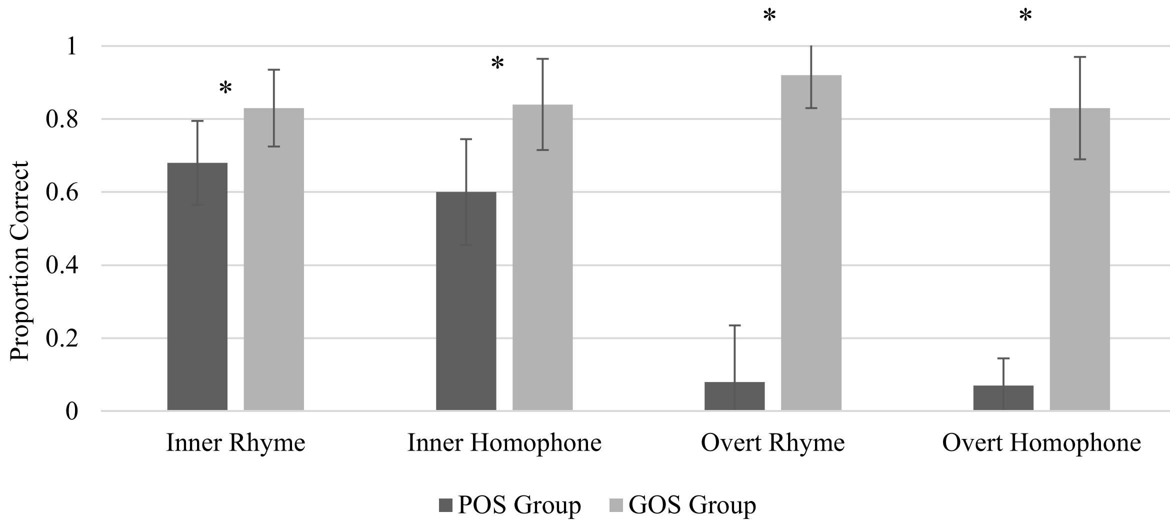

*Figure 2: Descriptive statistics of POS and GOS groups on PALPA inner and overt speech subtests; error bars are standard deviation; * = significant p<0.05*

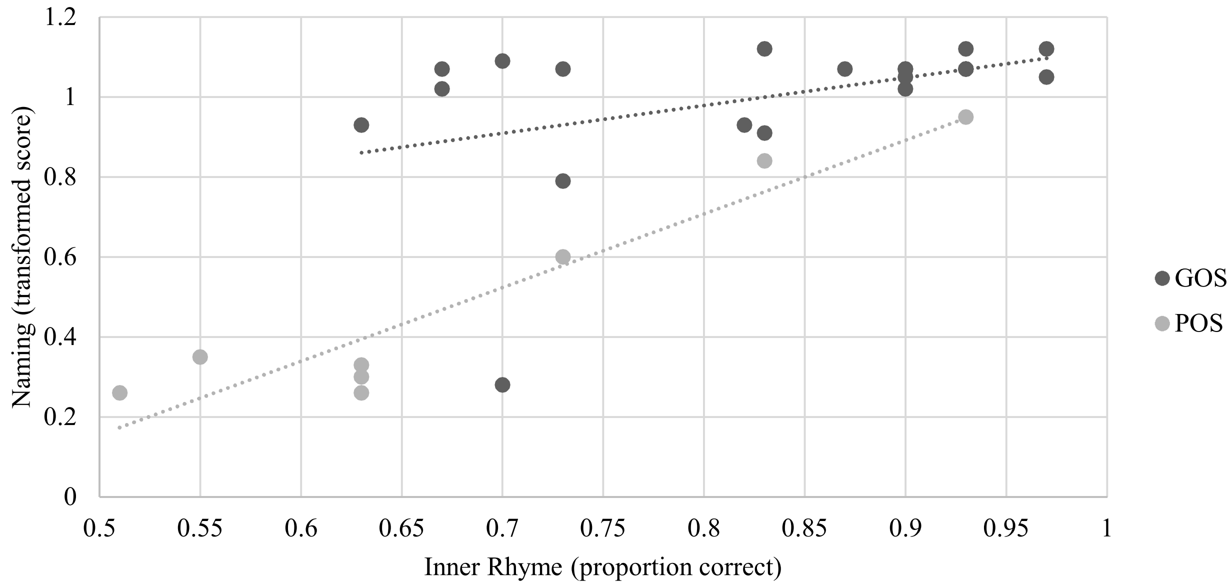

Figure 3: Relationship of inner speech (rhyme) and naming in the GOS and POS groups; graph only includes values of inner speech (rhyme) over 0.50, as all participants showed values higher than chance

Supplementary Table 1: Participant biographic demographics

Participant	Age (yrs)	Sex	Hand[1]	Education[2]	Time Since Stroke (mos)	Stroke Type
1	73	M	L	Age 11	18	Ischemic
2	61	M	R (0.83)	MA	38	Ischemic
3	66	M	R	HS	11	Ischemic
4	78	M	L	Age 14	20	Ischemic
5	48	F	R	MA	10	Hemorrhagic
6	62	M	R	MA	10	Ischemic
7	78	M	A	Age 17	64	Ischemic
8	63	F	R	PhD	72	Ischemic
9	69	M	R	HS	25	Ischemic
10	60	M	R	Age 16	14	Ischemic
11	78	F	R	Age 14	9	Ischemic
12	75	M	R	BA	19	Ischemic
13	69	M	R	BA	22	Ischemic
14	78	M	R	BA	12	Ischemic
15	73	M	R	Age 16	10	Ischemic
16	21	F	R	HS	15	Ischemic
17	47	M	R	HS	12	Ischemic
18	42	F	R	HS	13	Ischemic
19	81	M	R	Age 16	19	Ischemic
20	62	M	R	PhD	16	Ischemic
21	61	M	R	Age 16	22	Hemorrhagic
22	78	M	R	MA	19	Ischemic
23	65	F	R	Age 15	24	Ischemic
24	71	M	R	Age 15	59	Ischemic
25	71	M	R	Age 15	111	Ischemic
26	79	M	L	HS	8	Ischemic
27	49	F	R	BA	20	Ischemic
28	70	M	R (0.4)	HS	29	Ischemic
29	70	M	R	Age 16	87	Ischemic
30	55	M	A (0.16)	MA	49	Ischemic
31	45	F	R	MA	20	Ischemic
32	54	M	R	MA	48	Ischemic
33	65	M	R	HS	23	Ischemic
34	53	F	R	BA	36	Ischemic
35	55	M	R	HS	48	Ischemic
36	87	F	R (0.85)	BA	13	Ischemic
37	75	F	L	BA	66	Hemorrhagic
38	65	F	R	Age 12	Not recorded	Ischemic

[1]L=Left, R=Right, A=Ambidextrous. In brackets: the score achieved on the Edinburgh Handedness Inventory for ambidextrous participants, where (−1) = strongly left-handed, (1) = strongly right-handed, and (0) = completely ambidextrous.
[2]Education: HS = finished high school, BA = Bachelor’s degree, MA = Masters degree, PhD = Doctorate degree

Supplementary Table 2: Percentage correct from PALPA tests for all participants and their group of classification

Participant	Inner Rhyme	Inner Homophone	Overt Rhyme	Overt Homophone	Group
1	70%	No Score	No Score	50%	Not classified
2	No Score	60%	No Score	63%	Not classified
3	No Score	63%	No Score	73%	Not classified
4	63%	No Score	No Score	50%	Not classified
5	93%	80%	83%	93%	GOS
6	97%	100%	100%	100%	GOS
7	63%	63%	0%	0%	POS
8	83%	90%	100%	67%	GOS
9	87%	95%	97%	90%	GOS
10	90%	98%	97%	85%	GOS
11	97%	98%	93%	100%	GOS
12	83%	63%	47%	53%	POS
13	47%	26%	0%	0%	Not classified
14	63%	67%	17%	0%	POS
15	93%	90%	97%	98%	GOS
16	82%	43%	93%	40%	GOS
17	67%	97%	100%	97%	GOS
18	63%	60%	53%	53%	GOS
19	63%	27%	0%	0%	POS
20	90%	100%	90%	93%	GOS
21	43%	24%	0%	0%	Not classified
22	No Score	No Score	No Score	No Score	Not classified
23	73%	100%	93%	93%	GOS
24	51%	65%	0%	0%	POS
25	93%	78%	0%	0%	POS
26	93%	98%	97%	100%	GOS
27	93%	48%	97%	100%	GOS
28	90%	85%	100%	98%	GOS
29	No Score	32%	No Score	No Score	Not classified
30	73%	87%	100%	95%	GOS
31	70%	87%	100%	97%	GOS
32	73%	73%	0%	0%	POS
33	83%	71%	100%	57%	GOS
34	55%	47%	0%	0%	POS
35	No Score	No Score	No Score	No Score	Not classified
36	70%	77%	73%	55%	GOS
37	90%	93%	90%	85%	GOS

38	67%	60%	72%	52%	GOS

Supplementary Table 3: Rhyming and Homophone Stimuli for Inner Speech

Rhyme		Homophone	
List 1	List 2	List 1	List 2
1. Town / Gown	1. Pleat / Treat	1. Wime / Waime	1. Byme / Bime
2. Rush / Gush	2. Ghost / Roast	2. Fick / Phic	2. Quib / Kwib
3. Boot / Flute	3. Creak / Break	3. Bick / Blic	3. Zoar / Zure
4. Pea / Play	4. Paw / Hour	4. Coim / Koym	4. Peam / Pame
5. Sort / Part	5. Match / Hatch	5. Voar / Vore	5. Scad / Skad
6. Wart / Fort	6. Hive / Dive	6. Zoal / Zole	6. Thib / Shib
7. Hush / Bush	7. Bowl / Mole	7. Hain / Hine	7. Grex / Geks
8. Sauce / Worse	8. Flair / Year	8. Phex / Ffeks	8. Heem / Heam
9. Bone / Cone	9. Tone / Gone	9. Shad / Chad	9. Tain / Tane
10. Bond / Hand	10. Zoo / Thou	10. Noal / Nool	10. Foym / Fyme
11. Tint / Pint	11. Low / Toe	11. Bury / Berry	11. Prey / Pray
12. Tweak / Freak	12. Down / Flown	12. Sea / See	12. Pail / Pale
13. Dull / Hull	13. Comb / Gnome	13. Frey / Fey	13. Pout / Port
14. Call / Ball	14. Rose / Lose	14. Route / Root	14. Peach / Poach
15. Pool / Wool	15. Mint / Hint	15. Earn / Urn	15. Some / Sum
16. Four / Saw	16. Bait / Skate	16. Kill / Sill	16. Maid / Made
17. Wand / Pond	17. Horse / Force	17. Fury / Ferry	17. Pear / Pair
18. Jute / Foot	18. Glove / Wove	18. Beach / Beech	18. New / No
19. Food / Blood	19. Card / Ward	19. Pour / Pore	19. Sew / So
20. Bear / Chair	20. Gull / Full	20. Ear / Oar	20. Dough / Doe
21. Boast / Cost	21. Fall / Shall	21. Might / Mite	21. Dual / Jewel
22. Batch / Watch	22. Doe / Cow	22. Sail / Soil	22. Shoot / Soot
23. Shoe / Screw	23. Love / Dove	23. Row / Rough	23. Neigh / Nigh
24. Cheat / Sweat	24. Date / Plait	24. Raid / Ride	24. Pea / Pie
25. Head / Bed	25. Sea / Quay	25. Weigh / Way	25. Break / Brake
26. Chew / Hoe	26. Wed / Bead	26. Flay / Flee	26. Dear / Dare
27. Five / Give	27. Dome / Bomb	27. Weak / Wake	27. Duet / Cruet
28. Fool / Tool	28. Yard / Hard	28. Cell / Sell	28. Sore / Saw
29. Pose / Prose	29. You / Two	29. Bore / Bow	29. Sight / Sigh
30. Hole / Owl	30. Mood / Brood	30. Quay / Key	30. Home / Hum