Critical Review: Inner and overt speech post-stroke: Is there a dissociation?

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This critical review examines the possibility of a dissociation between inner and overt speech capabilities in persons following a stroke using evidence from two neuroimaging studies and one mixed (within and between subject) nonrandomized clinical control trial. Overall, divergent performance on tasks of inner and overt speech production indicates that a post-stroke dissociation between inner and overt speech skills may be observed. This is supported by the identification of neural regions uniquely responsible for each as depicted by functional neuroimaging and lesion-mapping structural analyses. This informs the construction of language imaging paradigms for future studies and the clinical treatment of post-stoke aphasia.

Introduction

Inner speech is generally classified as the internal representations of auditory word forms and the ability to process and manipulate these representations (Geva, Bennett, Warburton, & Patterson, 2011). This ability to talk to oneself in one's head and listen to what is being said is a skill involved in memory, reading, language development and general cognitive processing (Geva et al., 2011). Comparatively, overt speech refers to the physical articulation of one's thoughts (Huang, Carr, & Cao, 2001). Models of language processing fail to reach a consensus in their accounting for inner speech, making it difficult to determine its relationship to overt speech and a possible dissociation (Geva et al., 2011.

Some have postulated that overt speech is simply produced by the same mechanisms as inner speech, with the obvious addition of a motor component (Huang et al., 2001). In other words, inner speech is modulated by the speech production system alone and its capacity should mirror that of overt speech (Vigliocco & Hartsuiker, 2002). However, drawing on evidence from individuals with aphasia, the reporting of a poor correspondence between words thought and words spoken in the absence of dysarthria, apraxia or other motor speech difficulties indicates this may not be the case (Marshall et al., 1998).

Alternatively, some scholars have concluded that inner speech is dependent on systems of both speech production and comprehension (Oomen, Postma, & Kolk, 2001). In other words, inner and overt speech abilities do not necessarily mirror one another. This is supported by studies examining aphasic patients' patterns of speech error correction compared to normals' during episodes of inner and overt speech in various environments (Oomen et al., 2001).

Ideally, neuroimaging studies would provide a more concrete means by which to clarify these discrepancies and isolate the mechanisms involved, jointly or separately, in the production of inner and overt speech. However, objectively measuring the neural correlates of inner speech is an intricate process often confounded by methodological limitations (Geva et al., 2011). These limitations have prevented the valid neural mapping of inner and overt speech production areas, making the concrete identification of a dissociation difficult to assert.

Objectives

The primary objective of this critical review is to identify and evaluate evidence for the existence of a dissociation between inner and overt speech capabilities post-stroke. Secondarily, evidence-based clinical implications arising from such a discrepancy will be explored.

Methods

<u>Search Strategy</u>
Computer-based databases supplied by the library of Western University were searched: PubMed, CINAHL and Cochrane Library. Articles were constrained to publication dates during or after the year 2000. The search terms were as follows: ((inner voice) or (inner speech) and (overt speech) and (aphasia) or (stroke)).

<u>Selection Criteria</u>
Studies selected for inclusion were constrained by the following criteria. Studies must explore the comparison of inner and overt speech capabilities in aphasics, or document the measurement of inner speech capabilities post-stroke. Due to the paucity of research in this area,

outcomes measures and demographic profiles of research participants were not a barrier to inclusion.

Data Collection

As dictated by the selection criteria described above, literature employing the following study designs was yielded: a mixed nonrandomized clinical control trial and two neuroimaging studies (one voxel-based lesion-symptom mapping following magnetic resonance imaging [MRI] and one event-related functional MRI [fMRI]).

Results

Geva et al. (2011) conducted a mixed nonrandomized clinical control trial to investigate whether post-stroke patients with impaired overt speech production experience impairments of inner speech as well. The language abilities, cognitive capacity (including non-verbal IQ), speech apraxia and performance on inner speech tasks of 27 patients with aphasia following a left middle cerebral artery (MCA) stroke were compared against those of 27 healthy controls. The aphasia diagnosis was based on clinical consensus and the results on the Comprehensive Aphasia Test (CAT).

To assess speech abilities, the following three tasks were given as adapted from the Psycholinguistic Assessments of Language Processing in Aphasia (PALPA). One, participants were asked to determine whether 60 pairs of written words rhymed. Two, participants were asked to determine whether 40 pairs of written words were homophones. Last, participants were provided a list of 20 non-word pairs and asked to determine if the pairs were homophones. For each of these tasks, patients performed half the items using inner speech (silent judgment) and the other half using overt speech, allowing for a quantification of differences between inner and overt speech skills.
The results of a Mann-Whitney test ($p= <0.05$) showed a significant difference in performance between the two groups for all three inner speech tasks: the patients as a group were impaired compared to the controls. Interestingly, the patient group results were heterogeneous: inner speech skills ranged from normal to severely impaired.

Additionally, patients' scores on the inner and overt speech tasks were compared to assess evidence of a dissociation. Significant correlations (one-tailed Kendall's tau > 0.4) were obtained between the following measures: inner and overt speech; overall severity of speech production (as per CAT) and inner speech; and overall severity of speech comprehension (as per CAT) and inner speech.

A major strength of this study is the reliability and validity of its measures. Specifically, because inner speech is inherently difficult to assess, the researchers' use of tasks that reduced interference from confounding variables (such as working memory and reliance on orthographic cues) contributed to its validity. Furthermore, an item analysis was performed on the controls' results to exclude items for which performance was not significantly above chance. As the majority of participants completed all measures, an appropriate control comparison was used and methodological modifications were not made *post hoc,* the evidence presented by Geva et al. (2011) is compelling. It is worth noting, however, that despite identifying that all patients had impaired speech production with relatively more intact comprehension, the authors failed to identify the specific classifications(s) of aphasia represented by the participants. This makes generalizing the results problematic.

Neuroimaging studies of cortical language functions provide objective data regarding neural correlates of inner and overt speech. However, fMRI studies of cortical language functions are often undertaken with only inner speech-based paradigms because vocalizing creates severe motion artifacts in the images (Huang, Carr, & Cao, 2001). This poses a problem for determining if the neural substrate of inner speech is dissociated from that of overt speech.

In order to address this, Huang et al. (2001) conducted an event-related fMRI study using techniques to identify, reduce and correct motion-related interference. Seven healthy right-handed native English speakers performed four language paradigms during separate functional scans. Two of the paradigms required inner speech (silently naming a letter and silently generating the name of an animal beginning with a certain letter) and two required overt speech (speaking aloud a letter and overtly generating the name of an animal beginning with a certain letter).

Using a multiple-step image processing protocol that separated motion-induced from activation-induced fMRI signals, Huang et al. (2001) compared the activation of cortical pathways potentially relevant to language production during both silent and overt speech. This protocol allowed for the deletion of artifact from the images, providing a viable comparison of inner and overt speech mechanisms (Huang et al., 2001). Both inner and overt speech activated wide neural networks, with several cortical regions activated during all four tasks. The researchers focused on three discrepant areas of activation: the 'mouth, lips and tongue' (MLT-PMC) and 'inferior vocalization' (IV-PMC) regions of the primary motor cortex, and Broca's area and its homologue.

The MLT-PMC and IV-PMC regions were robustly activated bilaterally above baseline during overt speech tasks but displayed negligible activation during inner speech. Broca's area and its right homologue were activated to their greatest extent in the inner speech paradigms. Interestingly, during overt generation of an animal name, activation of Broca's area decreased relative to inner speech generation. Conversely, during letter naming, activation increased in the overt paradigm relative to its inner speech counterpart.

The measures enacted by Huang et al. (2001) to ensure the validity and reliability of the fMRI results are commendable. The images obtained were assessed and corrected for in-plane transitions and head rotations through a complex series of computations, resulting in a highly accurate neural composition for analysis. While the validity and reliability of this study allow it to significantly inform the understanding of inner and overt speech mechanisms in healthy adults, its contribution to the understanding of these processes post-stroke is not as clear. While suggestive of a dissociation between inner and overt speech mechanisms in typical brains, similar inferences from this data regarding the aphasic brain must be made mindfully. The authors suggest that the evidence can be applied within aphasiology, but this should be undertaken cautiously until similar protocols have been conducted with an aphasic population.

In order to assess a dissociation between inner speech overt speech specifically in individuals with post-stroke aphasia, Geva et al. (2011b) applied a voxel-based lesion-symptom mapping technique. 17 patients with aphasia completed a series of inner speech tasks (rhyme and homophone judgments as described in Geva et al., 2011a) and overt speech production (reading aloud) as imaging was performed using a 3T MRI scanner. After lesions were defined, statistical analysis was conducted using voxel-based lesion-symptom mapping. In this procedure, patients were divided into two groups based on whether or not a lesion was identified as affecting a specific voxel. Behavioural scores were compared between groups and a *t*-statistic was generated for affected voxels. Each voxel included in the analysis underwent this procedure several times. The covariate of interest (either rhyme or homophone judgment) was examined by itself. Following the computation of a *t*-statistic (corrected for multiple comparisons with a non-parametric permutation test), analyses were conducted to either isolate specific cognitive components or examine the influence of other variables on the data.

Performance on the rhyme judgment tasks was significantly associated with lesions to an area covering the left inferior frontal gyrus pars opercularis and pars triangularis, continuing posteriorly through the pre-and post-central gyrus into the anterior part of the supramarginal gyrus and its medial white matter. When overt speech production scores were added as a covariate to control for speech production ability, the correlation between poor performance and lesions to this area remained significant. For homophone judgment tasks of inner speech, identical lesion sites were related to performance but lesser effects were observed.

Using lesion analysis is an effective means of avoiding methodological caveats associated with functional imaging studies described previously by Huang et al. (2001). This study presents a reliable structural analysis obtained by thorough adherence to evidence-based lesion mapping protocol. However, it is worth noting that this study included a number of participants who were not strongly right-handed—a possible confound for an analysis focusing on language impairment following a left MCA stroke. Additionally, the authors used a *post hoc* false discovery rate correction after conduction of permutation testing to identify the main neural correlates of inner speech. This technique is sometimes discarded in favour of a procedure involving the regression of the non-interest covariate and subsequent permutation testing on the residuals using the covariate of interest (Nichols et al., 2008). Overall, the results of this study offer an equivocal level of evidence for a dissociation between inner and overt speech abilities post-stroke.

Discussion

The results of a mixed nonrandomized clinical control trial provide compelling evidence for a dissociation of inner and overt speech abilities post-stroke (Geva et al., 2011a). If inner speech were simply overt speech with an additional motor component, only one type of dissociation would be expected in post-stroke speech production: impaired overt speech with intact inner speech. This is not the case.

In the homophone judgment task, some patients performed at or close to chance level on the inner speech judgments but showed relatively good ability to read words aloud (Geva et al., 2011a). Others showed this same trend in the homophone judgment task. This impairment cannot be attributed to a deficit in phonemic discrimination because these patients were able to judge accurately when the pairs were read aloud by an examiner (Geva et al., 2011a). Conversely, some patients had intact or relatively intact inner speech, performing above chance in the rhyme and homophone judgment, but evidenced a distinct impairment in overt speech by experiencing difficulty reading the words aloud (Geva et al., 2011a). This discrepancy may be accounted for by the presentation of apraxia in some of the patients—a reality which should provide support for the inclusion of inner speech tasks in clinical assessment. For the patients without motor deficits, the dissociation observed lends credence to the idea that both overlapping and unique neural areas are responsible for inner and overt speech production (Geva et al., 2011a).

This is underscored by data achieved through event-related fMRI analyses. A direct comparison of the neural networks activated for both inner and overt speech paradigms identified overlapping brain activation; however, the two conditions also produced separate activations reflecting distinct, non-motor cognitive processes at work (Huang et al., 2001). The pattern of task-dependent activation of the PMC indicates that overt speech utilizes mechanisms that can be consciously (de)activated. However, Huang et al. (2001) demonstrated that when these motor processes were not in use, Broca's area and its right homologue were active. This suggests that it is inappropriate to attribute production of inner and overt speech to the same process up until motor execution; rather, it is indicative of a dissociation between the neural substrates responsible for both (Huang et al., 2001).

Analyzing the neural correlates of inner and overt speech using voxel-based lesion-symptom mapping identified that the left inferior frontal gyrus pars opercularis, left supramarginal gyrus and its adjacent white matter were significantly more involved in inner than overt speech production (Geva et al., 2011b). This suggests that inner speech is produced by frontal regions and transferred via the arcuate fasciculus to posterior regions when speech production is linked to comprehension, confirming that inner speech is not simply overt speech without a motor component (Geva et al., 2011b). Instead, this explicitly suggests that a dissociation exists between inner and overt speech post-stroke as lesions affecting specific neural substrates result in divergent speech profiles (Geva et al., 2011b).

Conclusion

The studies reviewed provide an equivocal level of evidence to support the possibility of a dissociation between inner and overt speech post-stroke. Further event-related fMRI-based neuroimaging studies measuring cortical activation during inner and overt speech production in persons with aphasia would be of immense value. A continued exploration of the mechanisms underlying inner speech in healthy brains would also be useful for identifying more effective ways to assess this unique but intrinsically mysterious function.

Clinical Implications

It is evident that following a stroke, a person's inner speech may remain relatively intact while their overt speech is preserved (Geva et al., 2011a). For patients with or without motor impairments, inner speech tasks may reveal speech capabilities missed if only overt speech is assessed. Alternatively, impaired inner speech may co-occur with preserved overt speech (Geva et al., 2011a). Thus, an assessment of and probing for a dissociation between inner and overt speech abilities will provide a clinician with a clearer profile and more accurate depiction of a patient's strengths and weaknesses, influencing both the diagnosis and prognosis procedures of post-stroke patients with aphasia (Geva et al., 2011b).

Additionally, both neuroimaging studies inform the construction of future language imaging paradigms. As the evidence suggests that the neural substrates of inner and overt speech are *not* the same up until motor execution, it is inappropriate to use inner speech tasks as a means of bypassing motion-induced artifact in studies of speech production. Rather, the use of event-related fMRI techniques or voxel-based lesion-symptom mapping structural analyses would allow for inner and overt speech to be accounted during scanning. This is relevant in the contexts of pre-operative neural evaluations and language-based research.

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