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Review Article

Aphasia Rehabilitation of Auditory Word Comprehension-Impaired Stroke Patients

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Abstract

Auditory word comprehension is the process through which spoken language is heard, interpreted and understood. This ability is impaired when there is damage to specific language areas in brain as a result of stroke. Auditory word comprehension impairment is a disabling sequalae of stroke characterised with semantic and phonological deficits. This review summarises key findings on stroke induced auditory word comprehension deficit and approaches to treatment leading to a new hypothesis of semantic treatment that we term integrated semantic treatment. Integrated semantic treatment offers solution to treatment of auditory word comprehension impairment by manipulation of some neuroscientific principles.

INTRODUCTION

In order to comprehend the utterance "The house is big" listeners must recognise and understand the individual words in that utterance. Comprehension of each word must be achieved by integrating the auditory information in the speech input onto stored semantic representations of words in the semantic lexicon [1]. Auditory word comprehension is the process through which spoken language is heard, interpreted and understood. That is, the process of word comprehension does not only entail the sensation of an incoming auditory stimulus, but also its processing and interpretation in the context of previous experience [2]. Auditory word comprehension is a highly developed ability in human beings. Despite the high complexity of the speech signal and the processes of decoding the speech signal, it is often executed effortlessly by human beings. Auditory word comprehension is facilitated by some neural mechanisms in the language areas of the human brain and damage to these mechanisms as a result of cerebrovascular accident (CVA) can be debilitating for the stroke patient.

The purpose of this article is to provide an evidence based approach to aphasia rehabilitation of comprehension deficits in auditory word comprehension-impaired stroke patients. We start with a discussion of the prognosis of auditory word comprehension deficit following stroke. We then review literature on neuroplasticity and discuss evidence of plasticity associated with aphasia recovery. We review literature on the efficacy of aphasia rehabilitation and highlight some approaches to aphasia rehabilitation of auditory word comprehension-impaired aphasic patients. We then provide a description of the Dual Stream model of speech comprehension, review other related research and draw out some essential neuroscience principles. Ultimately, we propose a new treatment hypothesis that can bring about better treatment outcome in auditory word comprehension-impaired stroke patients.

PROGNOSIS OF STROKE-INDUCED AUDITORY WORD COMPREHENSION DEFICIT

Stroke, also known as cerebrovascular accident (CVA), is a neurological disease that occurs when blood supply to a particular part of the brain is disrupted. Acquired language disorder, otherwise called aphasia, is a common disabling sequalae of stroke occurring in 25%–40% of stroke survivors [3]. Aphasia is impairment in the use and comprehension of language as a result of brain damage especially stroke. In an attempt to classify aphasia, Ardila [4-7] suggests that there are only two fundamental forms of aphasia: the Wernicke's type aphasia is linked to impairments in the lexical-semantic (paradigmatic) system of language and the Broca's type aphasia is linked to impairments in the grammatical (syntagmatic axes) of the language system. From a neurobiological perspective, damage to the lower posterior portion of the frontal area in the dominant left hemisphere results in language production impairment (Broca's type of aphasia), while pathology of the temporal-parietal lobe in the dominant left hemisphere is associated with language comprehension deficit and disturbances in the phonological, lexical and semantic language systems (often Wernicke's type of aphasia) and damage in the surrounding areas is associated with perisylvian (transcortical) aphasias in the anterior and posterior regions, respectively [8].

Depending on the site of lesion stroke patients with auditory word comprehension deficit may express pure word deafness,

word meaning deafness, word meaning aphasia (gogi-aphasia), and sentence comprehension deficits. Persons with auditory word comprehension impairment may have difficulty expressing themselves through meaningful speech even though their use of grammar, syntax and intonation is relatively spared [9]. Auditory word comprehension deficit in characterised with poor speech comprehension, poor repetition of speech or single words and paraphasias, phonemic retrieval deficit as well as semantic access deficit [10]. Persons with auditory word comprehension impairment have problems in recalling from semantic memory and also in associating words with specific meanings: that is the semantics of spoken words can be abnormal [11]. Research has shown that stroke patients with auditory comprehension impairment typically show poor comprehension of pictures and it has been reported that comprehension-impaired stroke patients express semantic access deficits in the auditory-verbal domain as well as multimodal semantic deficits [10]. In the most severe cases, stroke patients with auditory word comprehension impairment comprehend almost nothing that is said, failing to respond appropriately to verbal questions, commands or single words. In more moderate cases, however, patients may be able to understand, with effort, a few words and statements [9]. Stroke induced auditory word comprehension deficit results more from semantic (access)-level impairments than phonemic level-impairments [12,13]. This finding corroborates the studies of Hickok and Poeppel, [14-16] who suggest that phonemic-level aspects of auditory word recognition are bi-hemispherically organised, as unilateral disruption, even in acute stroke, does not appear to lead to profound deficits in phonemic processing in auditory word comprehension.

In summary, auditory word comprehension stroke patients often manifest profound deficits in semantic access deficits as well as multimodal semantic deficits compared to deficits in phonemic processing.

LESION CORRELATES OF AUDITORY WORD COMPREHENSION IMPAIRMENT

Traditionally, the temporoparietal area (i.e.Wernicke's area) on the brain is regarded as the primary neural substrate underpinning auditory word comprehension. This view has shifted over time, and recent studies suggest that auditory comprehension of words relies on cortex considerably anterior to the traditional location of Wernicke's area in the posterior temporal lobe [17]. Kemmerer [9] suggests that some patients with Wernicke's aphasia have even larger lesions that extend dorsally and caudally into the left inferior parietal lobule. Mesulam, Thompson, Weintraub and Rogalski [18] recently examined patterns of cortical atrophy in primary progressive aphasia (PPA). The authors found an anatomical dissociation, in which word-level auditory comprehension related to cortical thinning in the anterior temporal lobe, whereas sentence-level auditory comprehension related to thinning in a more widespread network of posterior temporal and frontal sites. The authors suggests that the differences in localisation of auditory comprehension of words in PPA from the classical localisation based on stroke lesions were attributed to the white matter damage associated with stroke. These studies, consistent with other neuroimaging studies, have shown that auditory word comprehension involves a number of widely distributed regions within the frontal and temporal lobes. A recent prominent study examined white matter correlates of auditory comprehension outcome in chronic stroke patients. The findings implicate anterior temporal white matter and particularly the uncinate fasciculus in word-level comprehension. In contrast, posterior temporal white matter damage and lesion in the inferior longitudinal fasciculus related to sentence-level comprehension deficits. The inferior fronto-occipital fasiculus, with its long course from the frontal lobe through the temporal lobe, was implicated in both word and sentence comprehension. These findings demonstrate the importance of ventral stream white matter damage to auditory comprehension in stroke and suggest that anterior and posterior temporal white matter damage impairs different levels of auditory comprehension [19].

In addition, impaired noun retrieval is often associated with damage to the left temporal lobe, especially the temporal pole and the middle and inferior temporal gyri [20], whereas impaired verb retrieval is commonly associated with damage to the left frontal lobe, especially Broca's area and the underlying white matter [21]. Kemmerer [9] suggests that auditory word comprehension deficits in patients with transcortical aphasia has reliably been linked with lesions near the junction of the left temporal, parietal, and occipital lobes. The author noted that involvement of the posterior middle and inferior temporal gyri (roughly the posterior portion of BA21 and the lateral portion of BA37) as well as the inferior angular gyrus (roughly the inferior portion of BA39) is lesioned in persons with auditory word comprehension impairment.

This show that the neural substrate underpinning auditory word comprehension extends beyond that traditional Wernicke's area and extends to other surrounding areas of the frontal and temporal lobes and its underlying white matter.

AUDITORY WORD COMPREHENSION IMPAIRMENT RECOVERY AFTER STROKE

Predicting aphasia recovery is difficult because of substantial variability in outcomes. However, aphasia recovery potential is determined largely by the size of lesion, site of lesion, age of onset of lesion, handedness, gender, personality, temporal factors, intensity of treatment, timing of treatment delivery, socioeconomic factors, cognitive status, health status, salience of targeted stimuli and language skills, motivation, age, overall health status and interaction of these factors [8,22-24]. In particular, measures of cortical activations have been found to explain the recovery of language functions among aphasic patients [25]. This is due to the fundamental principle underlying language recovery in that the brain, regardless of age, is flexible and capable of change. In other words, the brain has the capacity for structural and functional plasticity throughout human life span [22]. Experience-dependent plasticity underlies normal human processes such as development, learning, maintaining performance while ageing and language recovery from brain injury. Neuroplasticity may be adaptive, as seen in the effect of therapy on language recovery; or maladaptive, as when a patient loses language ability from failure to use or comprehend language as a result of stroke [26].

Recently, neuroimaging technologies have provided researchers with a better understanding of the brain mechanisms of aphasia recovery in patients with brain damage. Neuroimaging studies have provided reliable evidence indicating the contributions of homologous right hemisphere and residual left hemisphere structures in aphasia recovery in patients with brain damage. In a review study, Raymer, et al. [26], suggest that aphasia recovery in the subacute stage following stroke is aided by a neurophysiological process associated with spontaneous recovery and that the damaged left hemispheric brain regions involved in language use or comprehension contribute to early aphasia recovery in stroke patients. In a neuroimaging study by Thompson [27], the researcher suggests two mechanisms of functional reorganisation of language in patients with stroke induced aphasia: (a) recruitment of premorbid residual left hemisphere language processing structures and (b) recruitment of typically homologous right hemisphere regions. Recruitment of residual damaged language regions in the left hemisphere for aphasia recovery has been documented in neuroimaging studies in patients with stroke and other forms of acquired brain damage [28-30]. Furthermore, aphasia recovery involving transfer of language function to homologous regions in the right hemisphere has also been documented in stroke patients with aphasia [23,24].

There is an ongoing debate on the contributions of left and right hemisphere changes in language recovery in aphasia treatment. Some researchers suggest that aphasia recovery supported by the right hemisphere may be less complete in comparison to that associated with left perilesional areas [31,32], and others suggest that right hemisphere changes may not influence long-term language recovery, and may even be maladaptive [33]. However, some factors such as the age of lesion onset or aetiology of the lesion (for example stroke) may determine whether patients develop intrahemispheric left hemisphere reorganisation or atypical right hemisphere dominance [34,35]. Crosson et al. [34], however, suggests that it is fruitless proving the participation of the left hemisphere to the exclusion of the right hemisphere for aphasia recovery because both hemispheres are implicated.

Research in neuroplasticity associated with aphasia recovery has primarily focused on spontaneous recovery compared to investigating the effectiveness of aphasia therapy [22]. Numerous studies have investigated functional-cortical reorganisation associated with aphasia therapy. These studies provide promising evidence that neuroplastic changes in the brain underlies aphasia recovery in patients with brain damage [35-44]. To improve language recovery in post stroke aphasics Raymer, et al. [22], suggests that speech and language pathologists must note the words of Shih and Cohen [45]:

"Before we ascribe too much significance to activation maps, we need to answer basic questions such as the specific functional role of activated regions, their contribution to task performance or functional recovery, and their significance in terms of the activity they reflect" (i.e., excitatory, inhibitory, both; p. 1773)."

For example, the homologous right hemisphere contributions to aphasia recovery in stroke patients may reflect recruitment of some cognitive abilities such as attention,memory, or executive functions [40].

In summary, there is a consensus that neuroplasticity influences aphasia recovery in patients with stroke. Neuroplasticity is the lifelong capacity of the human brain to reorganise itself in response to stimulation of experience. This can be attributed to the intimate relationship between specific cognitive operations, neural mapping activity and increased blood flow to the activated neural regions. Thus, it suggests that a major purpose of aphasia neurorehabilitation is to manipulate neuroscience principles to maximise neural plasticity that lead to improvement in language functions. Effective approaches to aphasia rehabilitation in stroke should be influenced by studies within the basic sciences on the neural underpinning of language organisation in the brain.

APPROACHES TO APHASIA REHABILITATION

Research on the efficacy of aphasia rehabilitation in post stroke aphasia has been on an increase in the last decade. Cochrane reviews on the efficacy and effectiveness of aphasia therapy provides evidence for the effectiveness of aphasia therapy on aphasia recovery in post stroke patients with aphasia in terms of improved functional communication, language comprehension, reading, writing, and expressive language compared with no therapy [44,46,47]. There are numerous aphasia treatments for word comprehension deficits in comprehension-impaired stroke patients. They are broadly categorised into three types: impairment-based approach, consequence based approach and direct electrical stimulation approach.

Impairment-based approach

The impairment-based approach is an evidence-based approach to aphasia rehabilitation that addresses impaired communication modalities (phonological or semantic deficits) and focuses on training those areas in which a person makes errors. Some treatments under this approach are:

Schuell's stimulation approach

Schuell's stimulation approach is regarded as the most effective approach to treatment of auditory word comprehension deficit [48,49]. Schuell's stimulation is an approach to treatment which utilises intensive auditory stimulation of the underlying comprehension deficit rather than stimulation of each modality with the underlying hypothesis that the effect of treatment will spread to other modalities [49].

Computer based treatment

The advancements in computer technology today have seen it implemented in aphasia rehabilitation. Computer based approach to aphasia rehabilitation can be implemented as a personalised method of treatment, where the patient does the exercises alone and then has his or her performance reviewed later by a speech and language pathologist. It can also be used to assist the speech and language pathologist to present stimuli. Although there is significant peer reviewed evidence supporting the use of computer based approach in aphasia rehabilitation this approach rely on pre-applied experiences or stimulus and rules and that they cannot anticipate diverse response to these experiences or stimulus by the patients [50]. Furthermore, this approach focuses more on visual stimulation compared to other modalities.

Word retrieval cuing strategies (e.g., phonological and semantic cuing)

This is a treatment that provides phonological and semantic cues, such as the beginning sound of a word (*phonological cuing*) or contextual cues (*semantic cuing*), to prompt target word retrieval in auditory word comprehension-impaired aphasics [51,52].

Verb network strengthening treatment (VNeST)

This is an aphasia treatment used to facilitate lexical retrieval in sentence context. SLPs employ VNesT to target verbs and their roles to activate semantic networks and to improve the production of basic syntactic structures [53]. For example, a comprehension-impaired aphasic is given a verb (e.g., play) and is asked to retrieve related agents and objects (e.g., footballer–*plays–football)*.

Semantic feature analysis treatment (SFA)

This is a word retrieval treatment in which the comprehension-impaired aphasic identifies important semantic features of a target word that is difficult to retrieve. For example, if the person has difficulty retrieving the word plate, then he or she might be prompted with questions to provide information related to plate (e.g., Where is it located? [kitchen]; What is it used for? [eating]). SFA facilitate word retrieval in comprehension-impaired aphasics by activating the semantic network associated with the target word, thereby increasing the likelihood of the word being retrieved [54,55].

Consequence-based approach

This approach to treatment employs compensatory/augmentative communication strategies to facilitate communication. Residual communication skills are usually utilised under this approach. Some of these approach include:

Context-based treatment

This approach to aphasia rehabilitation for comprehension-impaired stroke patients places emphasis on creating contexts that are applicable to the patient. That is: it is best to choose or create a context that the patient is familiar and comfortable with so they will be able to participate easily and actively in communication activities of the treatment. However, this approach has its shortcomings: it is time consuming and it requires the active support of the patient's caregivers because this treatment is best done at home [56].

Social treatments

The goal of this approach is to enhance conversational skills and functional communication skills as well as boost self confidence among comprehension-impaired stroke patients rather than work on discrete linguistic skill [57]. This model is built on the social model of language acquisition rather than evidence based neuroscientific principles. Examples of therapies under this type of treatments are conversation therapy, group therapy and compensatory strategies training.

Script training

This is a functional approach to aphasia treatment that uses script knowledge (understanding, remembering, and recalling event sequences of an activity) to facilitate participation in personally relevant activities [53]. Using this approach, the SLP and comprehension-impaired aphasic develop a scripted monologue or dialogue of an activity of interest to the client and then practice it intensely until comprehension and production of the scripted words becomes automatic and effortless [58].

Reciprocal scaffolding treatment (RST)

According to ASHA [53], RST is a group treatment that addresses communication skills using natural language in meaningful social contexts. A comprehension-impaired aphasic, who has a particular skill, is given an opportunity to use premorbid knowledge and vocabulary in reciprocal teaching interactions with a group of "novices." This reciprocal interaction is beneficial for all participants. The person with aphasia has an opportunity to convey knowledge to the novices, and the novices in turn learn a new skill and provide language models during realistic interactions [59].

Non-invasive brain stimulation approach (NBSA)

This is an emerging approach in aphasia rehabilitation that utilises non-invasive direct electrical stimulation of the brain in enhancing healthy performance and language recovery in aphasic patients. Emerging treatments under this approach are:

Repetitive transcranial magnetic stimulation (rTMS)

rTMS is a noninvasive painless brain stimulation procedure that employs the use of an electromagnetic coil which is held near the scalp of the head. For aphasia rehabilitation, an electromagnetic coil is place against the forehead near the targeted language area of the brain. The coil then passes repetitive magnetic pulses to a targeted part of the brain. This induces an electrical current in specific nerve cells in the brain. It is thought that these electrical currents stimulate brain cells in a complex way that can facilitate language recovery. A considerable number of studies have reported the efficacy of rTMS in improving healthy performance and stroke recovery [60-63].

Trancranial direct current stimulation (tDCS)

Transcranial direct current stimulation (tDCS) is a new noninvasive technique which can be used for aphasia treatment. According to Fiori et al. [64], "*During tDCS, weak polarising direct currents are delivered to the cortex via two electrodes placed on the scalp. The nature of the effect depends on the polarity of the current. Generally, the anode increases cortical excitability when applied over the region of interest with the cathode above the contralateral orbit or above the shoulder [as the reference electrode], whereas the cathode decreases it, limiting the resting membrane potential.*" Studies have reported the efficacy of tDCS in improving verbal fluency [65], picture naming [66-69], naming reaction time [70], word comprehension [71], speech production [72] and word retrieval [64].

Approach emerging from basic research

Many questions remain unanswered on how principles of neuroscience can be manipulated to maximise aphasia treatment outcomes. To develop effective behavioural treatment for auditory word comprehension deficit in stroke patients, a good theoretical base which explains the functional-anatomical organisation of speech comprehension in the brain is prerequisite.

There are numerous models that attempts to explain the functional organisation of speech perception/comprehension in the brain but the Dual Stream model of speech comprehension, developed by two cognitive neuroscientists: Gregory Hickok at the University of California, Irvine, and David Poeppel at New York University [14-16], provides an influential theoretical base for understanding the neural underpinning of speech comprehension [9]. According to the Dual Stream model of speech perception, early cortical stages of speech perception are organised both hierarchically—beginning in Heschl's gyrus and projects into the superior temporal gyrus (STG) and superior temporal sulcus (STS). and bilaterally—with the two hemispheres arguably making somewhat different functional contributions. More importantly, the Dual Stream model of speech perception suggests that after the early cortical stages of speech perception have been completed, further speech processing bifurcates into two separate streams: ventral stream, "what" pathway, links phonological representations with the lexical-semantic system which aids comprehension of utterances whereas the dorsal stream, "how" pathway, leads into brain regions that are involved in converting phonological representations with the motor–articulatory system.

According to the the Dual stream model, distinct functional-anatomical components underpin the mapping of the ventral stream and dorsal stream. Two functional-anatomical components of the ventral stream include: first, the lexical interface: a transmission terminal that maps phonological representations of words into semantic representations. This function depends on the posterior middle temporal gyrus (pMTG) and posterior inferior temporal gyrus (pITG) in both hemisphere but with a leftward bias. Secondly, the combinatorial network is executed by the anterior temporal lobe (ATL) with a leftward bias which is the hub for integrating the multimodal semantic and grammatical aspects of phrases and sentences. Similar to the ventral stream, the dorsal stream has two functional-anatomical components. The "sylvian parietal temporal" (Spt) in the left hemisphere underpins the sensorimotor interface which is a relay station that maps the sound structures of words onto the corresponding motor representations. The left posterior frontal lobe underpins the articulatory network which underlies the production of utterances. According to the Dual Stream model, in summary, the ability to perceive utterances and the ability to repeat utterances or closely monitor their phonological makeup facilitate speech comprehension. This ability is executed bi-laterally with a left-ward bias.

This model re-emphasises the importance of multimodal stimuli and semantic control as integral to auditory word comprehension. This is supported by Jefferies and Lambon Ralph [73] who reports that post stroke comprehension-impaired aphasics showed significant non-verbal and multimodal deficits and consistency across different input modalities and associative errors in picture naming. The study also reports that the picture naming performance of comprehension-impaired stroke patients improved considerably with semantic-phonemic cues which suggests that comprehension-impaired stroke patients retained semantic knowledge of picture-word representation that could not be accessed without contextual support or semantic cues [73]. Lambon-Ralph, Jefferies, Patterson & Rodgers [74] investigated the group difference between patients with semantic dementia and comprehension-impaired stroke patients. The researchers observe that comprehension-impaired stroke patients performed better in semantic tasks when presented with semantic cues compared to patients with semantic dementia. The researchers report that impairment in semantic dementia arises from degradation within the network for semantic representation, whereas the impairment in semantic aphasia reflects disordered control of activation within that network.

Studies have reported multimodal semantic deficits in patients with aphasia and patients semantic dementia [73-75]. However, the anterior temporal lobe (ATL) which is the hub for integrating the multimodal semantic and grammatical aspects of phrases and sentences is spared in comprehension-impaired stroke patients [74] whereas, patients with SD manifest damaged ATL [73-75]. This implies that comprehension impaired stroke patients may benefit from aphasia therapy with multimodal semantic cues with the help of a relatively spared ATL which may serve as a strong complementary mechanism in facilitating auditory word comprehension.

CONCLUSION

This study proposes a new hypothesis for semantic treatment of auditory word comprehension impairment in stroke patients. To this effect manipulation of these principles are proposed to facilitate language recovery. They are error-shaping auditory-verbal word repetition, multimodal semantic cues/contextual support and intensity of treatment. However, more research is needed to unravel the neural substrates underpinning auditory word comprehension and discover more effective ways of maximising neuroplasticity to bring about better treatment outcomes.

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