THE ROLE OF THE RIGHT HEMISPHERE IN LANGUAGE RECOVERY AFTER STROKE

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Abstract
Aphasia is common after stroke and could be chronically disabling. The advent of functional imaging has helped in developing interest in the study of the neural mechanisms involved in language recovery post stroke. The quest to understand the dynamics of the mechanisms involved in language recovery has led to the suggestion that both left and right hemisphere are involved in the process of language recovery. Although many studies have portrayed the importance of right hemisphere homologues of language network, there is some controversy as to whether these areas in the right hemisphere support language recovery or undermine effective language recovery. Moreover, the roles of the right hemisphere, in aphasia recovery may depend upon factors such as extent of the lesion on the left hemispheric language areas, degree of rehabilitation and the recovery time course. It is important to understand the mechanisms involved in recovery of language in aphasic patients as this could provide a basis for the design of treatment models.

Key words: *Language recovery, Stroke, Right hemisphere*

INTRODUCTION

Impairment of language ability, otherwise referred to as aphasia, is commonly experienced after stroke and could be chronically disabling[1]. A recent review has reported median frequencies of 30 and 34% for aphasia following mixed strokes (ischaemic and haemorrhagic) in acute and rehabilitation settings respectively[2]. Although patients generally experience some degree of recovery, aphasia typically results from injury to the network of cortical and subcortical structures that are supplied by the middle cerebral artery in the left hemisphere[3]. It is important to understand the brain mechanisms that contribute to recovery of language in aphasic patients as this could provide a basis for the design and evaluation of treatment models.

The advent of functional imaging has helped in fanning interest in the study of the neural mechanisms involved in language recovery after stroke. Although many studies (which would be discussed) have portrayed the importance of right hemisphere homologues of language network, there is some controversy as to whether these areas in the right hemisphere support language recovery or undermine effective language recovery.

LANGUAGE NETWORK IN THE BRAIN

Language has been known to be organized in a temporo-frontal network [4]. The left hemisphere is dominant for language in more than 90% of right-handed healthy people[5].

The neural substrate of language has been known to be composed of a distributed network centred in the perisylvian region of the left hemisphere [6]. The network involves the wernicke's area in the temporal gyrus and the Broca's area in the inferior frontal gyrus of the left hemisphere of nearly all right handed people and many left handed individuals. This long held notion of language organisation has been based on behavioural deficits in patients with brain lesions. However, with advance in neuroimaging, a new functional anatomic model of auditory language processing has been proposed [4]. This model identifies two neuro-anatomic routes namely; a ventral stream and a dorsal stream. The ventral stream, which is involved in lexical-semantic processing, projects from the core auditory cortices to various temporal lobe regions. It serves for recognition of auditory input and processing of speech signals for language comprehension. On the other hand, the dorsal stream which serves for phonological processing projects from the auditory cortices to the temporo-parietal and frontal lobe articulatory networks. The dorsal stream functions as a relay between the auditory and motor processing hence mapping sound onto articulatory constructs. The dorsal stream has been proposed to be left hemisphere dominant and the ventral stream more bilaterally distributed and both pathways are said to interact under normal circumstances [7]. This dual stream model also states that the bilateral superior temporal gyri are involved in the early stages of the cortical language processing system which then diverges into the ventral and dorsal stream, .

Further studies now imply that large scale networks are necessary for comprehension and production of language[9-12].

RIGHT HEMISPHERE'S BENEFICIAL ROLE IN SUPPORTING LANGUAGE RECOVERY

The notion of laterality shift as part of language reorganisation in post stroke aphasia recovery, i.e. the concept that the hemisphere contralateral to the lesion takes over some of the language functions, has long been a debate[13]. In 1887, Barlow reported the case of a 10-year old male who experienced aphasia after a left hemispheric stroke[14]. He later regained speech only to lose it following a second symmetric right-hemisphere stroke. Similarly, the cases of two females who had global aphasia after an extensive left hemisphere stroke and who later developed a new stroke in the right hemisphere were also reported[15]. They showed a considerable language recovery with the passage of time after the first stroke but with the second stroke their languages were reported to have deteriorated. Also, left-carotid injections of amobarbital have been known to suspend language functions in normal right-handed persons. Contrastingly, it has been shown that with extensive strokes involving the left hemisphere, residual speech could be suspended by right instead of left-sided injections of amobarbital[16]. Additionally, evidence to show that the right hemisphere possessed the ability for language processing in the absence of a functional left hemisphere was shown in a nine year old who developed speech after a left hemispherectomy[17].

Giving some credence to the concept of laterality shift in post-stoke language reorganisation Leff and colleagues using Positron Emission Tomography (PET) to measure cerebral activity identified a steeper activity-word rate response in the right posterior superior temporal sulcus of patients who had recovered single word auditory comprehension after infarction of the left posterior temporal cortex[18].

A handful of more neuroimaging studies have demonstrated increased activation pattern in structures both within the ipsilateral and contralateral hemisphere in the context of post-stroke language recovery[19-21].

In contrast to most studies which have used chronic patients, a longitudinal study was conducted to investigate the neural substrates that underlie language reorganisation after stroke in fourteen patients with a mixture of aphasia due to an infarction of the left middle cerebral artery territory[22]. These patients were studied by repeated functional Magnetic Resonance Imaging (MRI) with a parallel language testing in three consecutive stages while the control subjects were scanned once. These patients showed evidence of clinical recovery in the aphasia tests. In the acute stage (mean of 1.8 days post stroke) there was a little early activation of the perilesional left hemisphere language structures while in the sub-acute stage (mean of 12.1 days post-stroke), an increase of activation in the language structures of both hemispheres was noticed but interestingly with a peak activation in the right inferior gyrus (Broca homologue). However, in the chronic phase (mean of 321 days post-stroke), when the language function had largely recovered, there was a re-shift of the peak activation to left hemisphere language areas. The early improvement of language function was highly correlated with an increase of activation in the right inferior gyrus thus showing the functional significance of right frontal areas in the sub-acute stage of language recovery. The authors thus deduced that the up-regulation of the entire language network and particularly the right inferior frontal cortex should be taken as an early mechanism. The model of three phases of language recovery after stroke was then suggested [22]. These are as follows; acute phase which is characterised by loss of function, sub-acute phase that involves up-regulation of the language network and the chronic phase that is characterised by consolidation and normalization of activation. However some have posited that the interpretation of these right inferior cortex activation are difficult given the compound aphasia score reported by the authors. They argue that the changes in this score over time may be due to the recovery of different language functions among the patients, .

Additionally, a functional imaging study of a subject with conduction aphasia showed the activation of homotopic right language areas one month after stroke, while large perilesional left hemisphere activation was noticed later after 12 months [25]. This was similar to the findings of Saur and colleagues with regard to sub-acute right hemisphere involvement which declined over time.

It is also worth noting that in patients with left hemisphere tumour the slow progression of the lesion have been demonstrated to lead to reorganisation of language function to the right hemisphere in compensation for the defect on the left [26]. This could mean that the recruitment of the right hemisphere in language recovery may also depend on the time course of the development of the lesion.

EVIDENCE OF RIGHT HEMISPHERE BENEFICIAL ROLE FROM APHASIA TREATMENT

Some functional imaging studies documenting changes in brain activation following therapy for aphasia has shown evidence for changes in neural activity involving the right or both hemispheres.

In a study involving four patients with chronic aphasia, a correlation was noticed between improvement in comprehension and increased blood flow in the right superior temporal gyrus following intense language comprehension training[27].

Furthermore, it has been suggested that some degree of participation in language function by the right hemisphere prior to therapy facilitates the effects of constraint-induced language therapy (CILT) in a study of five aphasic patients[28]. Breier and colleagues using magneto-encephalography (MEG) found that the patients who responded the most to CILT had greater activity in homotopic areas within the right hemisphere and in the posterior language areas within the left hemisphere prior to therapy. They also found that response to CILT correlated positively to the degree of pre-therapy activation within the right hemisphere instead of the left hemisphere [28]. CILT has as one of its aim increment in the effectiveness of spoken language. Hence in order to avoid the effects of muscle artefacts and motion on obtaining signal during speech production tasks with MEG, an implicit verbal recognition memory task was used; it was not clear how the verbal memory (imaging task) relates to the speech production (treatment) and how the task could be used as a marker for speech recovery. Complementarily, in a functional MRI study[29], an overt naming task was administered to a bilingual(German and French) subject with aphasia before and after receiving CILT. The treatment was in German which was the patient's dominant language. This study revealed an increased activity bilaterally which was associated with an improvement in performing naming task only in German. Two other studies were also consistent with bilateral increases with neural activity following language treatment, .

The samples in most of the above studies were small thereby discouraging the generalizability of their findings. However they have shown the possibility that at least in some patients with chronic aphasia, response to language therapy may be related to activation of the right hemisphere.

MALADAPTIVE ROLE OF THE RIGHT HEMISPHERE IN LANGUAGE RECOVERY

Increased activity in the right hemispheric homologous language areas in post stroke aphasia may not be consistent with an entirely beneficial role to language recovery, , . The presence of right hemispheric activity in post stroke aphasia may represent maladaptive or inefficient patterns of changes underlying language reorganisation

On an investigation of picture naming with functional MRI among patients with aphasia noticed an increased activation in the right hemisphere of the patient with severe impairment producing only inaccurate responses[34]. This investigation was not able to directly compare the accurate and inaccurate responses because of the blocked design experimental paradigm used. Additionally, another study[35] was undertaken in a controlled model using functional MRI to examine the role of the right hemisphere in chronic aphasic patients who had achieved good recovery but had residual aphasic symptoms affecting mainly language production. The three aphasic patients involved in the study had left-sided infarcts in the territory of the middle cerebral artery. Overt naming task was used as a measure of word-finding difficulty and increased right frontal activation was correlated with inaccurate performance, thus it was adduced that the right frontal areas may play a dysfunctional role in good language production long after the left perilesional area have regained predominance.

EVIDENCE OF RIGHT HEMISPHERE MALADAPTIVE ROLE FROM APHASIA TREATMENT

Other evidence has shown that ineffective changes in language re-organisation to the right hemisphere may interrupt the more efficient language processing by the recovering left-hemisphere language networks. Belin and colleagues[36] examined seven nonfluent aphasic patients who were successfully treated with melodic intonation therapy (MIT). Using PET it was shown that prior to MIT, right hemisphere regions homotopic to the areas activated on normal subjects were abnormally activated in response to language tasks. However, with MIT there was a re-activation of the language areas in the left hemisphere and a deactivation of the homotopic areas of the right hemisphere. Thus the activation of similar right hemisphere regions was portrayed as maladaptive and may contribute to delay in language recovery.

Other evidence from non-invasive brain stimulation on the role of the right hemisphere in post stroke language recovery

The attempt to develop supplementary treatment approaches using non-invasive brain stimulation modalities like the repetitive Transcranial magnetic Stimulation (rTMS) and transcranial direct current stimulation (tDCS) has led to some studies which further elucidates the mechanisms that underlie language recovery.

Repetitive Transcranial Magnetic Stimulation (rTMS)

Naeser and colleagues[32] applied low frequency (1Hz) inhibitory rTMS to different areas on the right hemisphere perisylvian regions of six patients with chronic nonfluent aphasia. The results varied depending on the area that the inhibitory rTMS was applied. It was noticed that stimulation of the pars triangularis (anterior aspect of the right hemisphere Broca's homologue) led to a significant and transient improvement of picture naming task with decreased reaction time. In contrast, application of the inhibitory stimulation on the pars opercularis (posterior aspect of right hemisphere Broca's homologue) led to a transient decrement on performance in picture naming task with increased reaction time.

Another work[37] in which nine patients with aphasia of different types were studied at ten days and eight weeks after stroke was carried out to test whether the right IFG was essential for language performance. Positron emission tomography was used to map out the language areas and 4Hz repetitive transcranial magnetic stimulation(rTMS) was then applied to these areas in order to suppress the activities in these areas and test their functional significance. Application of rTMS on the left IFG had a profound adverse affectation of language at both times. In contrast, it was found that rTMS applied over the right inferior gyrus (IFG) suppressed only verb generation in four patients at ten days and in two patients at eight weeks. It was then deduced that the right does not necessarily take over the function of language in language recovery rather it plays a supporting role, .

Additionally, a controlled study of subjects with chronic aphasia found that application of low frequency rTMS to the pars triangularis was associated with significant improvements in auditory comprehension, picture naming and spontaneous elicited speech[38]. In yet another study39 an improvement in the Aachen Aphasia test was demonstrated in six patients with subacute post-stroke aphasia after low frequency (1Hz) inhibitory rTMS was administered to the pars triangularis of these patients. The control group of four similar patients who received sham stimulation did not have any significant improvement. Martin and colleagues[40] however, demonstrated contrasting results in two aphasic patients who received rTMS suggesting that differences in the anatomy of the lesion may modulate the effects of rTMS as an intervention.

Trancranial Direct Current Stimulation (tDCS)

The effect of tDCS depends on the electrode that is applied to the scalp. Cathodal stimulation results in decreased cortical excitability due to hyperpolarisation while anodal stimulation leads to increased cortical excitability because of sub-threshold depolarisation[41].

Studies with tDCS have reported differences in the polarity-specific effects which is somewhat problematic for proper understanding of the effects of tDCS on aphasia14. In a study[42] involving eight patients who had aphasia after suffering an ischaemic stroke, cathodal tDCS applied to left frontotemporal cortex led to improvement in accuracy on naming task, but another study[43] applying anodal tDCS to the left frontal lobe of 10 post stroke aphasic patients also resulted in improvements in naming accuracy. These differences in polarity with beneficial effects may be due to the methodological approaches and the number of sessions employed with the latter study employing longer sessions. A more recent study[44] concluded that the effects (improvement in picture naming) of cathodal tDCS on the contra-lesional right hemisphere vary depending on the damage to the Broca's area and the arcuate fasciculus. More still needs to be known about the effects of tDCS especially its effects on the unaffected right hemisphere as this may have implications for developing treatment modalities.

Generally the findings from non-invasive brain stimulation studies in chronic post stroke aphasia patients seem to support interhemispheric communication, . This interhemispheric inhibition model proposes that there exists in the right the capacity for language processing that are homotopic to left hemisphere perisylvian structures and this language network in the right hemisphere is normally inhibited by the intercallousal fibres from the left hemisphere[14]. However in stroke aphasia, due to loss of this inhibition, the right hemisphere becomes overactive. This over- activity in turn inhibits the residual language areas in the left hemisphere thus preventing language recovery, . However the limited topograghic specificity of these noninvasive interventions creates difficulty with ascertaining precisely the areas of the brain that are affected[14].

CONCLUSION

The quest to understand the dynamics of the mechanisms involved in language recovery has led to varying accounts that are not mutually exclusive which support the involvement of both left and right hemisphere in the process of language recovery. Hence a hierarchical model[14] has been suggested which is summarised as follows: (i) recruitment of the lesioned and perilesional left hemisphere areas for language processing, (ii) acquisition, unmasking or refinement of language processing ability in the non-dominant right hemisphere, and iii) dysfunctional activation of the non-dominant hemisphere that likely interferes with recovery of language. Moreover, the roles of the right hemisphere, in aphasia recovery may depend upon a number of factors such as extent of the lesion on the left hemispheric language areas, degree of rehabilitation and the time course of the recovery[48].

Finally, with the hope for the development of better treatment models that would benefit patients recovering from post-stroke aphasia, there is need for more research that would involve larger samples and ensure greater homogeneity among patient groups studied.

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