

VOICING PERCEPTION IN PATIENTS WITH CEREBELLAR PATHOLOGIES

**Radhika (A)
Reg.No.M 9715**

**This Dissertation submitted as a part fulfilment of the Final
M.Sc, (Speech and Hearing) University of Mysore, Mysore.**


**ALL INDIA INSTITUTE OF SPEECH AND HEARING
MYSORE 570 006.**

May 1999

CERTIFICATE

This is to certify that this Dissertation entitled :
**VOICING PERCEPTION IN PATIENTS WITH
CEREBELLAR PATHOLOGIES** is the bonafide
work in part fulfilment for the degree of Master of
science (Speech and Hearing) of the student with
Register No.M9715. Mysore.

May, 1999


Dr.(Miss) S. Nikam
Director
All India Institute
of Speech and Hearing
Mysore 570 006.

CERTIFICATE

This is to certify that this Dissertation entitled
**VOICING PERCEPTION IN PATIENTS WITH
CEREBELLAR PATHOLOGIES** has been
prepared under my supervision and guidance.

Mysore
May 1999

Savithri S.R
Dr.Savithri, S.R.
Reader in Speech Sciences
All India Institute of Speech & Hearing
Mysore 570 006.

DECLARATION

This Dissertation entitled **VOICING PERCEPTION IN PATIENTS WITH CEREBELLAR PATHOLOGIES** is the result of my own study under the guidance of Dr.Savithri, S.R. Reader in Speech Science, Department of Speech Sciences, All India Institute of Speech and Hearing, Mysore and has not been submitted earlier at any University for any other diploma or degree.

Mysore

May, 1999

Reg. No.M97I5

असतोमा सद्गमय ।
तमसोमा ज्योतिर्गमय ।
मृत्योर्मा अमृतम्गमय ॥

***Research is the process that leads
a field from
fiction to facts
Darkness to Light of Knowledge
Stagnation to Progress***

***This work of mine is Dedicated to Research and
my ardent Researcher and Guide
Dr. Savithri.***

ACKNOWLEDGEMENT

This research of mine, would never been complete if I don't acknowledge all those who have been the backbone of this, helping me directly or indirectly.

My heartfelt gratitude to my guide *Dr.Savithri*,
Ma'm, without a say, you are my inspiration. You stand as an evidence for
this quote

*"A Teacher affects Eternity;
No one can tell where her influence stops"*

- Henry Adams

I thank **Dr.Nikam**, Director, All India Institute of Speech and Hearing,
Mysore for granting me permission to carry out this study.

My sincere thanks Dr.Nataraja N.P., Prof. and HOD-Speech Sciences,
AIISH, Mysore for permitting me to use the Software in Speech Science
Lab. for my research.

My special thanks goes to *Dr.Chellappan*, HOD-Institute of Neurology,
Chennai Govt.MedicalCollege, *Dr. Srinivasan, R.*, Institute of Neurology
and *Mr. Vijaya Raghtivan*, Speech Pathologist at Chennai Govt. Medical
College, Chennai for their timely help in my data collection for this research.

I will never be able to thank all my subjects enough, who with all their
problems came forward and underwent the long test procedures. *"It is
subjects like you who keeps the research going in its pace"*.

My gratitude to all my teachers at school *and* at AIISH, who have been the
ladder of knowledge.

To My Beloved Parents,

" Your Confidence in Me is the Essence of My Success."

To my Little Sisters, Annu and Dolly,

*Every page I turned
in the book of my life
I see that you have written
the best parts of my life.*

Thanks for being there at all times with me.

To all my *Uncles, Aunts, Cousins, Akkas and Bhavas,*

I can't imagine my stay in Mysore without your support.

Thanks a ton for being there during the roughest tides of my life.

My friends,

Proverb says "A Friend in Need is A Friend Indeed", but I say "A friend is always there whether you need or not, U notice him only when U need".Such are my friends Kumar and Sridhar.

Kumar, U will always be *my best friend*.

SRIDHAR. U will always be *Inspiration*.

Vandu, Abhi, Vijimma, Sanyu, & Hia,

*"The roughest tides of my life
Seemed much smoother
When our hands were
Held together".*

I love you and I will miss you all is all that I can say !

To my dear classmates of B.Sc, and M.Sc, thanks for making everyday an experience by itself. *"Will surely miss you a lot"*.

To my dear little friends,

CHIMPU,

Don't ever change !

Always be my Chimpu, for I shall always be UR Gorrs

Cheluve, Shiva, Varshu, Kuttu and Prachi,

Colours of life a brighter and each day a different shade when the day starts with you ! Love you all lots.

Ram Pravesh, my analysis would never have been complete without your help. Thanks for everything.

To dear Rajalakshmi Akka,

I am sure You would have had tough time solving all the jig-saw puzzles typing this. Hats of to your patience and thanks a ton for making this work presentable. *Akka, I will surely miss you ,keep in touch!*

TABLE OF CONTENTS

Chapter	Page No.
I INTRODUCTION	1
II REVIEW OF LITERATURE	5
III METHODOLOGY	32
IV RESULTS AND DISCUSSIONS	39
V SUMMARY AND CONCLUSIONS	47
VI REFERENCES	52

LIST OF TABLES

No.	Title	of	the	table	Page	No.
2.1	Stop Consonants in Tamil					9
2.2	Cerebellar Participation in Human Mental Function					27
3.1	Details of the Subjects Studied					33
3.2	Details of VOT Continua					34
3.3	Pairs of Tokens Generated					35
3.4	Details of CD Continua					36
4.1	50% Cross-over					39

LIST OF FIGURES

No.	Title of the Figure	Page No.
2.1	Major Fissures, Lobes and Lobules of the Cerebellum.	15a
2.2	Functional Afferent Areas of the Cerebellum	16a
2.3	Cerebro-Ponto-Cerebellar Circuit	16b
2.4	Efferent Fibres of Fastigial Nucleus showing both Ascending and Descending Pathway	1 7a
2.5	Illustration of Sonic RC and AC Fibres of Brainstem.	17b
2.6	Parts of Right IOC via OC Fibres to Areas of Left Half of Cerebellum.	18a
2.7	Distributed Modular Architecture	23
2.8	Output Channels in the Dentate	24
2.9	Newly Evolved Connections Between Cerebellum and Cerebral Cortex.	26
3.1	Waveforms of Synthetic Stimuli /ka-ga/ - VOT	34a
3.2	Waveforms of Synthetic Stimuli /ṭa-ḍa/ - VOT	34b
3.3	Waveforms of Synthetic Stimuli /ta-da/ - VOT	34c
3.4	Waveforms of Synthetic Stimuli /pa-ba/- VOT	34d
3.5	Waveforms of Synthetic Stimuli /ka-ga/ - CD	35a
3.6	Waveforms of Synthetic Stimuli /pa-ba/ - CD	35b
4.1	Pattern of Shift in Percept for Different Stimuli in VOT	39a
4.2	50% Cross-over for /ka-ga/ - VOT in Patients	41 a
4.3	50% Cross-over for /ṭa-ḍa/ - VOT in Patients	4 1b
4.4	50% Cross-over for /ta-da/ - VOT in Patients	41 c
4.5	50% Cross-over for /pa-ba/ - VOT in Patients	41 d
4.6	Waveforms of /ṭa/ in English and Tamil	44 a

शिरस्ताल्वन्तर्गतं सर्वेन्द्रियपरं मनः ।
तत्रस्थं तद्विषयानिन्द्रियाणां रसादिकान् । ।
समीपस्थान् विजानाति त्रीन् भावनांश्च नियच्छति ।
भेलसंहिता ।

Lying between the hardpalate and the skull, the indispensable structure : the brain, describes the senses like taste and controls the three radical emotions.

CHAPTER I

INTRODUCTION

One of the ironies of work on the cerebellum is that, its uniformity of architecture would seem to imply a uniformity of function, whereas its diversity of input and output means that it has many different roles in many different neural processes. The role of cerebellum in motor functions is well established, but in the new line of research, attributing non-motor functions to cerebellum is taking its turn to attract the centre of importance in research. Thus, one of the non-motor functions, cognition, and its relation with cerebellum seems to be less researched. Role of cerebellum in higher mental functions is found as one of the more neglected areas.

Perception, is one of the higher mental functions. Thus speech perception, a branch of the over all science of perception, is widely studied in most population. The various topics like basic unit of speech perception, cross language perceptual skills, cues for speech perception were and are still under study. Many temporal and spectral cues are found to be useful in the perception of speech in normals. The different changes in these parameters give rise to change in percept of the speech stimulus given.

Considering patients with cerebellar pathology, it was found that, cerebellum was more involved in motor learning (*Thompson, 1988 and 1991*). Because classical conditioning has been interpreted as procedural learning (*Solomon, Stowe and*

Pendlebury, 1989), it is of specific interest to assess the performance of cerebellar patients on other forms of procedural learning that do not concern motor performance per se and are of wider use in neuropsychology, such as perceptual or cognitive skill acquisition.

Research has emphasized the role of cerebellum in visuospatial organization, visuospatial recall, deficits in anticipatory planning in cerebellar disorder, due to its bidirectional connections with regions specialized for these tasks (*Leiner, Leiner, and Dow*, 1995). Also neuropathological and behavioural evidence emphasize the role of cerebellum in diverse higher cognitive functions (*Schmahmann and Sherman*, 1998).

Timing is another function that has been attributed to cerebellum (*Irvy and Keele*, 1989). In line with this view, patients with cerebellar dysfunction have shown impairments in motor as well as perceptual timing tasks, which required rhythmic tapping or the judgement of time intervals (*Irvy and Baldo*, 1992; *Irvy and Keele*, 1989; *Irvy, Keele and Diener*, 1988). The classical conditioning deficits described earlier have also been attributed to deficient timing mechanism (*Irvy, et al.* 1988).

Assuming the timing function of cerebellum, *Irvy and Keele* (1991) conceptualized the cerebellum as an "Internal Clock" required for temporal computations both in the motor and the perceptual domain. On the basis of their timing model, *Irvy and Keele* (1991) expected distorted phoneme-boundary effects with

respect to the voicing contrast in patients with cerebellar pathology. However, when *Irvy and Gopal* (1992) conducted a study on voicing contrast in patients with cerebellar disorders using VOT, they found a quite similar crossover from one response category i.e. /ba/ to the other i.e. /pa/ in patients with cerebellar pathology and their controls. Thus a categorical perception of voiced-voiceless distinction of initial stops seemed to be preserved. But the study was replicated with both VOT and Closure Duration by *Ackermann, (Gaber, Hertrich and Daum* (1997) using ten patients with cerebellar pathology. They used Closure Duration considering it to be a purely temporal parameter than VOT. Their results showed that patients with cerebellar pathology (Bilateral) performed worse than normals only in Closure Duration; whereas their performance in VOT continuum was found to be similar to that of normals. Hence, they concluded that, the more temporal the parameter is, the less it is perceived in patients with cerebellar pathology. They hypothesized, based on their results, that, processing of occlusion time (CD) might require a more complex mechanism comprising, among others, a cerebellar clock and also that the discrepancies of identification functions on VOT and Closure Duration are due to different underlying decoding mechanism.

This area of speech perception is less researched and needs to be probed in to for the identification of the role of cerebellum in speech perception. Hence, finding the role of cerebellum in perception of temporal parameters in speech is of basic interest. Further, the fact that other than temporal cues: aspiration: arc present for word - initial stop consonants is true for

English. In Tamil voicing is phonetic and word - initial stop consonants are unaspirated. This necessitates one to hypothesize that the listener response may be different than those studied by *Ackermann et al. (1997)*. In this context the present study was planned.

The present study aims at investigating the role of cerebellum in voicing perception when the temporal parameters (voice onset time and closure duration) are changed.

Specifically the perception of voicing in Tamil speaking patients with cerebellar pathology was compared with that of normals. It was hypothesized that the perception of voicing in patients with cerebellar pathology would be different from normals, if the cerebellum acted as an 'Internal clock' in both motor and perceptual domains.

CHAPTER II

REVIEW OF LITERATURE

This review has been organised under the following headings :

1. Speech Perception - General Remarks
2. Perception of Stop Consonants
3. Speech Perception in Clinical Population
4. Cerebellum, its Functions and Speech Perception.
5. Speech Perception in Patients With Cerebellar Pathologies.
6. Cerebellum as an Internal Clock.

1. Speech perception - General remarks

Speech may be defined as a form of oral communication in which transformation takes place by means of speech waves which are in the form of acoustic energy (*Fant, 1960*).

Perception of speech is a specialized aspect of a general human ability, the ability to seek and recognize patterns. The auditory mode is the primary mode of speech perception. The perception of speech, one or two phonemes long is mostly studied, because the listeners rather readily accept the sort of experimental situation where they are asked to simply identify brief utterances and not always meaningful words in their language.

The main aim of such studies is to understand, what goes on when people perceive speech; which areas respond to particular cues transmitted and description of the linguistic, phonetic and acoustical structure of speech (*Haggard, Amber & Callow, 1975*).

The processing of speech signals within the existing constraints of natural language has interested speech scientists for many years. The ear seems to be custom built for the purpose of detecting and analyzing sounds. The speech signals which are long spurts of a complex and constantly changing stream of sounds radiate from the speakers lips, travel in air, impinge upon the eardrum of the listener and reach the higher cortical structures through middle and inner ears and the auditory pathways. The speech signal is analysed at lower centers (below the thalamus level) to some

extent and processing of specific speech parameters and other complex acoustic features of natural stimuli begins only at the levels of Medial Geniculate Body (MGB) which is located in the thalamus (*Kiedel, Kallert, North and Humes, 1983*). The linguistic components are added only at the higher centers of the cortex to the already analysed signal to reconstruct the percept intended by the speaker. When the listener has reconstructed this signal (i.e. decoded and interpreted) speech perception is said to have occurred.

Speech sounds are varied and have numerous acoustic cues like the formants, their bandwidths and levels, fundamental frequency, energy, duration of closure, preceding Vowel Duration (PVD), burst energy & voice onset time etc.

2. Perception of Stop Consonants

Stop consonants are produced by occluding the oral cavity by an articulator. Air is held behind the articulator for sometime and is released.

The stops are special in that they represent the nonlinearity of the speech production system. They also demonstrate the redundancy of acoustic cues available to distinguish speech sounds. The nature of stop perception provides the best example of listener's use of the acoustic overlapping of phonemes in speech systems. Also, they have consistently produced evidence for phonetic level processing. They appear to be the most highly encoded speech sounds (*Day and Vigorito, 1973*) and they are the information bearing elements of speech.

Five quantitatively distinct segments can be identified for stop consonants -

1. A period of occlusion (silence/voiced)
2. A transient explosion (usually less than 20 msec) produced by shock excitation of the vocal tract upon release of occlusion.
3. A very brief (0-10 msec) period of frication as articulators separate and air is blown through a narrow constriction as in the homo-organic fricative.
4. A brief period of aspiration (2-20 msec) in which, may be detected noise excited formant transitions reflecting shifts in vocal tract resonance, as the main body of the tongue moves towards the position appropriate for the following vowel.

5. Voiced formant transitions, reflecting the final stages of the articulatory movement into the vowel during the first few cycles of laryngeal vibration.

Of these five segments, bursts and voiced formant transitions may serve as cues to place of articulation of word initial stop consonants. Voice onset time and closure duration serve as cues to voicing of stop consonants in the initial and medial position respectively.

As the present study investigates speech perceptual ability in Tamil speakers, the stop consonants of Tamil are described. Tamil is a Dravidian language, spoken by the people of Tamil Nadu in South India.

In Tamil there are 10 stop consonants as shown in Table 2.1

Unvoiced unaspirated		Voiced unaspirated
Bilabial	p	b
Dental	t	<u>d</u>
Alveolar	t	d
Retroflex	<u>t̡</u>	<u>d̡</u>
Velar	k	g

Table 2.1 : Stop consonants in Tamil.

While (the) velars and retroflex are characterized by bursts at mid frequency, the dentals and alveolars have bursts at high frequency and the bilabials have low frequency bursts.

Several important differences are found to exist between the stop consonants of Tamil and English which are as follows :

- 1) While voicing is phonemic in English, it is phonetic in Tamil.
- 2) Stop consonants appear in word-final position in English, but not in Tamil.
- 3) By rule, word-initial unvoiced stop consonants in English are aspirated, but in Tamil they are not.
- 4) In English, three places of articulation are identified for stop consonants and in Tamil, five places are identified.

Tamil is one of the languages which has voicing represented phonetically. The word-initial stop consonant is voiced and the word-medial stop consonants are unvoiced. It would be interesting to study the voicing cues in such a language.

3. Speech Perception in Clinical Population

Studies related to speech perceptual abilities in adult brain damaged patients is mostly restricted to aphasics and apraxics. Also, there seems to be very little research in the specific area of speech perception in these population. The impairment of comprehension of spoken language is observed in nearly all aphasic patients. This may reflect deficits in different levels of processing of verbal messages. The levels may be acoustic, phonetic, phonological, syntactic or semantic. Most of the studies in this population are aimed at studying the overall auditory comprehension or auditory processing deficits rather than speech perception deficits specifically.

Blumstein, Cooper, Zurif and Caramazza (1977) were the first to study the perception of VOT in aphasics. They studied perception of VOT in identification and discrimination tasks of synthetic syllables /d/ and /t/ for 15 American aphasics. Their results showed that responses of aphasics could be classified into three groups. First group consisted of eight patients whose responses were almost similar to normal controls. In second group, three patients were not able to identify or discriminate the test stimuli reliably and third group consisted of four subjects, who were not able to identify the stimuli, but performed normally on the discrimination tasks. This led Blumstein et al, to hypothesize that discrimination was preserved while the process of labelling (identification - considered to be related to linguistic skills) was the one that was disrupted in aphasics.

They found no relation between the ability of VOT perception and level of auditory language comprehension. Also, there was no relation found between the type of aphasia and VOT perception.

Barso, Casati and Vignolo (1977) examined the ability to identify synthetic CV syllable /d/, /t/ with different VOT in Italian speaking aphasics. They reported that, "in over 70% of them (aphasic), the identification of the boundary zone between voiced and voiceless consonants along the VOT continuum was either impossible or abnormal". The results of this study also showed that neither clinical type nor the level of auditory language comprehension seemed to be intimately related to the defects in VOT perception.

Gandour and Dardarananda (1982) replicated *Blumstein et al's (1977)* study in Thai aphasics. Their results showed that "the identification function of all six of the aphasic patients were abnormal". This study also supported *Blumstein et al's* study by finding no correlation between deficits in VOT perception and deficits in auditory language comprehension.

Although, the clinical type of aphasia had no correlation with VOT perception, *Wernicke's* patients generally performed poorly in this study.

Another study by *Motonubu, Tatsumi and Sasanuma (1986)*, on seventeen aphasics, found that perception of VOT was

affected in Japanese speaking aphasics, also. They attribute this confusion to the inability to assign a category label to a set of phonetic feature for a given stimulus. Again, their results also followed the same pattern of previous studies, where no relation was found between deficits in VOT perception and that in auditory language comprehension, and the type of aphasia and VOT perception deficits did not show any relation or different patterns.

A few studies have attempted to compare the perceptual and production deficits in apraxics. Study by *Hoit, Kopp and Murray* (1982) explored the relation between perception and production of VOT in apraxic subjects using the stimulus "*peas*" and '*bees*'. The results showed that "*the range of responses were very wide in apraxics and did not maintain group voiceless-voiced distinction found in normal subjects*". The results also demonstrated clearly that VOT production and perception was not related in their subjects. This dissociation between production and perception was also reported earlier in studies by *Blumstein et al.* (1977) and *Dibrell* (1977).

To summarize, perception of voicing was affected in aphasics and apraxics, but its relations with other language or motor deficits are yet to be understood.

4. Cerebellum, its Functions and Speech Perception.

Cerebellum forms the hind part of the brain and is attached to the posterior surface of pons. It is known that the phylogenetically older parts of the cerebellum interact primarily with brainstem and spinal cord, whereas the phylogenetically newer parts of cerebellum interact primarily with the cerebral cortex. Thus the current studies on the cerebellum seek to identify some universal information processing role for the uniform cerebellar architecture, while at the same time seeking to determine the special roles of the numerous different segments of the cerebellum as identified by their different input and output pathways.

4.1. Cerebro-cerebellar Communication Systems

In view of the extensive development of the cerebellar hemispheres and the cerebral cortex in mammals, it is natural to inquire whether some highly significant and unique functional interrelationship exist between them.

Overview

Evoked potential studies have made it clear that there are functional connections between the cerebral cortex and the cerebellar cortex. From this, it is known that the cerebral pathways primarily influence the intermediate and lateral zones of the contralateral cerebellum and the intermediate and lateral zones of cerebellum primarily influence on the motor area of the contralateral

cerebral cortex. The lateral zone of the cerebellum receives inputs from large areas of cerebral cortex, including many association areas as well as the sensorimotor area. The intermediate zone, on the other hand receives its inputs primarily from the sensorimotor cortex. Since the cerebrocerebellar and the cerebellocerebral influences are both primarily crossed, there is apparently a closed sensorimotor cerebellar sensorimotor loop through the intermediate zone and a more open association, sensori-motor cerebellar sensorimotor loop through lateral cerebellum (Fig. 2.1 and 2.2).

4.2 Cerebro-Cerebellar Pathways

The main outflow from the cerebral cortex is contained in the pyramidal tract (PT) and that the messages traveling along this tract are important for the skilled usage of the musculature. The main portion of the PT arises from motor cortex and nearby cortical areas. Before the PT fibres reach the spinal cord, they give off collaterals that innervate many brainstem nuclei, some of which project to the cerebellum.

Electrophysiological evidence has confirmed that the cerebrocerebellar influences are mediated by the pyramidal tract and the accompanying corticobulbar fibres. Since both mossy and climbing fibre responses were induced by stimulating medullary pyramid caudal to pre-cerebellar nuclei, it was concluded that the cerebrocerebellar relay nuclei are innervated by corticospinal collaterals as well as cortico-bulbar terminals (*Allen et al. 1974*).

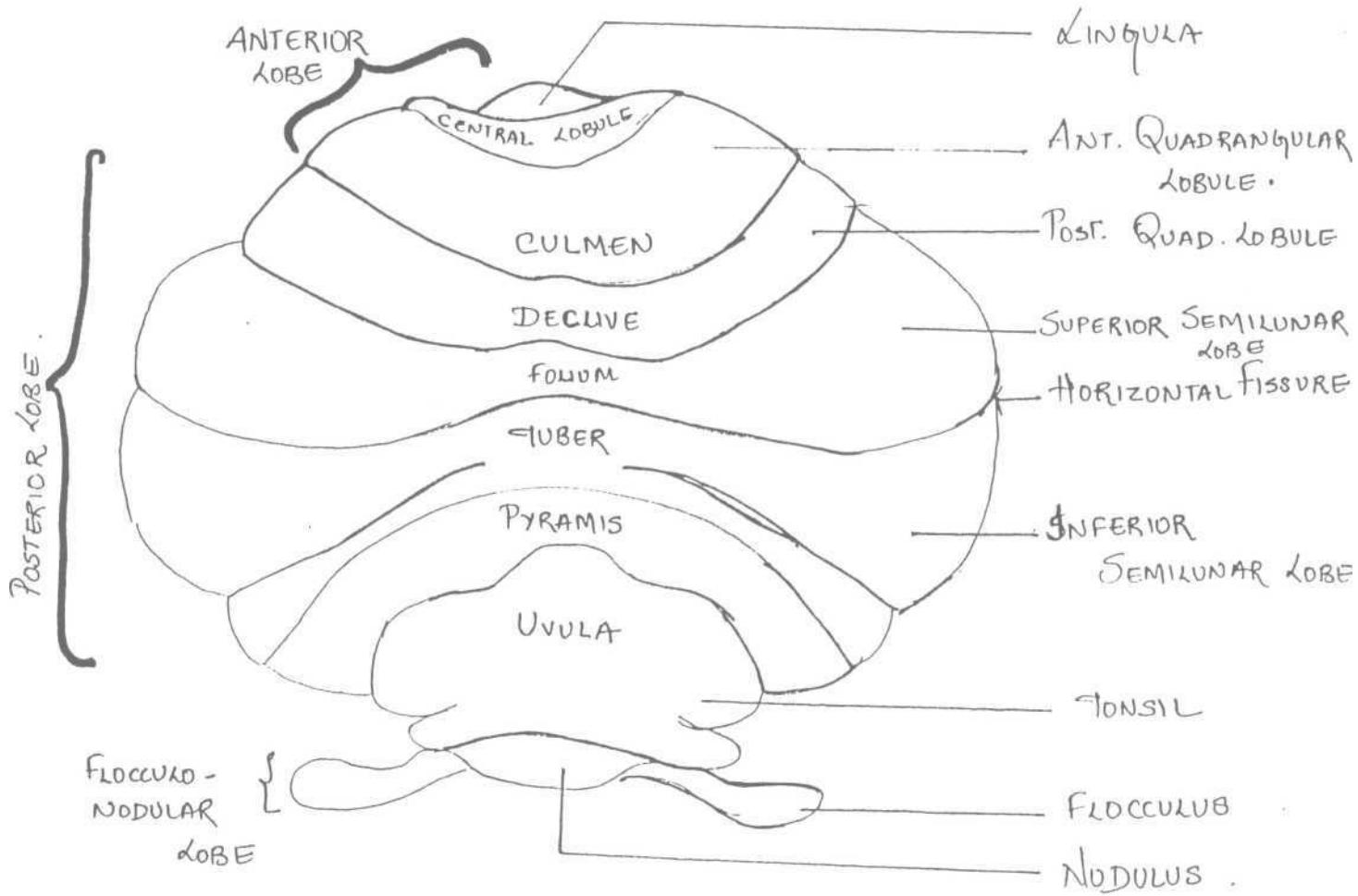


Fig. 2.1 Major Fissures, Lobes and Lobules of the Cerebellum.

Along with this, several brainstem nuclei have been shown to receive cortical inputs and also to project to the cerebellum; notably, the pontine nuclei (PN), the inferior olive (IO) and lateral reticular nuclei (LRN). It is generally concluded that the inferior olive is the principal source of climbing fibres (*Allen, et al. 1974*) (Fig.2.6).

All other precerebellar relay nuclei send fibres that terminate as mossy fibres. Of these, the pontine and lateral reticular nuclei are considered to be the most important cerebrocerebellar relays on the basis of number of fibres that they project to the cerebellum and the number of cortical fibres terminating within the nuclei. Since the cerebro-ponto - cerebellar pathway (Fig.2.3) enters the cerebellum through the brachium pontis and the cerebro-reticulo - cerebellar pathway (Fig.2.5) enters via the restiform body, it has been possible to compare the contributions of these two pathways by creating electrolytic lesions through the electrodes stereo taxically inserted into these peduncles. This approach shows that with cerebral stimulation approximately half of the mossy fiber input to the pass intermedia and vermis of anterior lobe is carried by each of these two pathways, while nearly all that to the hemisphere is carried by the cerebro-ponto-cerebellar pathway (*Allen et al. 1974*) (Fig.2.3).

4.3 Pontine Nuclei

This may be divided into two components -

- a) more ventrally located basilar pons or pontine gray.
- b) the nucleus reticularis tegmenti pontis (NRTP)

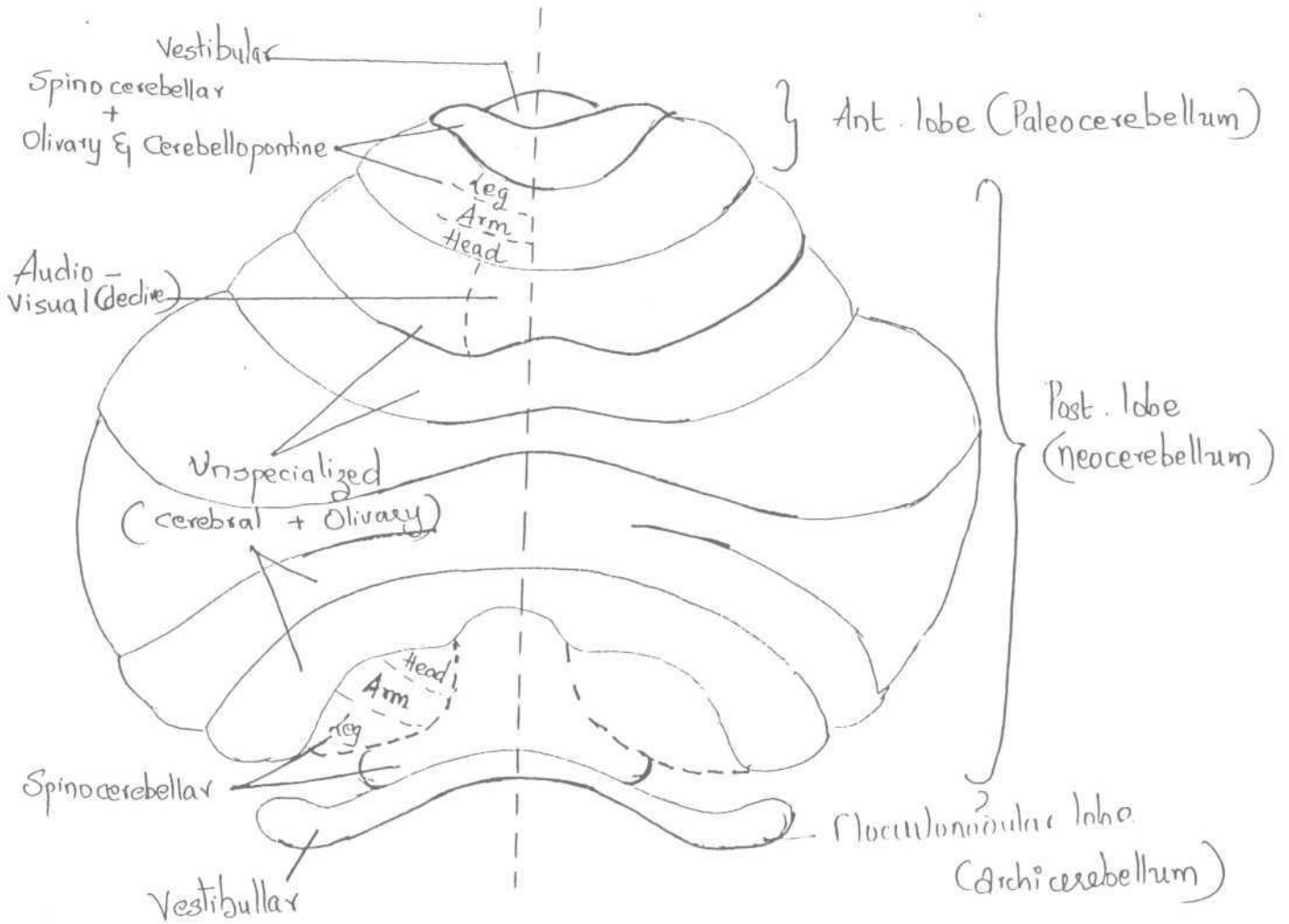


Fig. 2.2 Functional Afferent Areas of the Cerebellum

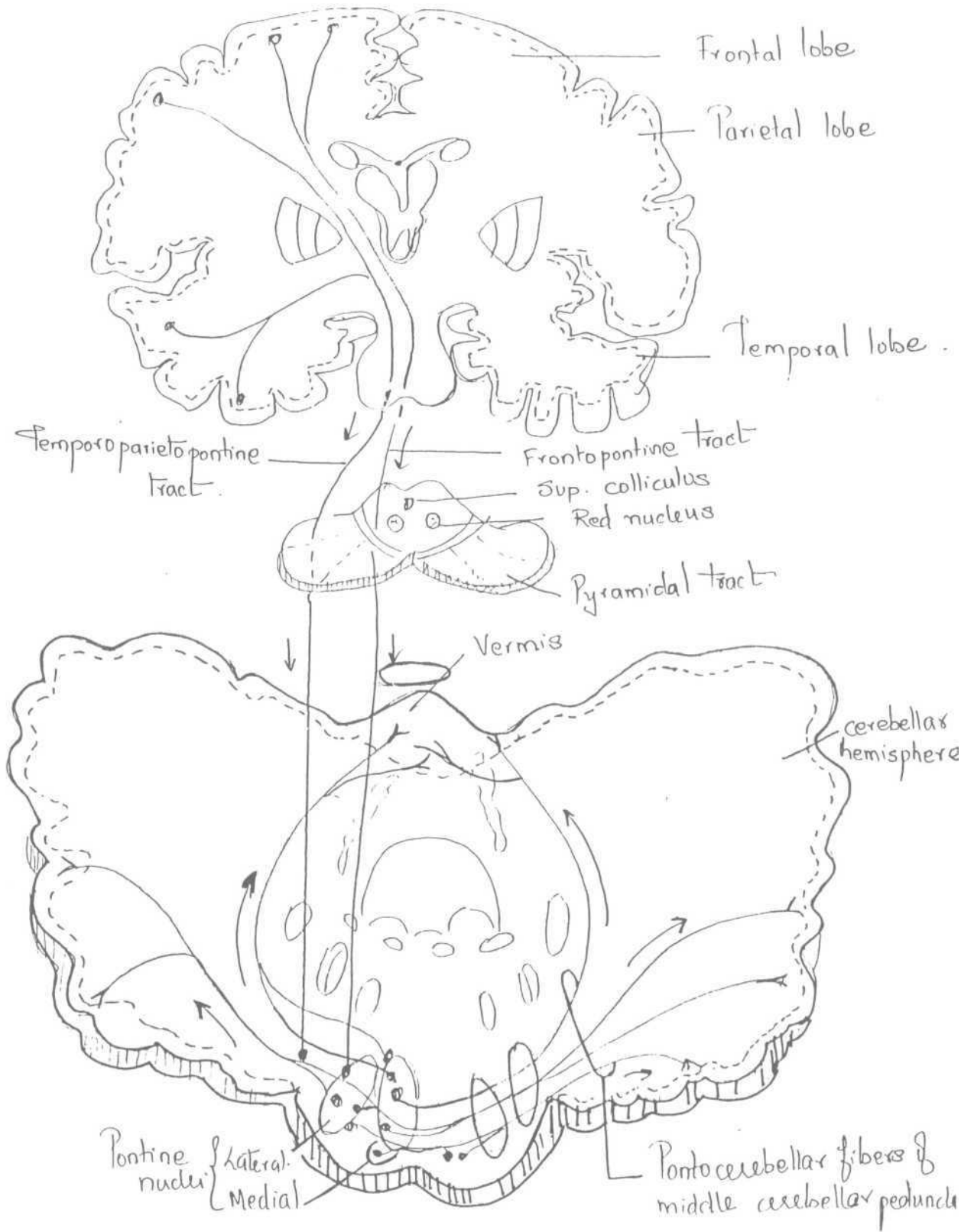


Fig. 2.3 Cerebro - Ponto - Cerebellar Circuit

Both of these pontine groups receive PT fibres and project to the cerebellum through the brachium pontis. Pontine gray receives fibres from nearly the whole cerebral cortex and each region of the cerebral cortex terminates in a specific zone of the ipsilateral pontine gray, with limited overlap of different cortical areas onto a given pontine zone. By contrast, only restricted regions of the cerebral cortex terminate in NRTP and the cortical overlap onto a given zone in the NRTP is more extensive, suggesting that more integration of cortical information takes place along this route to the cerebellum. Also, since these two regions are of different embryological origin and are cyto architectonically different, it is likely that they have different functional significance (Fig.2.3).

4.4 Inferior Olive

The inferior olive is divided into the principal nucleus and the dorsal and medial accessory nuclei. Portions of these nuclei serve as relays for cortically induced climbing fibre responses.

By comparison with pontine neurons, the inferior olivary neurons seem capable of transmitting only low frequency bursts that exert an intense effect on its target neuron, the Purkinje cells. Nearly all the olivocerebellar fibres cross the midline before entering the contralateral cerebellum through the restiform body. Both the cortico-olivary and olivocerebellar links are found to be relatively slow conducting, with the consequence that the cortico-olivocerebellar pathway becomes slow.

17a

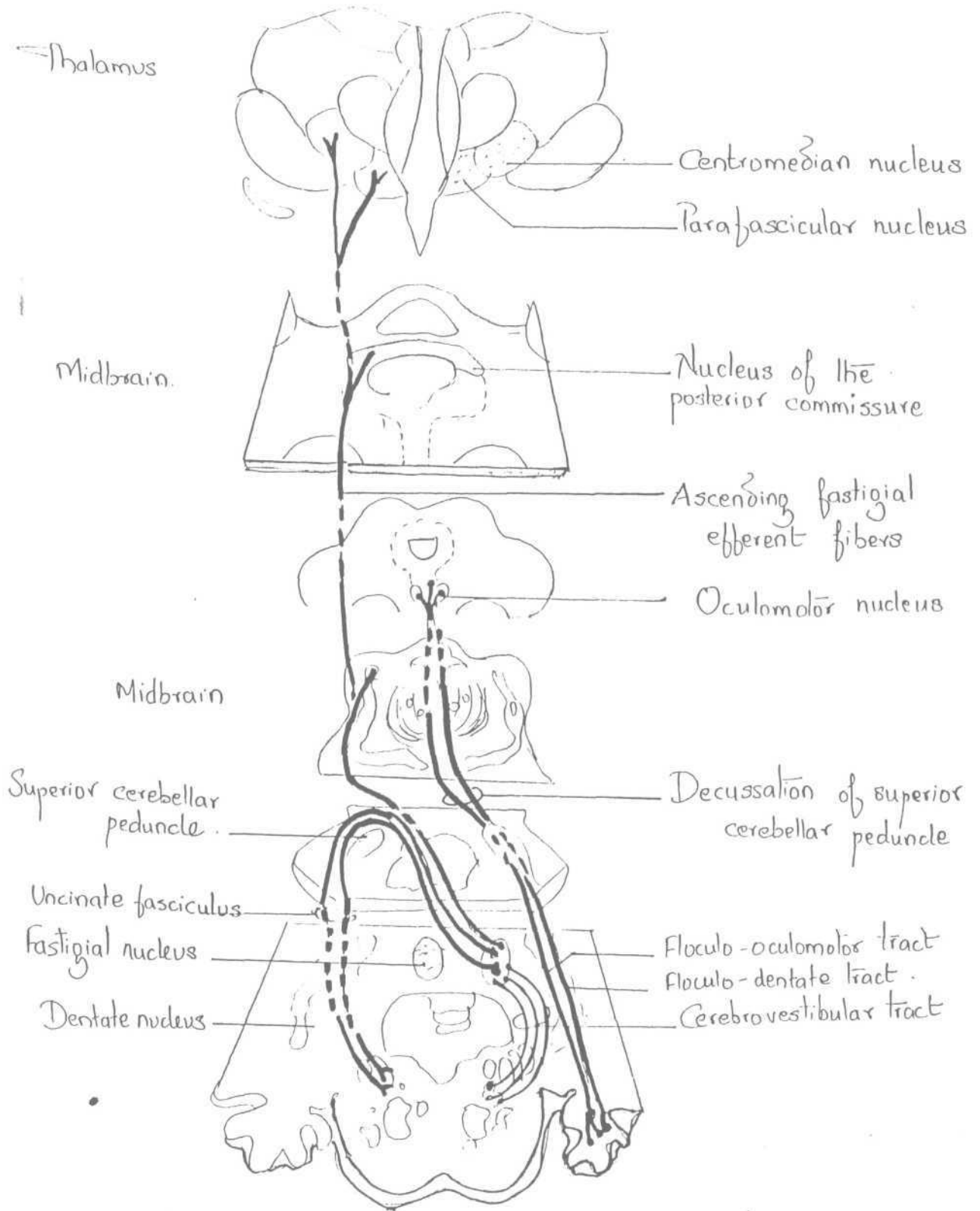


Fig. 2.4 Efferent Fibres of Fastigial Nucleus showing both Ascending and Descending Pathway.

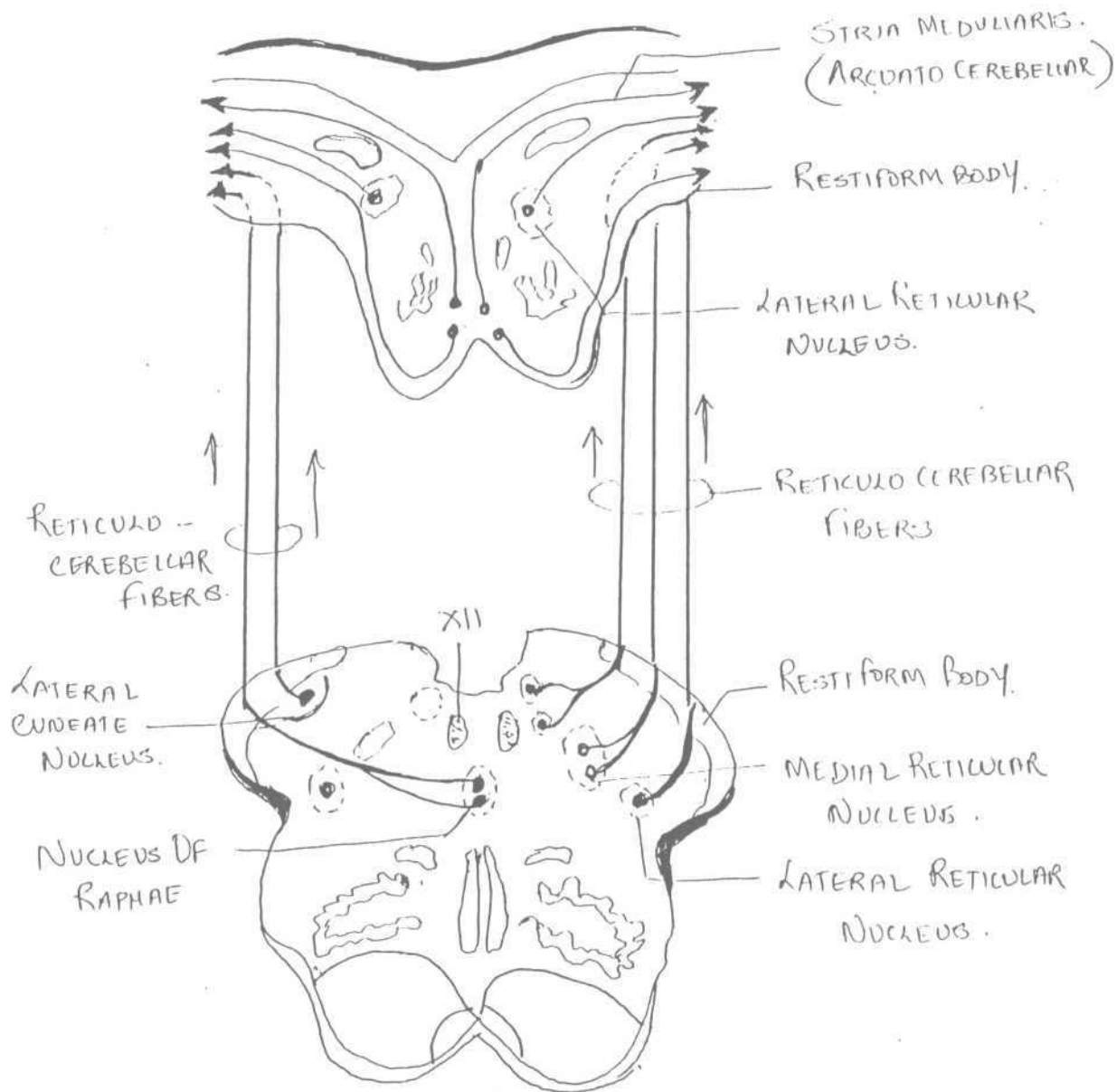


Fig. 2.5 Illustration of some RC and AC fibres of brainstem

The principle nucleus projects to the cerebellar hemisphere, including the paramedian lobule, whereas the cortico-olivary inputs to the pars intermedia of the anterior lobe and vermis are relayed in the dorsal and medial accessory nuclei (Fig.2.6).

4.5 Lateral Reticular Nucleus (LRN)

LRN is located in the ventrolateral medulla immediately caudal to the inferior olive. The LRN is divided into a parvicellular portion a magnocellular portion and a subtrigeminal portion. *Brodal, et al. (1972)* have shown that only the magnocellular portion receives a projection from the cerebral cortex and this is restricted to the contralateral pericruciate region in the cat. In contrast to the cortico pontine projection, those authors were unable to find a somatotopical projection from the cerebral cortex. A finding in the study of LRN has been that these neurons are relatively difficult to activate from the cerebral cortex (*Kittai, Defrance, Hatada and Kennedy, 1967*). Presumably most neurons are activated in directly either via cortico rubro LRN pathway or other polysynaptic pathways. One characteristic feature of the LRN responses to cortical (and nerve) stimulation is a strong inhibition that may follow the excitation or appear without preceding excitation (*Rosen and Scheid, 1969*). *Bruckmoser et al. (1969)*, observing the differential effects of pyramidal tract lesions on cortically induced excitation and inhibition of LRN neurons, concluded that pyramidal pathways play a large role in the excitation but that the inhibitory influence is mediated by a non pyramidal pathway passing through the midbrain in the trapezoid body region (Fig.2.5).

18a

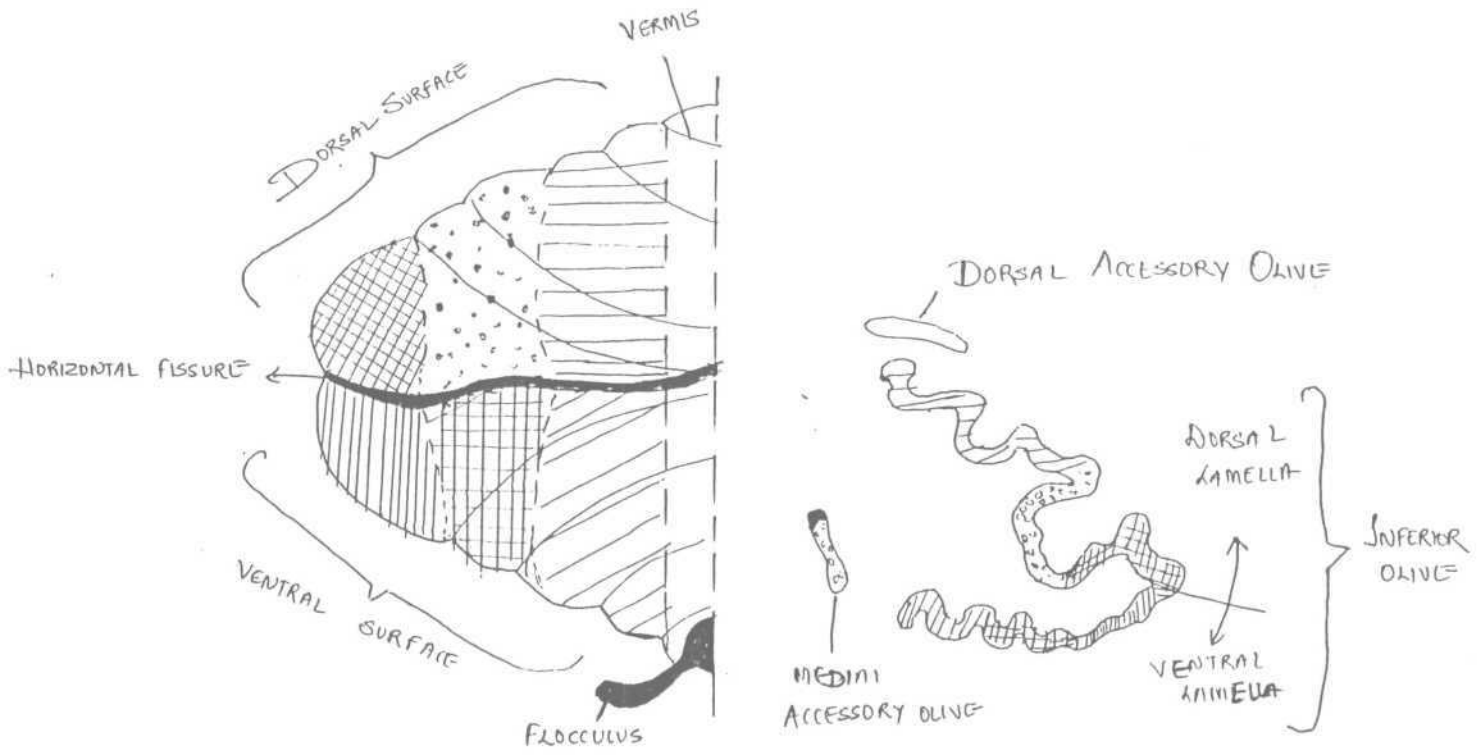


Fig. 2.6 Parts of Right IOC via OC Fibres to Areas of Left Half of Cerebellum.

The LRN projects through the ipsilateral restiform body to the cerebellum. *Brodal and Jansen* (1969), concluded that both the parvicellular and magnocellular divisions project to the whole ipsilateral hemi-cerebellum except the flocculus and nodules, which receive input from the subtrigeminal division. They concluded that parvicellular division projects primarily to the vermis and the magnocellular to the paravermian and lateral zone, although none of their lesions was restricted to the lateral zone. *Clendenin et al.* (1955), have shown that very few LRN neurons project to the cerebellar hemispheres. Therefore, it is likely that the magnocellular division projects primarily to the intermediate zone of the cerebellum including the paramedian lobule.

4.6 Other Relay Nuclei

Other brainstem nuclei that receive cortical inputs and project to the cerebellum, making small contributions to the cerebro-cerebellar pathways, are the paramedian reticular nuclei (PMRN), perihypoglossal nuclei (PHN), and the external cuneate nucleus. These fibres enter the cerebellum through the restiform body with slightly more than half the fibres projecting ipsilaterally.

There is convincing evidence for involvement of cerebellum in motor learning. Animal studies by *Thompson* (1989, 1991) have shown that classical conditioning of a specific motor response, is disrupted by cerebellar lesion, whereas the reflex unconditioned responses remain unaffected. Because classical conditioning has been interpreted as procedural learning (eg

Solomon et al. 1989), it is of specific interest to assess the performance of cerebellar patients on other forms of procedural learning that do not concern motor performance per se and are of wider use in neuropsychology, such as perceptual or cognitive skill acquisition.

Patients with cerebellar damage have been reported to perform worse than controls on visuomotor prism adaptation task (*Weiner, Hallett and Funkenstein, 1983*) and motor tracing tasks (*Sanes, Dimitrow and Hallett, (1990)*). These studies demonstrate the contribution of the cerebellum to the acquisition of motor skills (i.e.) to adaptive, long term processes of motor control and integration of sensory inputs with motor demands.

Some researchers have emphasized the role of cerebellum in visuospatial organization, which is thought to be mediated by cerebellar-parietal association area loops (*Sasaki et al. 1979*).

4.7 Cerebellum and Cognition

Historically, the cerebellum has been thought of as a structure that coordinates movements. Accordingly, the cerebellum is proposed to be primarily concerned with coordination in skilled voluntary movement as well as control of motor tone, posture and gait (*Holmes, 1939; Ito, 1984*). However, in the past decade, a growing body of empirical data, largely derived from functional neuroimaging studies and neuropsychological studies, have

implicated the role of cerebellum in diverse higher cognitive functions (*Leiner, et al. 1995*). *Kish, et al. (1988)* and *Bracke-Tolkmitt et al. (1989)* described difficulties with concept formation, learning of paired-associated and generalized intellectual slowing in patients with olivo-ponto-cerebellar atrophy.

These theoretical accounts are based on two major lines of evidence:

First, the cerebellum is extensively connected with association areas of the frontal and parietal cortex (*Sasaki, et al. 1979*), indicating "*cerebro- cerebellar learning loops*" and the possibility of cerebellar influence on cognitive processes (*Leiner, et al. 1986*).

Second, an increasing number of researchers have postulated cognitive deficits extending beyond impaired motor control in patients with cerebellar pathology (*Bracke-Tolkmitt, et al. 1989; Leiner, et al. 1986*).

Impairments in visuospatial recall and on visuo spatial manipulations in 3-dimensional space have been observed in patients with cerebellar lesions (*Bracke-Tolkmitt et al. 1989; Wallesch and Horn, 1990*). Also improvements in visuospatial organization in association with improvements in cerebellar ataxia, have been reported (*Botez, Gravel, Attig and Vezina, 1985*).

Other researchers have emphasized the importance of connections between the cerebellum and frontal cortex via the thalamic nuclei (*Sasaki et al.* 1979). *Leiner et al.* (1986) reported deficits in anticipatory planning, a frontal lobe function, in a patient with unilateral cerebellar damage. Also, 'mutism' in unilateral cerebellar damage was reported, which turned to subsequent dysarthria (van Dongen, Catsman, Berrewetz & Ven, Mousik, 1994). *Bracke-Tolkmitt et al.* (1989) described difficulties with concept formation, learning of paired associates, and generalized intellectual slowing in patients with olivo-ponto cerebellar atrophy. Patients with cerebellar cortical atrophy were found to have impaired executive function demonstrated by increased planning time when performing the lower of Hanoi Test (*Grafman et al.* 1992).

Linguistic processing was impaired in patients with right cerebellar infarction as evidenced by agrammatism in one case (*Silveri et al.* 1994) and impaired error detection and practice-related learning of a verb for noun generation task (*Fiez et al.* 1992). *Honk* (1997) proposed a distributed modular architecture, explaining the role of a cerebellum and basal ganglia in cognitive information processing. (Fig. 2.7).

Purkinje cells receive input from cortico-ponto-cerebellar pathway and a specialized training signal from climbing fibres (CF).

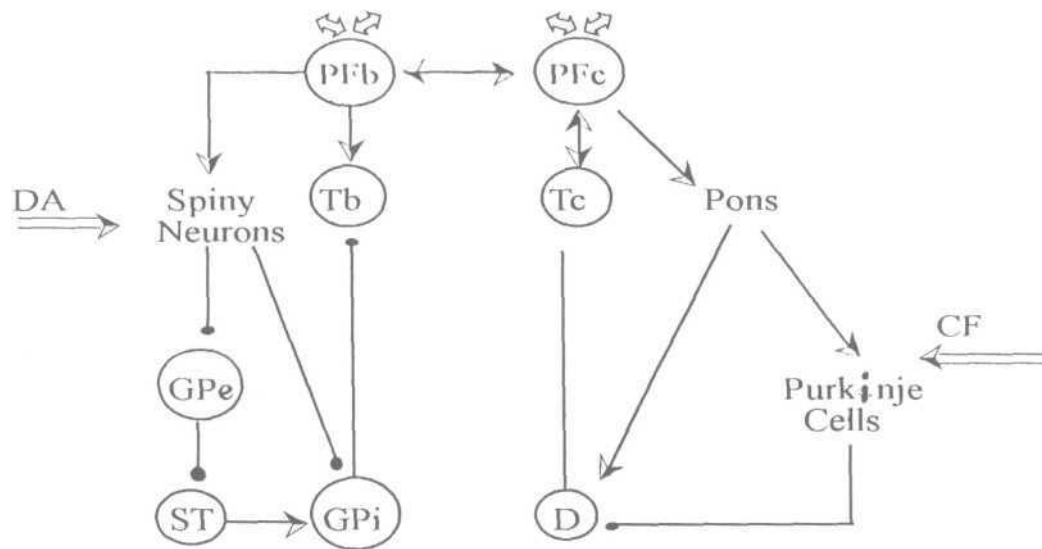


Fig. 2.7 : Distributed Modular Architecture (*Honk, 1997*)

- Inhibitory connections
- Excitatory connections

PFb and Fc - 2 frontal cortical columns

Fb - Thalamic region

[PFb is connected to Basal Ganglia via Fb)

Pc is connected to cerebellum via Fc

Fc - Thalamic region.

Spiny neurons in striatum receive convergent cortico-striatal afferents along with.

D- Dentate Nucleus

GPe - external division of globus pallidus

GPi - Internal division of globus pallidus

ST - Subthalamic nucleus.

4.8 Cerebellum and Cognition : Anatomical Evidence

On the role of cerebellum in cognitive signal processing, studies have highlighted the importance of widespread cerebello cerebral connections. In research on the neural basis of cognitive and language skills, one of the large structures in human brain has often been over looked. This structure is located in the lateral part

of the human cerebellum, which enlarged enormously in the course of hominid evolution.

The lateral part of cerebellar cortex sends its output to a lateral nucleus, called dentate nucleus in humans, which is embedded in the white matter beneath the cortex. With evolution, this nuclei underwent significant differentiation and formed neodentate nucleus. Neurosurgeons have provided a provocative piece of evidence by reporting that lesion, when placed in the neodentate failed to produce some classical motor signs of cerebellar dysfunction, which leads us to think neodentate might be performing non-motor function. Neodentate sends outputs to structures located in widely separate locations in brainstem, thalamus and in cerebral cortex. The expanded connections from cerebellum to cerebral cortex and from cortex to cerebellum helps to provide this system with expanded cognitive and language abilities.

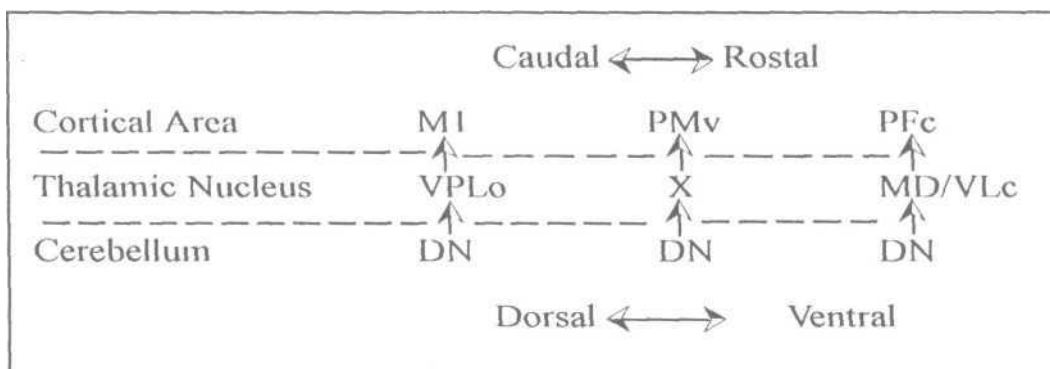


Fig. 2.8 : Output channels in the dentate.

Regions of the motor cortex (M I), premotor cortex (Pv) and Prefrontal cortex (PFc) are each the target, via the thalamus, of projections from distinct regions of the dentate VLC - Ventralis lateral is pars caudalis VPLo - Posterior ventral is pars oralis.

4.9 Neodentate Connections

Results of study by neurosurgeons, show that, in humans, the primary target, the neodentate projection, is the frontal lobe. This is known to have enlarged in the course of evolution, both in its posterior areas (motor areas) and its anterior areas (prefrontal association areas), concomitantly with cerebellar enlargement. These particularly reach area No. 44, 45, 4 and 6 and area No.8 in superior prefrontal cortex. These were earlier related to function motoric nature but is now found to be broader. This expanded view of their functions is based on imaging studies and on neurosurgical reports. Area 8 which was initially regarded as a motor area; seem to be activated when human listen to verbal information. Broca's prefrontal area and adjacent prefrontal areas seem to be involved in processes of word finding, which are regarded as cognitive processes. Newly evolved connections between cerebellum and cerebral cortex are show in Fig.2.10. Broca's prefrontal area and adjacent prefrontal area seem to be involved in processes of word finding, which are regarded as cognitive processes. In such cognitive word processing, the lateral cerebellum evidently participates.

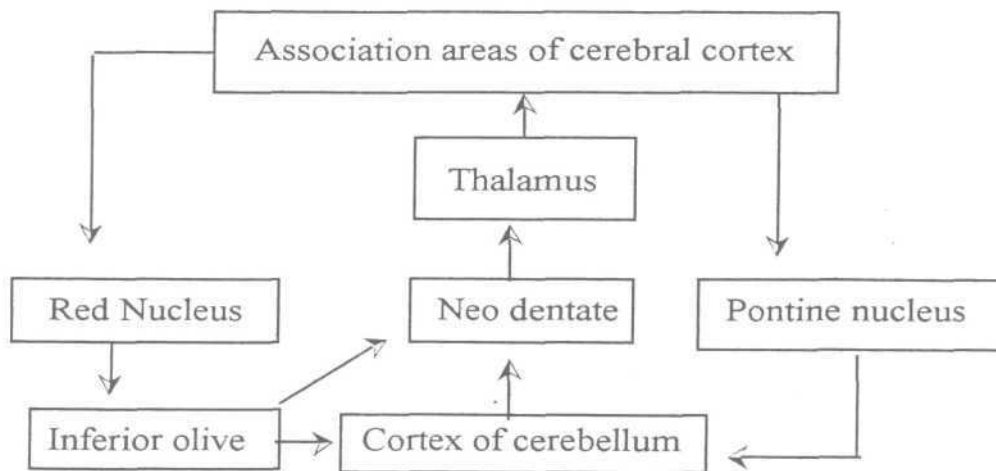


Fig. 2.9 : Newly evolved connections between cerebellum and cerebral cortex

Also data on PET scans, and neuroimaging studies showed activation of posterior lateral part of the cerebellum during both mental counting and the mental imagery.

Also with its connections to limbic parts of the brain, the cerebellum can modulate emotional and vegetative functions (Ryding, *et al.* 1993) and when connected to the cognitive parts of the frontal cortex, cerebellum can also improve cognitive processes that are associated with human language.

Data on cerebellar participation in cognitive and language functions are summarized in Table 2.1

Sl.No.	Subjects	Published Data	Authors
1.	Children with cerebellar damage due to surgical resection.	Cognitive deficit in shifting attention rapidly between sensory modalities	Akshoomoff etal.(1992)
2.	Adult patient with cerebellar degeneration	Deficits in verbal & non-verbal intelligence, in verbal associative learning and in visuospatial skills.	Akshoomoff etal. (1992)
3.	Cerebellar Atrophy	Deficits in word retrieval -	Appollonio etal. (1993)
4.	Children whose cerebellum is normal but cerebrum is reduced.	Good linguistic skills	Bellugi, etal.(1994)
5.	Patients with bilateral or unilateral cerebellar damage.	Deficits in visuo spatial organisation in cognitive planning & in speech of information processing	Botez. etal.(1992)
6.	Patients with cerebellar lesions or atrophy	Deficits in verbal associative language, in spatial and general intelligence.	Bracker-Tolkmitt, etal.(1989)
7.	Patients with cerebellar atrophy	Deficits in cognitive Planning Deficits in cognitive planning	Grafman, etal.(1992) Grafman, etal. (1992)
8.	Patients with cerebellar lesions.	Impaired in judging time interval & in judging velocity of moving stimuli.	Irvy, et al. (1992)
9.	Cerebellar Atrophy	Deficits in procedural language	Pasubal-Leone et al. (1993)
10.	Adult patient with a right side cerebellar infarct.	Impaired non-motor Language and error development	Peterson etal.(1993)
11.	Normal adult, PET scans	Cerebellar activation during word processing.	Peterson, etal. (1993)
12.	Normal adults, SPECT scans	Cerebellar activation during mental imagery	Ryding, etal (1993)
13.	Patients with lesions in the left neocerebellum	Deficits in cognitive operations in 3-dimensional space	Wallesch etal.(1990)

Table.2.1 :Cerebellar participation in human mental function

A study done by *Kim et al.* (1994) in which MRI was used to examine the involvement of dentate nucleus of cerebellum in cognitive operations, provides support for the concept that the computational role of cerebellum is applied not only to the control of movement but also to cognitive functions.

Timing is another function that has been attributed to the cerebellum (*Irvy and Keele, 1989*). In line with this view, patients with cerebellar dysfunction have shown impairments in motor as well as perceptual timing tasks, which required rhythmic tapping or the judgement of time intervals. As concerns perceptual processes, *Irvy and Keele* (1989) documented for the first time that cerebellar disorders may interrupt the ability to estimate durations demarcated by pairs of auditory clicks. Patients with cerebellar damage performed worse than normal controls. A later experiment revealed impaired judgements of the velocity of a moving stimuli-a task which also required precise timing in cerebellar subjects (*Irvy, Keele and Diener, 1998*).

5. Speech Perception in Patients With Cerebellar Pathologies

When perception of speech is considered, timing aspect becomes more essential. Perceived phonetic features depend, among others, the durational parameters of the acoustic signal such as VOT (*Lisker and Abramson, 1964*). It is well established that continua of speech utterances varying in VOT of word-initial stop consonant are perceived categorically giving rise to an abrupt transition between two response categories (*Lieberman et al. 1961*).

On the basis of timing model, it is expected that the phoneme - boundary effects may be distorted with respect to voicing contrast in cerebellar disorders. In contrast to this *Irvy and Gopal (1992)* reported a similar crossover from one category to another in both normals and in cerebellar disordered. Using a series of monosyllabic stimuli with systematically varied VOT (end points -10 and +70 ms), (i.e.) /ba/ and /pa/ as stimuli, they reported that categorical perception of voiced-voiceless distinction of initial stops seemed to be preserved.

These authors also hypothesized that the identification of speech sounds by means of durational parameters does not depend upon the assumed cerebellar clock. But it should be noted, however, that listeners integrate a variety of acoustic cues in order to extract phonetic features from the speech signal (*Repp, Liberman, Eccardt and Pesetsky, 1978*). Thus based on the study by *Miller et al. (1976)*, identification of voiced and voiceless stops, respectively

does not necessarily require the computation of durational parameters but might depend on the detection of unharmonic acoustic energy preceding vowel onset. Cerebellar patients may thus, be able to perceive voicing contrasts despite of impaired internal clock mechanisms.

Hence, in order to test whether cerebellum contributes to temporal computations during speech perception, stimuli varying in a purely durational parameter are required. A study by *Ackermann et al.* (1997) investigated the perception of stops using VOT and CD as parameters in patients with cerebellar pathologies.

The words 'Tick' and 'Dick' were considered as stimuli for VOT and 'Boten' and 'Boden' for the CD continua. Results indicated that, in the identification of stops in VOT continua, both cerebellar patients and their controls produced, in accordance with findings of *Irvy and Gopal* (1992) - where both the groups were reported to show a rather abrupt transition from one response type to other i.e. a pattern indicating categorical perception.

But, in results of CD continua, the subjects with cerebellar atrophy i.e. bilateral pathology, were reported to have not shown a discernible phoneme-boundary effect. But it was reported that two subjects with unilateral cerebellar lesion behaved similar to the normal controls. It was concluded that perception of linguistically relevant intervals, seems to be impaired in bilateral cerebellar disorders, if the stimuli did not provide further task

relevant cues. These findings were reported to be compatible with the hypothesis give by *Irvy and Keele* (1991).

In summary, the impairments found to be associated with cerebellar dysfunction includes deficits on verbal and performance IQ verbal learning, visuospatial memory, conditional associative learning, anticipatory planning and manipulation and timing (*Botez, et al.* 1985; *Bracke-Tolkmitt et al.* 1989; *Leiner et al.* 1986; *Wallesch and Horn,* 1990).

6. Cerebellum as an Internal Clock

Since at least some cerebellar motor deficits can be considered to reflect disordered central timing mechanism, *Irvy and Keele* (1991) conceptualised the cerebellum as an "Internal clock" required for temporal computations both in motor and perceptual domains.

This review has shown perceptual impairment for temporal parameters in patients with cerebellar pathologies. It is of interest to investigate these in languages like Tamil or Kannada which do not have aspiration as a cue for word - initial unvoiced stop consonants. In this context, the present study aims to investigate the speech perceptual abilities in Tamil speaking patients with cerebellar pathologies .

CHAPTER III

METHODOLOGY

Subjects

A total of ten cerebellar dysarthrics diagnosed by Neurologists based on the symptoms and the CT and MRI reports formed the experimental group. Their age ranged from 24 to 69 years. All the subjects were native Tamil Speakers. The control group constituted often age matched normal (normal speech and hearing abilities) Tamil speakers. Table 3.1 shows the subject details.

Material

Two temporal parameters, voice onset time (henceforth VOT) and closure duration (henceforth CD) were chosen for the study. VOT - is the time difference between the release of the articulator and the onset of voicing (*Lisker and Abramson, 1964*). CD - is the time duration for which the oral tract is closed during the production of stop consonants.

For VOT, four voiced unaspirated stop consonants *in* the initial position of the CV syllable consisting vowel /a/ were selected. They were the bilabial /b/, retroflex /ɖ/, dental /d/ and the velar /g/.

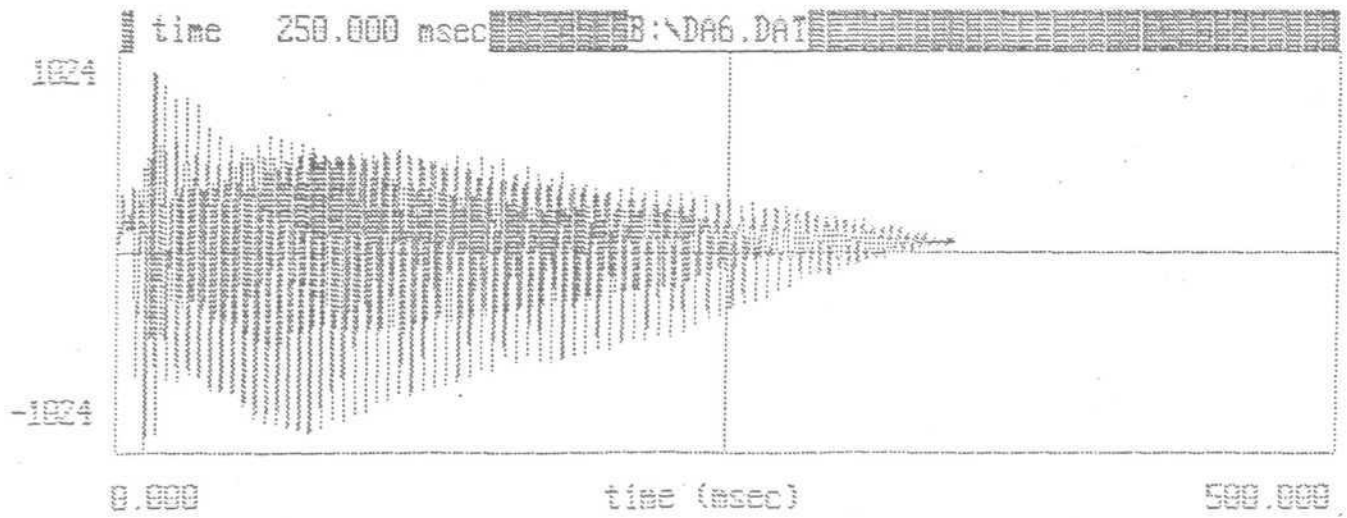
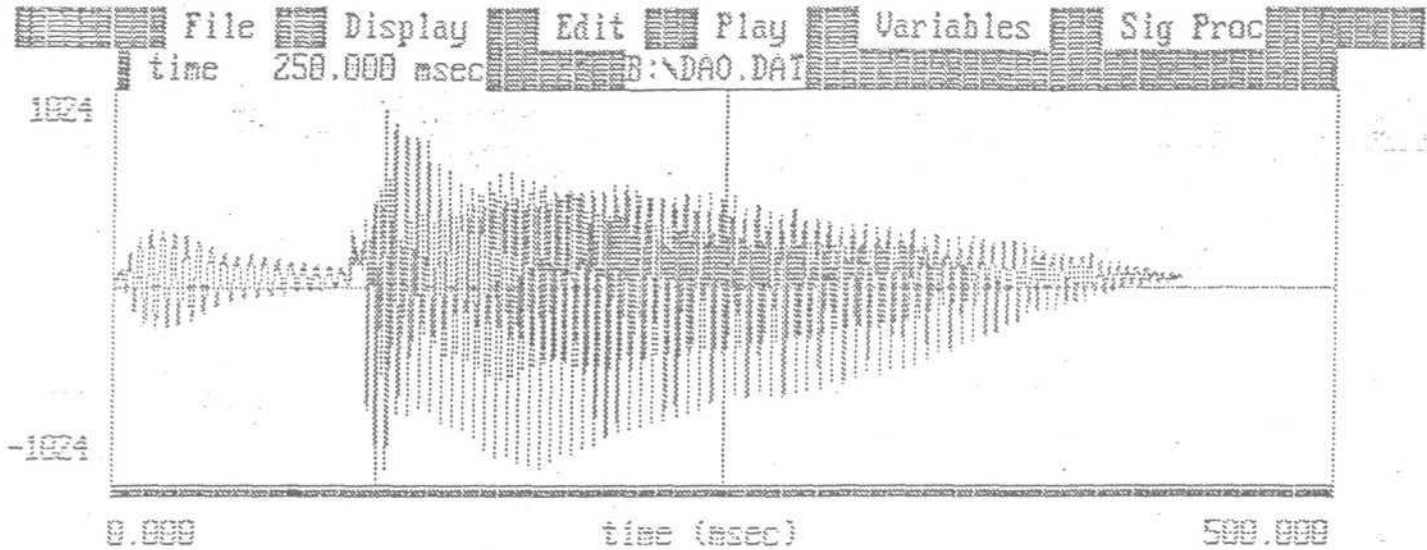
Sub.	Age/ sex	Diagnosis	CT and MRI Reports
1.	57/M	Cerebellar atrophy	Involvement of midbrain structures initial stages. Right cerebellar hemisphere atrophy
2.	35/M	Cerebellar atrophy	Normal structure and contents in serial axial section (cortex). Lateral 3-4 ventricles normal. Brainstem - normal. Cerebellum both hemispheres show atrophic changes Rest of brain parenchyma normal.
3.	51/F	Diffuse cerebellar atrophy ?(demyelination)	Atrophic changes in both cerebella hemispheres
4.	49/M	Cerebellar atrophy	Demyelination in cerebellar hemispheres.
5.	69/M	Cerebellar atrophy	Not available.
6.	58/M	Diffused Cerebellar atrophy	Both cerebellar hemispheres atrophied.
7.	24/M	Post traumatic Cerebellar atrophy	Hypodense area with in the region of right cerebellar hemisphere.
8.	45/M	Post surgical Cerebellar - dysfunction (left hemisphere)	No atrophic changes in right cerebellar hemispheres.
9.	59/M	Surgical removal of right cerebellar hemisphere	Post traumatic injury in cerebellum.
10.	32/F	? cerebellitis (Diffuse)	Atrophic (mild) changes in cerebellar hemisphere.

Table 3.1: Details of the subjects studied

The syllables as uttered by a Kannada speaking normal female aged 24 years were recorded in to the computer memory at 16000 Hz sampling rate using a 12 bit A/D converter. Using the Waveform Display of the SSL -VSS Software VOT for all the stop consonants were measured. A VOT continuum from the original to +40 msec, were generated, using waveform editor of SSL-VSS software. VOT was truncated in steps of far pitch Dulses till the burst and when the VOT was zero, silence in steps of 10 msecs, was inserted between the burst and the following vowel. Twelve stimuli for each syllable and a total of 48 synthetic stimuli were generated. Table 3.2 shows the stimulus details. Figures 3.1 - 3.4 show the waveforms of the synthetic stimuli generated.

VOT stimulus	VOT in msec. for			
	/g/	/ḍ/	/d/	/b/
Original S0	-101.0	-98.0	-91.50	-118
S1	-86.0	-86.0	-81.5	-97
S2	-73.0	-72.0	-69.5	-83
S3	-59.0	-57.0	-54.5	-68
S4	-44.0	-41.0	-39.5	-54
S5	-34.0	-25.0	-20.5	-38
S6	-17.0	-3.0	-0.5	-22
S7	0	0	0	0
S8	10	10	10	10
S9	20	20	20	20
S10	30	30	30	30
S11	40	40	40	40
Total no. of stimuli	12	12	12	12

Table 3.2 : Details of VOT continua



Readings at Cursor: Mark 1: Mark 2: Diff:

Fig. 3.2 : Waveform of Synthetic Stimuli /da/ - Upper Half and /da/ Lower Half.

34b

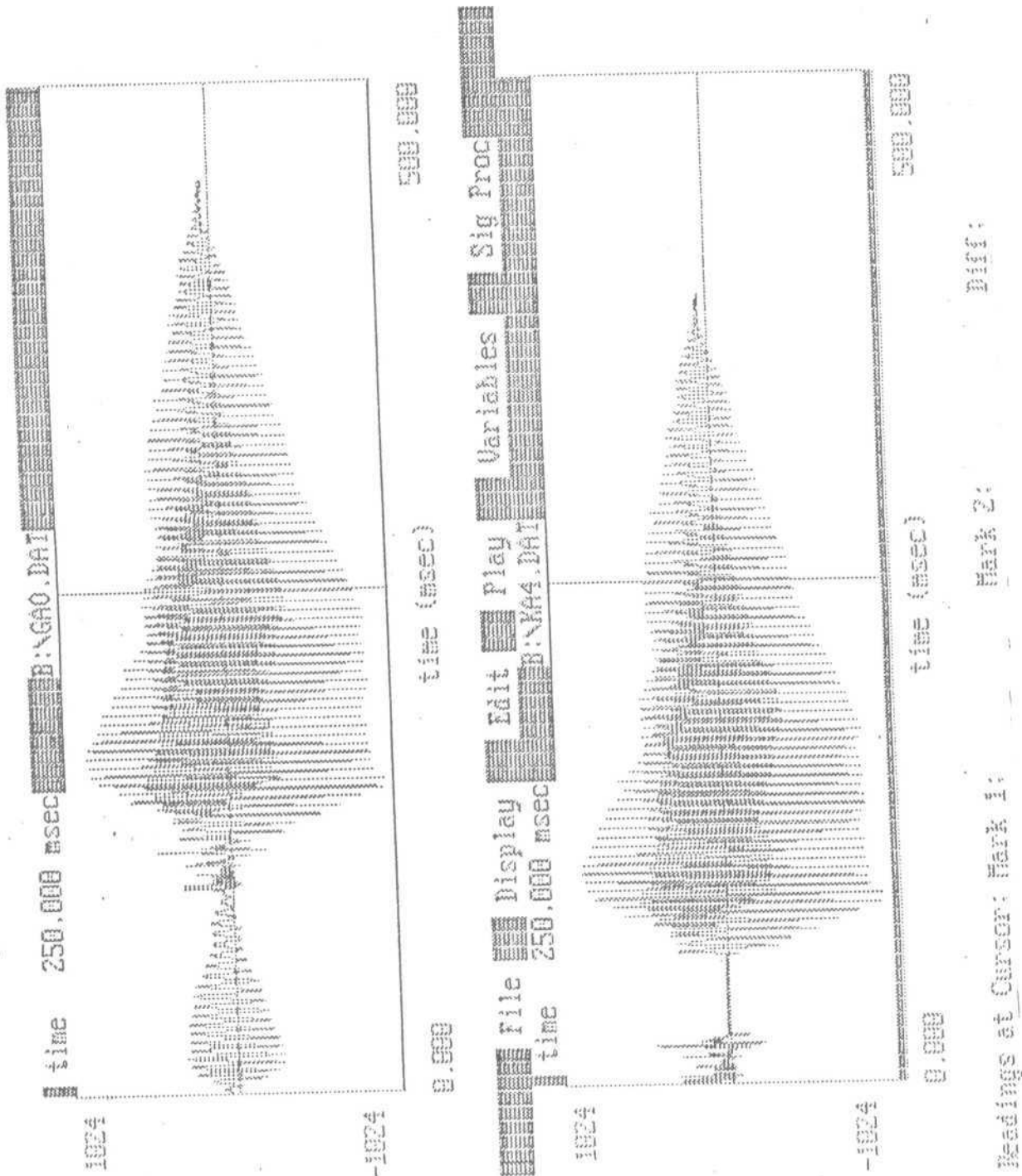


Fig. 3.1 : Waveform of Synthetic Stimuli /ga/ - Upper Half and /ka/ Lower Half.

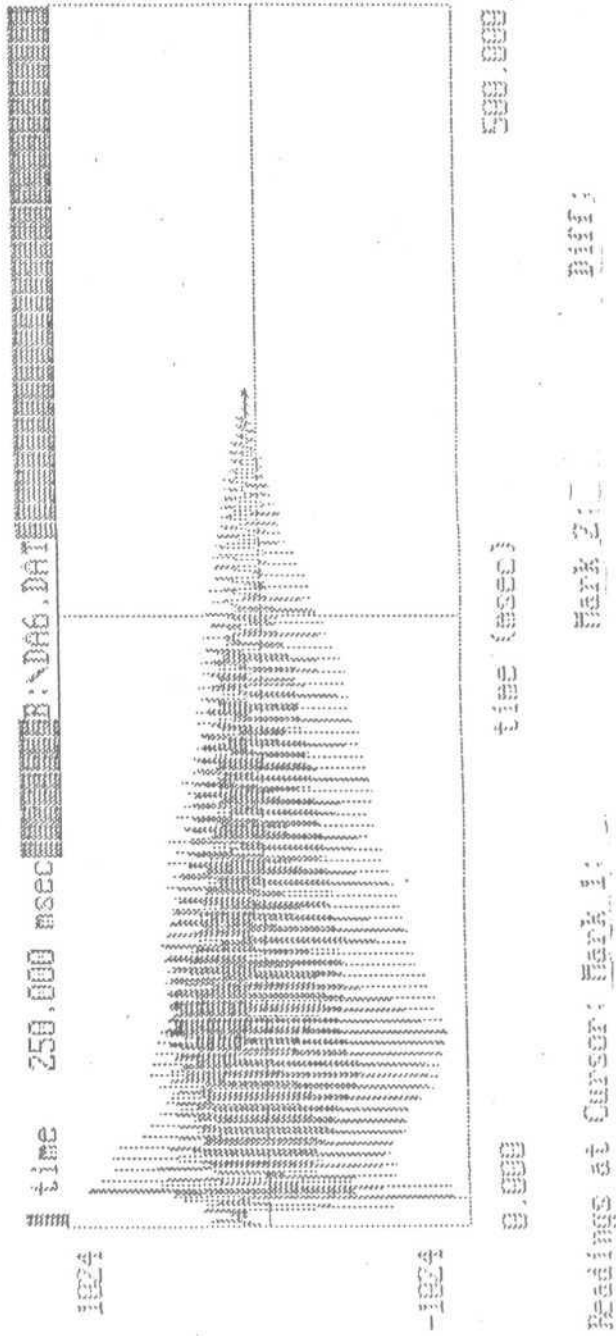
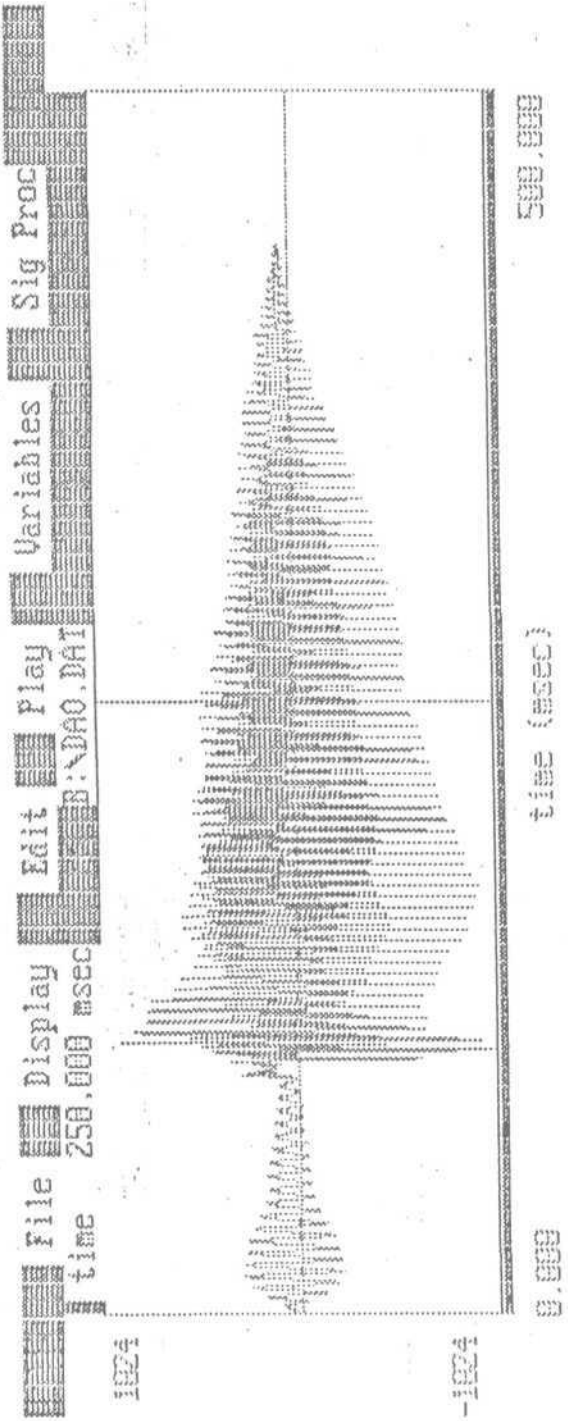
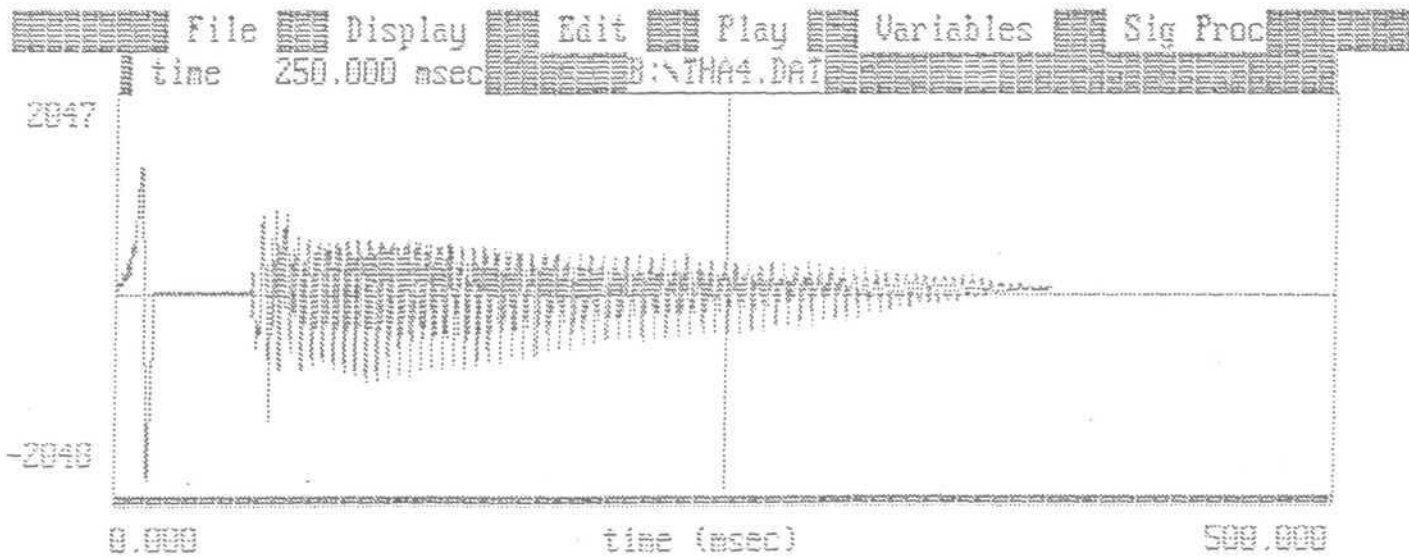
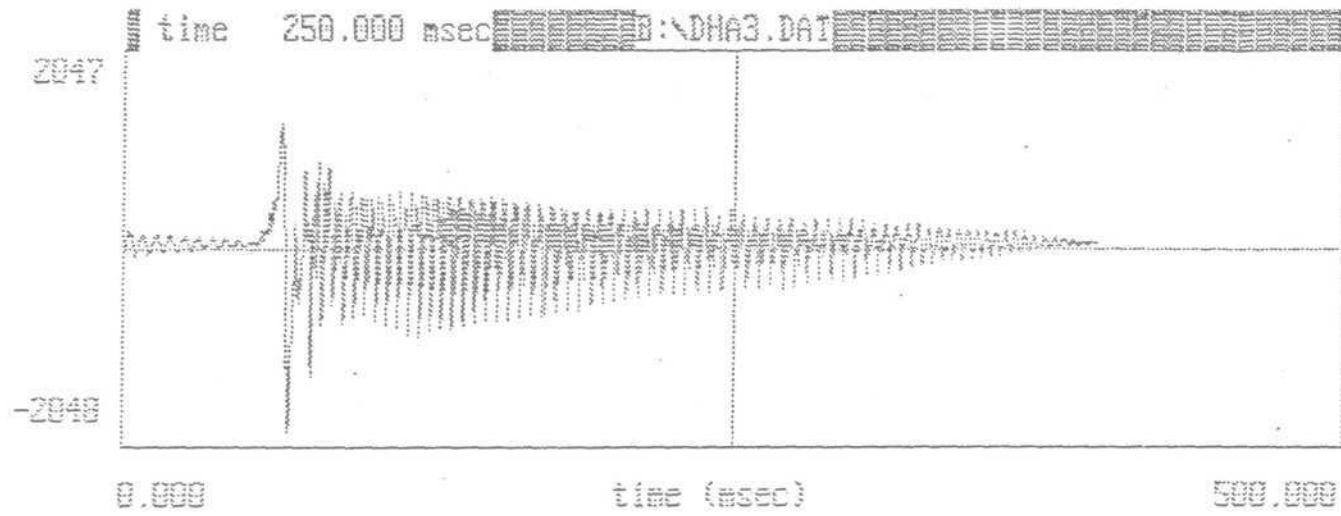


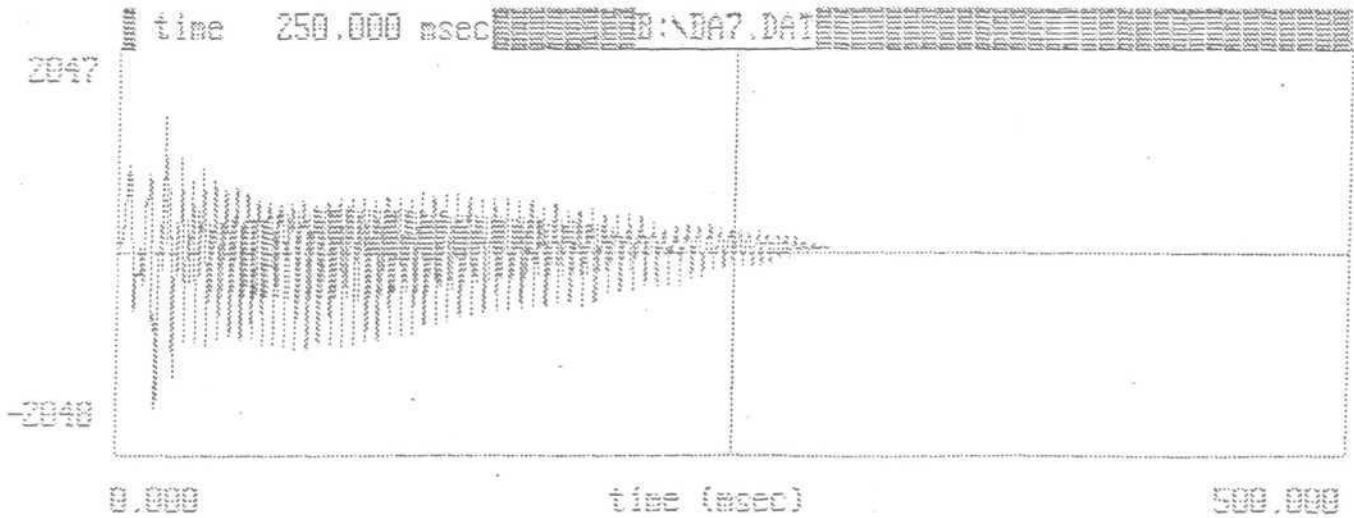
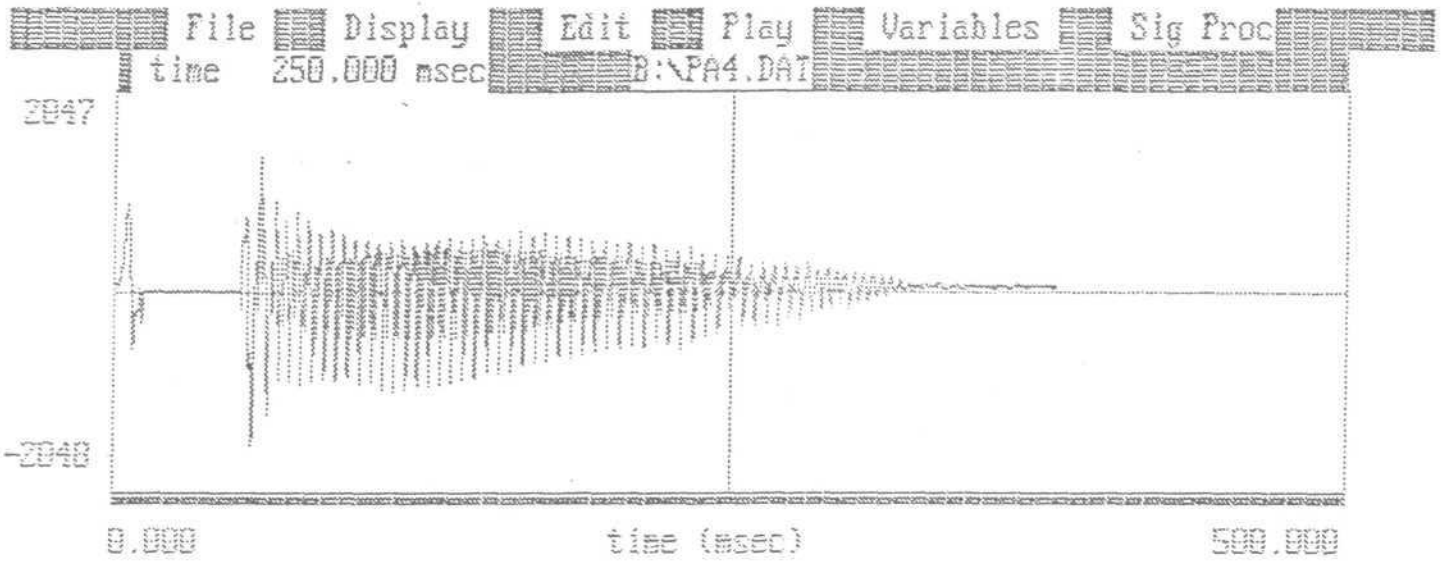
Fig. 3.2: Waveform of Synthetic Stimuli /da/ - Upper Half and /da/ Lower Half.



34 C

Readings at Cursor: Mark 1: Mark 2: Data:

Fig. 3.3 : Waveform of /da/ (Upper Half) Synthetic Stimuli
/da/ - Lower Half.



Readings at Cursor: Mark 1: Mark 2: Diff:

343

Fig. 3.4 : Waveform of Synthetic Stimuli /pa/ - Upper Half and /ba/ Lower Half.

Tokens for each phoneme were considered as a set, and with in each set, the tokens were paired with the others as shown in Table 3.3. The paired tokens were randomized with in each set, iterated thrice and audio-recorded using the 'playbat' program of the SSL-VSS. A total of 223 pairs of stimuli formed the material for VOT.

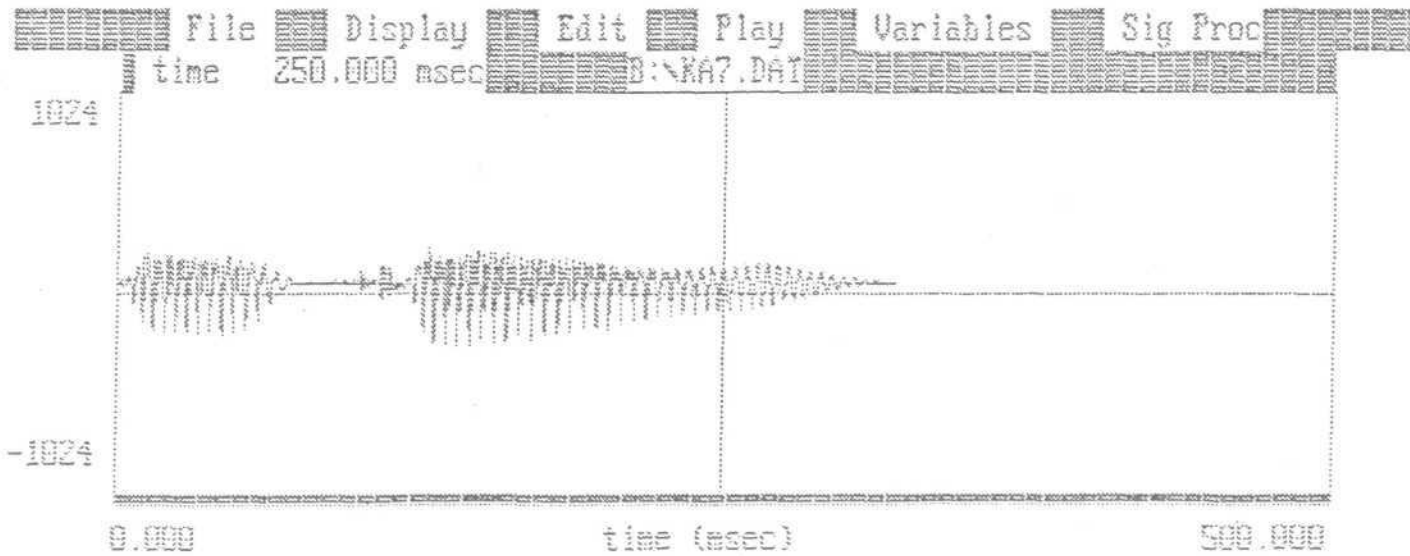
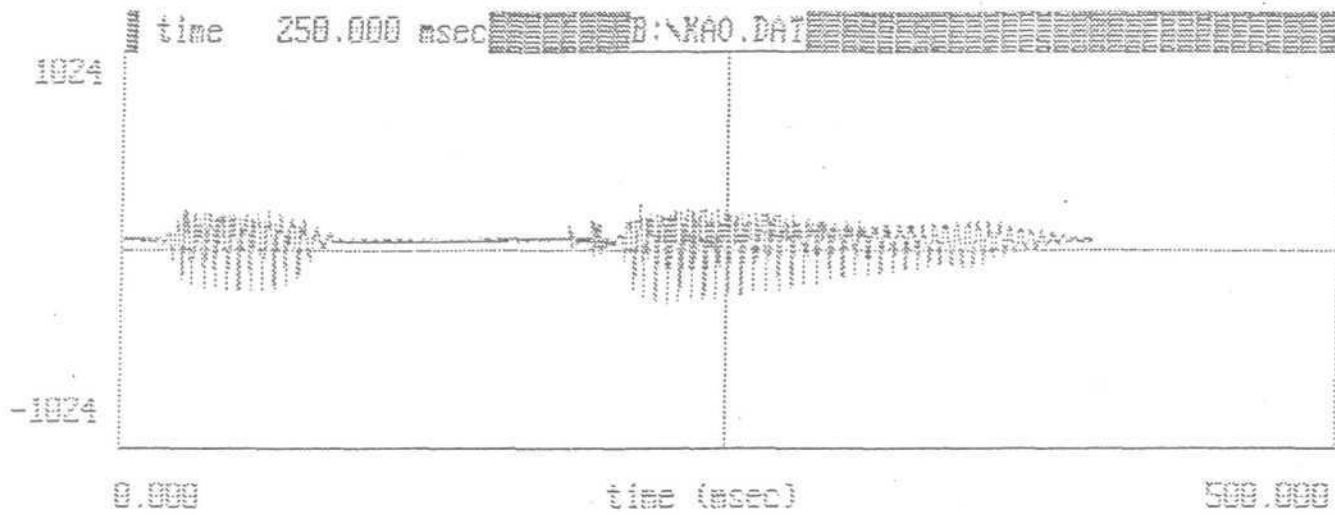
	S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
S0	-	+	+	+	+	+	+	+	+	+	+	+
S1	-	-	+	+	+	+	+	+	+	+	+	+
S2	-	-	-	+	+	+	+	+	+	+	+	+
S3	-	-	-	-	+	+	+	+	+	+	+	+
S4	-	-	-	-	-	+	+	+	+	+	+	+
S5	-	-	-	-	-	-	+	+	+	+	+	+
S6	-	-	-	-	-	-	-	+	+	+	+	+
S7	-	-	-	-	-	-	-	-	+	+	+	+
S8	-	-	-	-	-	-	-	-	-	+	+	+
S9	-	-	-	-	-	-	-	-	-	-	+	+
S10	-	-	-	-	-	-	-	-	-	-	-	+
S11	-	-	-	-	-	-	-	-	-	-	-	-

+ = indicates a pair

- = indicates no pair

Table 3.3 : Pairs of tokens generated

For closure duration, two unvoiced unaspirated stop consonants in the medial position of VCV syllables:- bilabial /p/ as in /apa/ and velar /k/ as in /aka/; were selected. The words as uttered by an adult female normal Kannada speaker aged 24 years,



Readings at Cursor: Mark 1: Mark 2: Diff:

Fig. 3.5 : Waveform of the original and Synthetic Stimuli /aka/

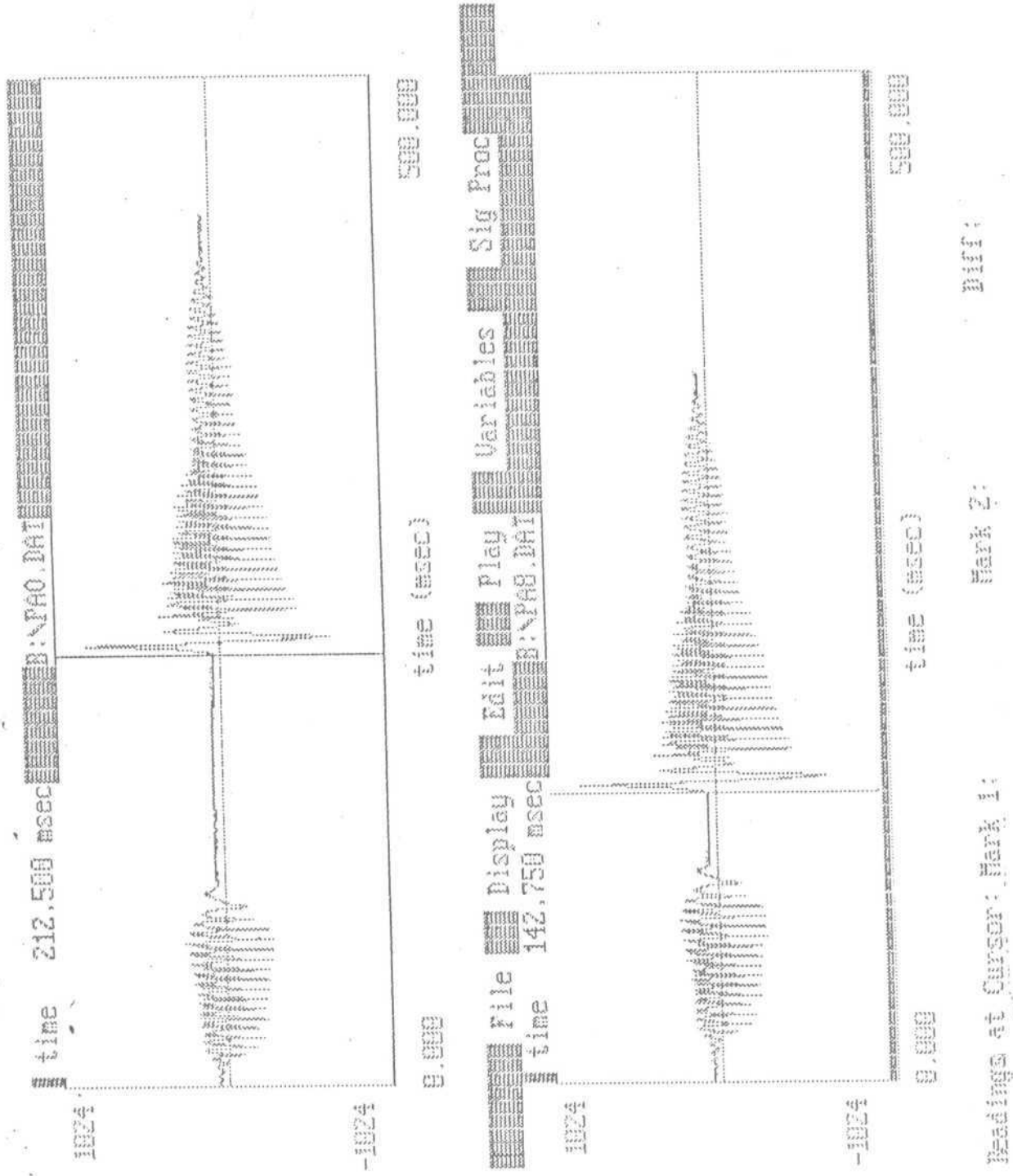


Fig. 3.6: Waveform of the original and Synthetic Stimuli (apa)

were recorded in to the computer memory at 16000 Hz sampling rate using a 12 bit A/D converter. The waveform was displayed on the screen and the CD was measured. The CD continuum was generated by truncating the original CD in steps of 10 msec using the waveform editor of SSL-VSS Software. Table 3.4 shows the details of CD continuum. Figures 3.5 and 3.6 show the waveforms of the synthetic stimuli generated.

CD/Stimuli	/p/	/k/
Original S0	113	96
S1	103	86
S2	93	76
S3	83	66
S4	73	56
S5	63	46
S6	53	36
S7	43	26
S8	33	16
S9	23	0
S10	13	-
S11	0	-

Table 3.4 Details of CD continua

A total of 22 stimuli, 12 and 10 each for /p/ and /k/ were generated and tokens for each phoneme were considered as belonging to a set. Within each set, the tokens were paired as in Table 3.3 All the tokens within a set were randomized, iterated

thrice and audio-recorded using the 'Playbat' program. A total of 150 paired stimuli formed the material for closure duration.

Method

Patients were individually tested in the Institute of Neurology in patient wards of Chennai Government Medical College, Chennai. A detailed case history preceded the testing. At a time, a patient was tested only for 20 minutes. The normal subjects were tested at their houses in Chennai.

The stimuli were audio presented through headphones of the tape recorder (Aiwa-HS-GSI22) and the subjects were instructed to say whether the two stimulus in the pairs were the same or different. The responses were recorded by the experimenter immediately on the response sheet.

Analysis

The responses of the subjects were tabulated and percent same and percent different for each token for each subject was calculated. The mean percent same and percent different for patients with cerebellar pathologies and normals were calculated.

The mean percent same and percent different were plotted on a graph against the stimuli for each set of tokens and the following parameters were measured from the curve.

- a) **50% crossover** - It is that point on the graph where the two curves (same/different) meet. When more than a single crossover was observed, the first crossover from the left end of the graph was considered.

- b) **Lower limit of Phoneme Boundary Width** - defined as that point along the acoustic cue continuum where an individual identified the differences in the voiced-voiceless stop 35% of the time.

- c) **Upper Limit of the Phoneme Boundary Width** - defined as the point along the acoustic cue continuum where an individual identified the differences in the voiced-voiceless stop 75% of the time.

- d) **Phoneme Boundary Width (PBW)** - between category PBW, defined as the arc boundary cross point along the acoustic continuum obtained by subtracting lower limit from upper limit.

$$PBW = UL - LL$$

These measures of normal adults and patients with cerebellar pathologies were compared to bring about the differences between the groups.

CHAPTER IV

RESULTS AND DISCUSSION

RESULTS

I VOT

50% Crossover

In general, it was found that the shift in perception from voiced to unvoiced was earlier in normal controls (-46.5 to -51.5 msec) than in patients with cerebellar pathology (+5.5 to +25 msec). Table 4.1 gives the 50% crossover values for VOT.

Stimulus	Normal control	Patients with cerebellar pathology
k/g	- 51.5 msec	+ 5 msec
ṭ/ḍ	- 49 msec	No crossover
t/d	- 47.5 msec	- 15.5 msec
p/b	- 46 msec	+ 25 msec.

Table 4.1 : 50% crossover

Considering the different stimuli taken for VOT, the analysis indicated that -

- a) For velar and bilabial stops shift in percept was in the lead VOT region for normals and in the lag VOT region for patients with cerebellar pathology, indicating a wide difference in the 50% cross over between the two groups (Fig.4.1)

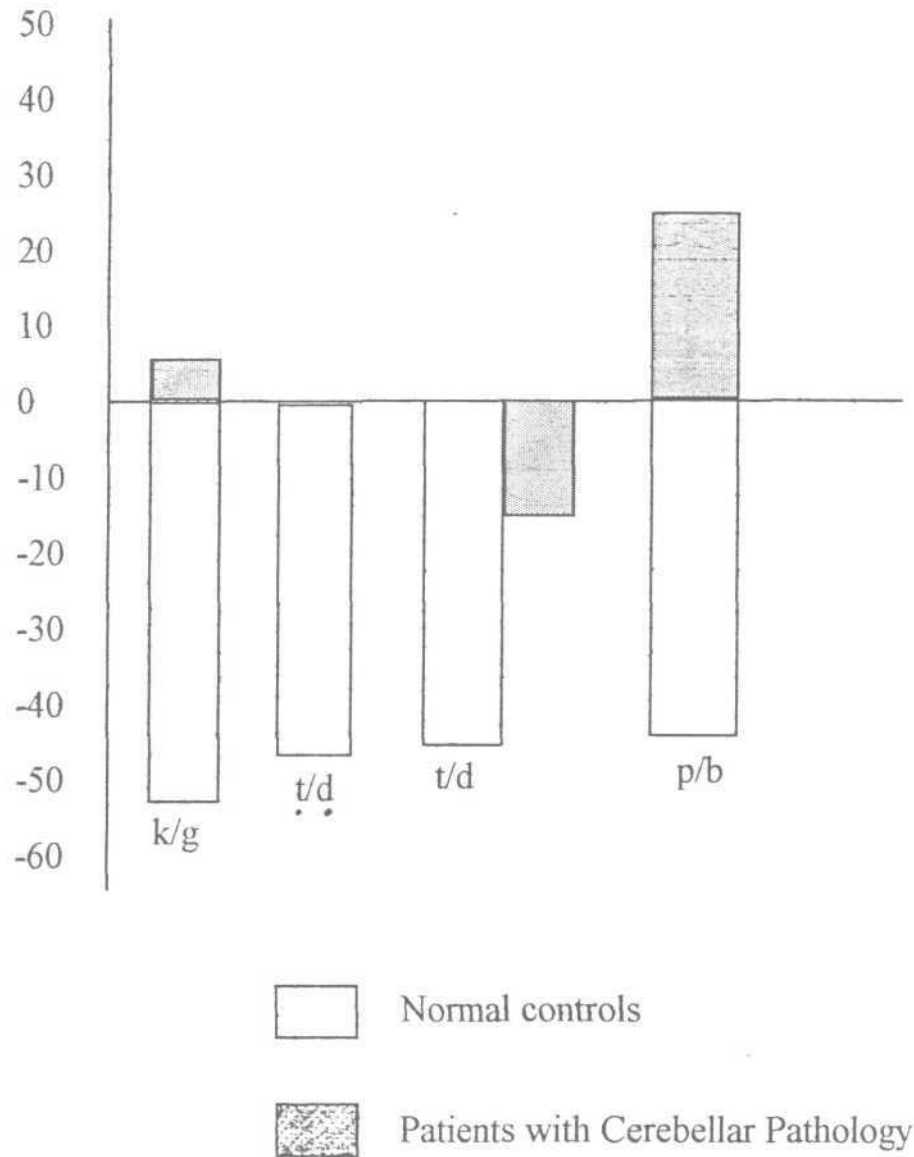


Fig.4.1 : Pattern of shift in percept for different stimuli inVOT

- b) For alveolar stops, shift in percept was in lead VOT region both for normal controls and patients with cerebellar pathology and for retroflex the shift in percept was absent in patients with cerebellar pathology, but present in lead VOT region for normal controls.

However, for all the four places of articulation, the crossover occurred in lead VOT region and earlier in normals.

It was also observed that the shift in percept in normal controls was earlier for velar stop consonants followed by retroflex, alveolar and bilabial stop consonants.

Lower Limit, Upper Limit and Boundary Width

These could not be calculated for patients with cerebellar pathologies as there was no crossover or the responses were not equal to or above 75%.

Not all patients performed in the same way. Considering the performance of individual patients, it was found that only five out of ten patients (patients 1, 2, 4, 7, and 9) with cerebellar pathology shifted their percept from voiced to unvoiced stops.

This shift in percept was seen only in the first set, (where the original stimulus was paired with all other synthetic tokens - 11 pairs) in three patients (patients 1, 2 and 4). However, patients

7 and 9 showed a shift in percept upto 4/5 sets/5/6 pairs. Figure 4.2 to 4.5 shows the 50% cross for the first set of stimuli in patients with cerebellar pathology.

While for [k/g] and [t/d] patients 7 and 9 shifted the percept, patient 4 did not. For t/d and p/b all the patients showed a shift in the percept. Patient 9 with removal of right cerebellar hemisphere had responses closer to the normal and patient 4 with cerebellar atrophy had most deviant responses. While patients 7 and 9 can be classified under Group 1, i.e. 'close to normals', patients 1,2, 4 can be classified as belonging to Group 2 i.e. 'deviant' and the patients 3, 5, 6, 8 and 10 under Group 3, i.e. those who could not discriminate the stimuli ('no response').

It was also observed that in over 80% of the patients with cerebellar pathologies, the identification of the boundary zone between voiced and unvoiced stop consonants along the VOT continuum was either abnormal or impossible.

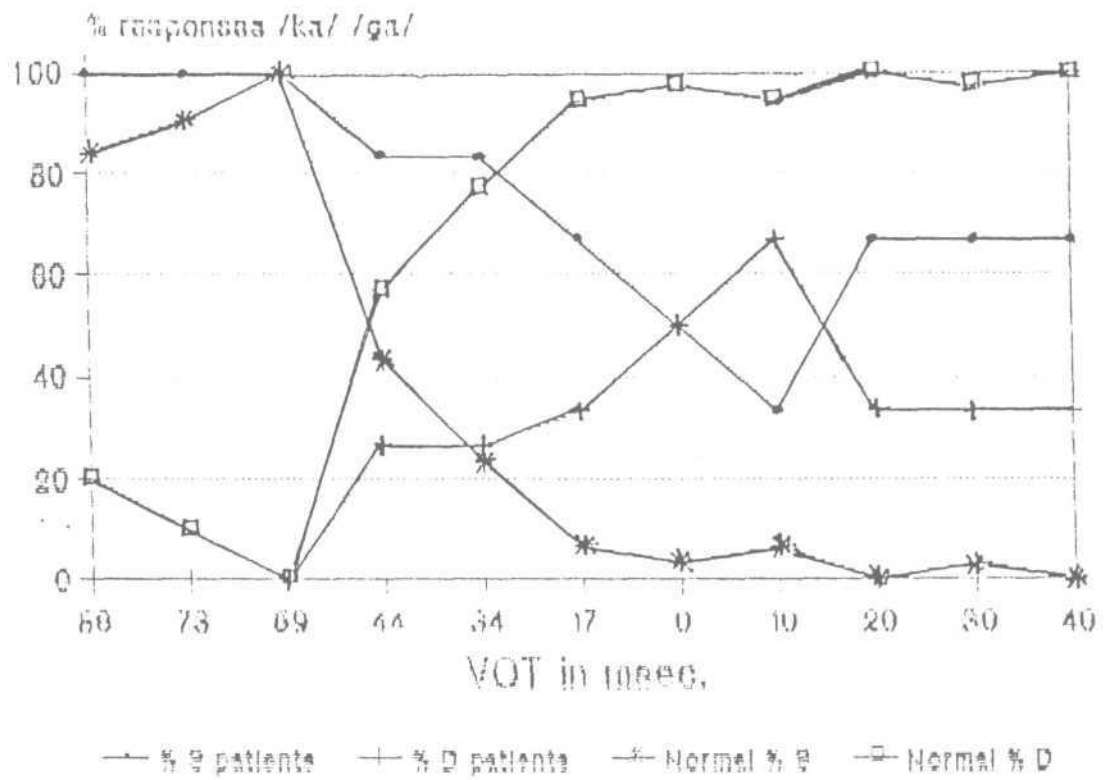
II CD

50% Crossover

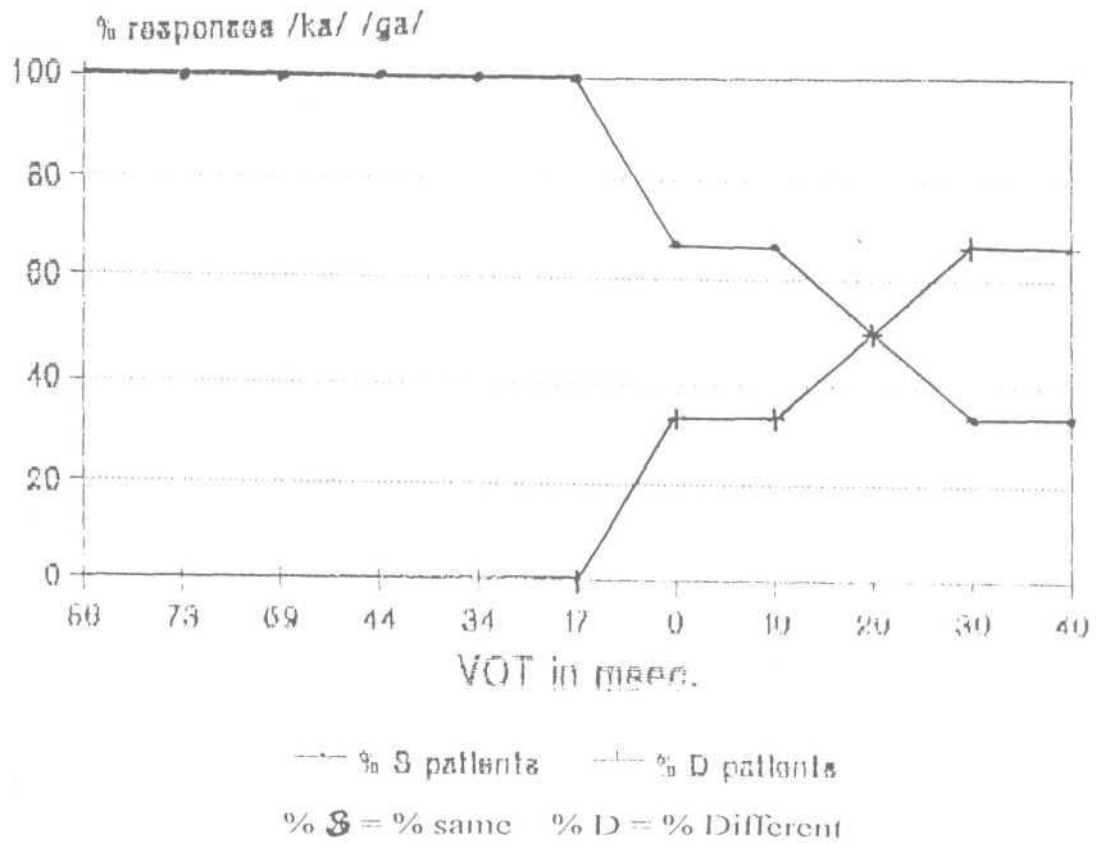
The 50% crossover in normals was found to occur at around 78-71 msec. and no shift in percept was observed in patients with cerebellar pathologies.

41a

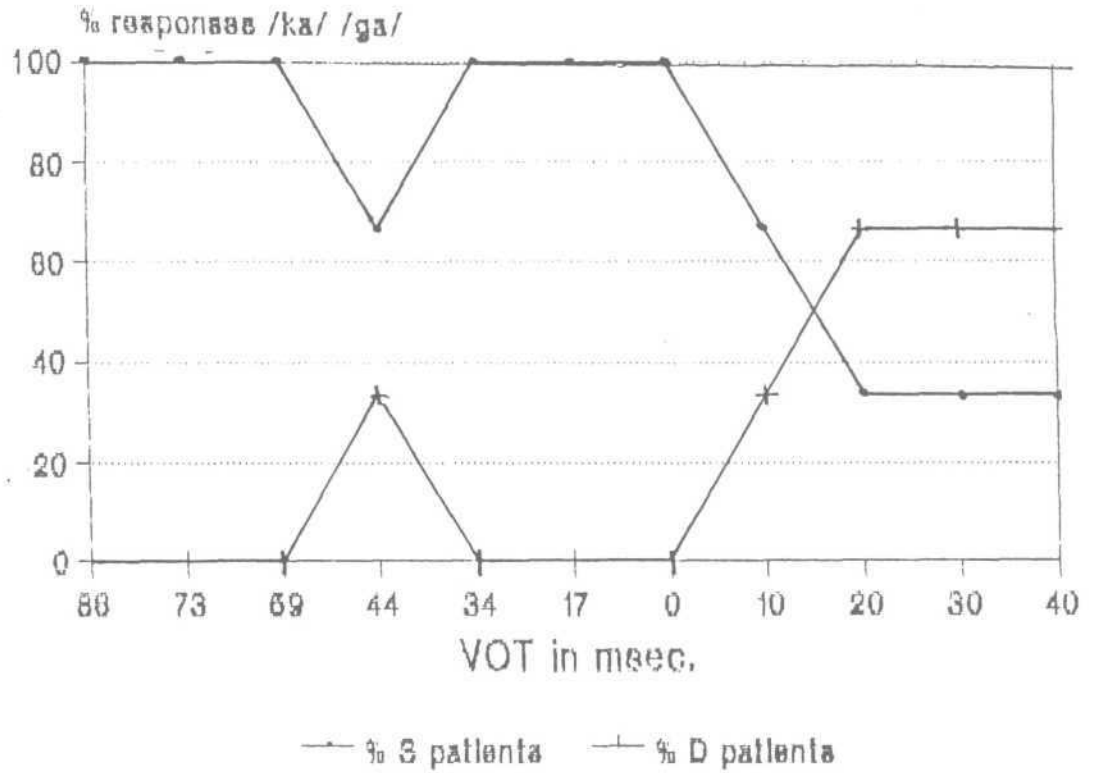
Patient No.9



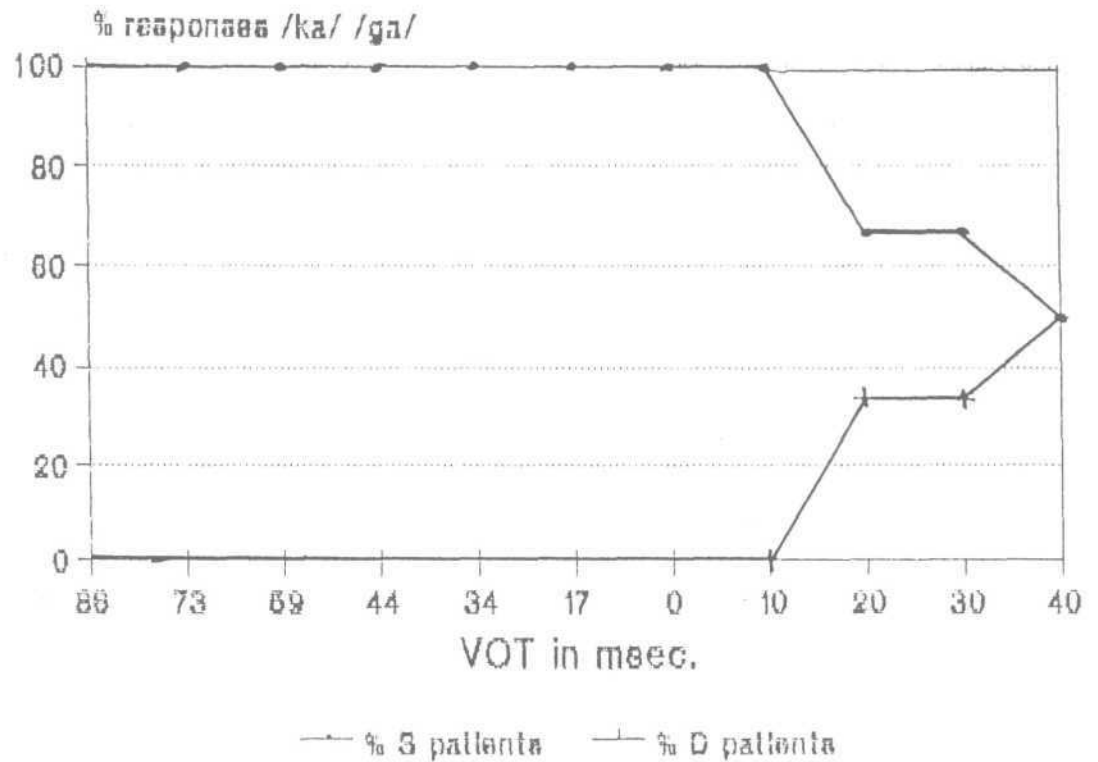
Patient No.7



Patient No.1



Patient No.2



Patient No.1

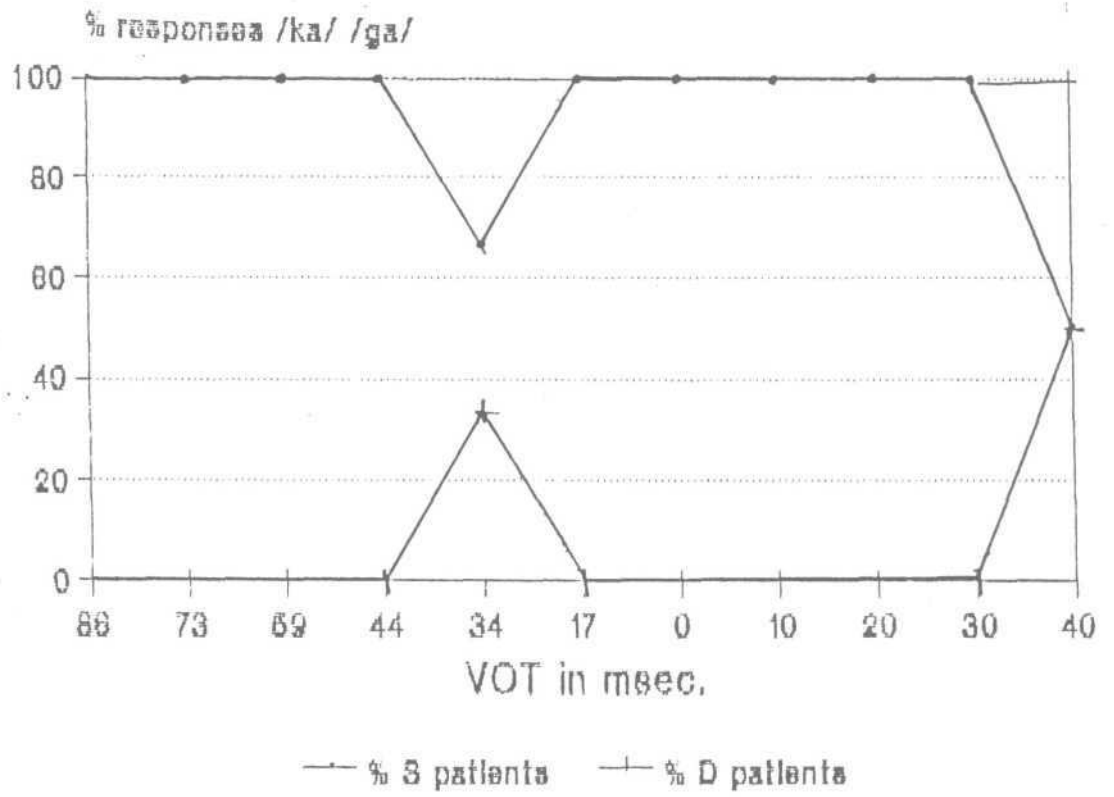
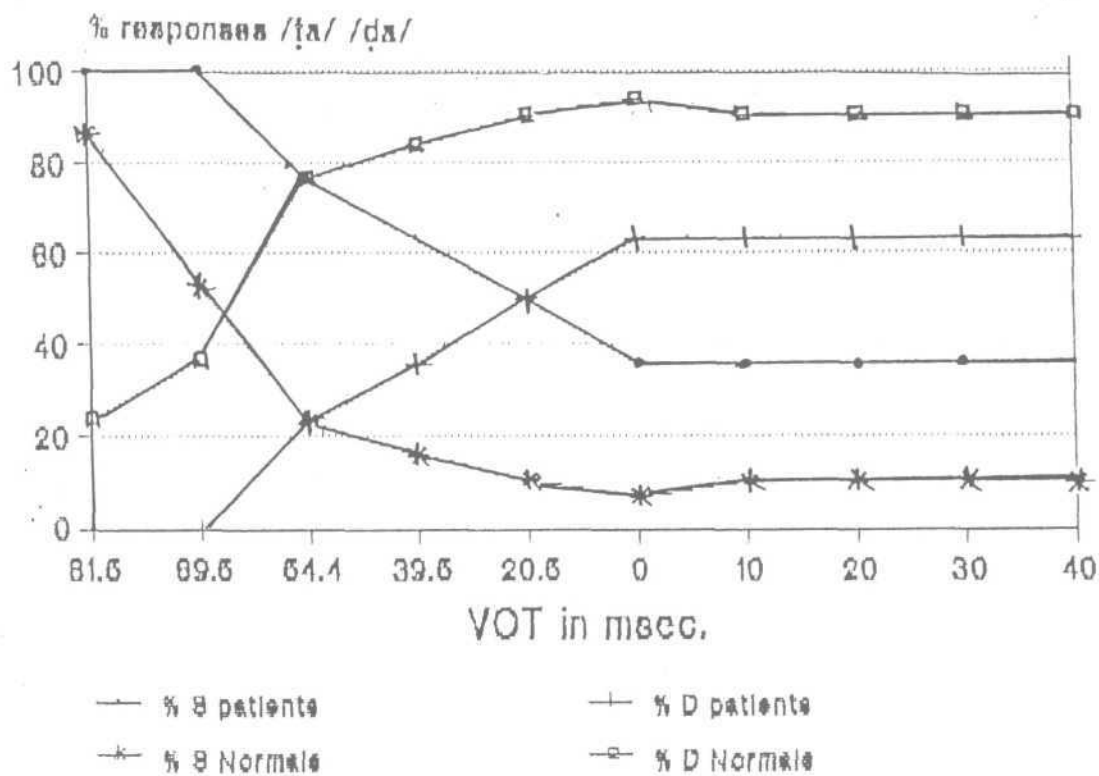
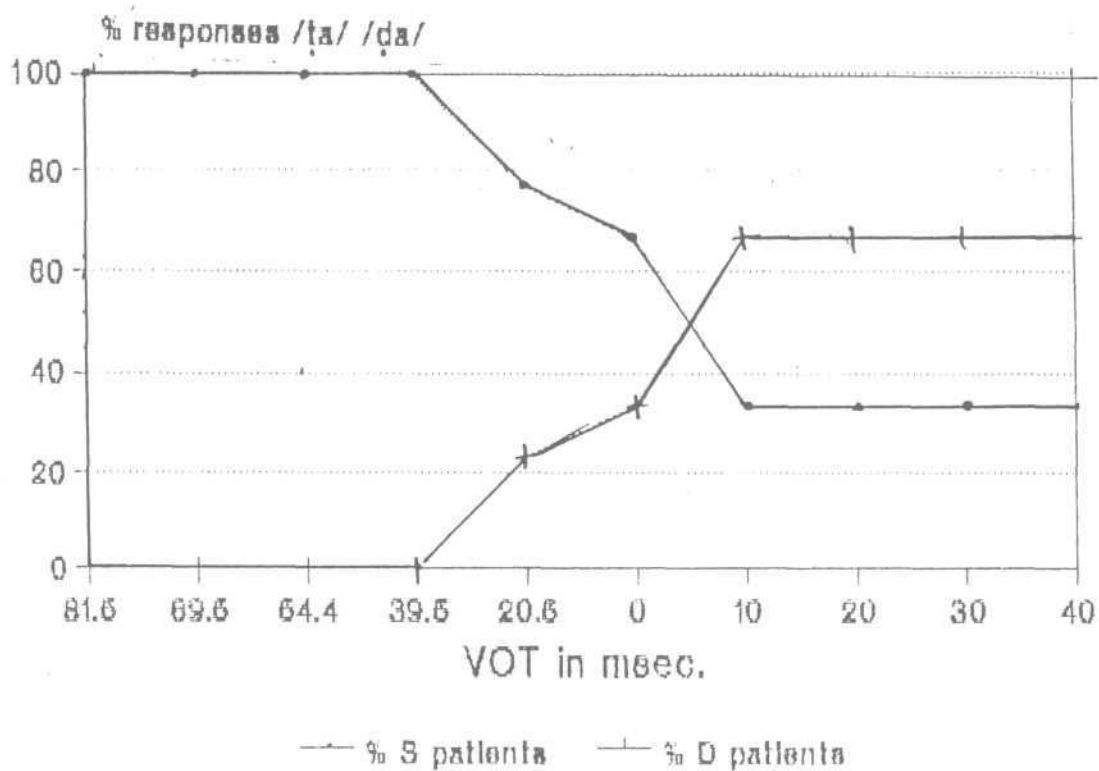


Fig. 4.2 50% Cross-over for /ka - ga/ - VOT in patients

4) b
Patient No.7



Patient No.9



Patient No.2

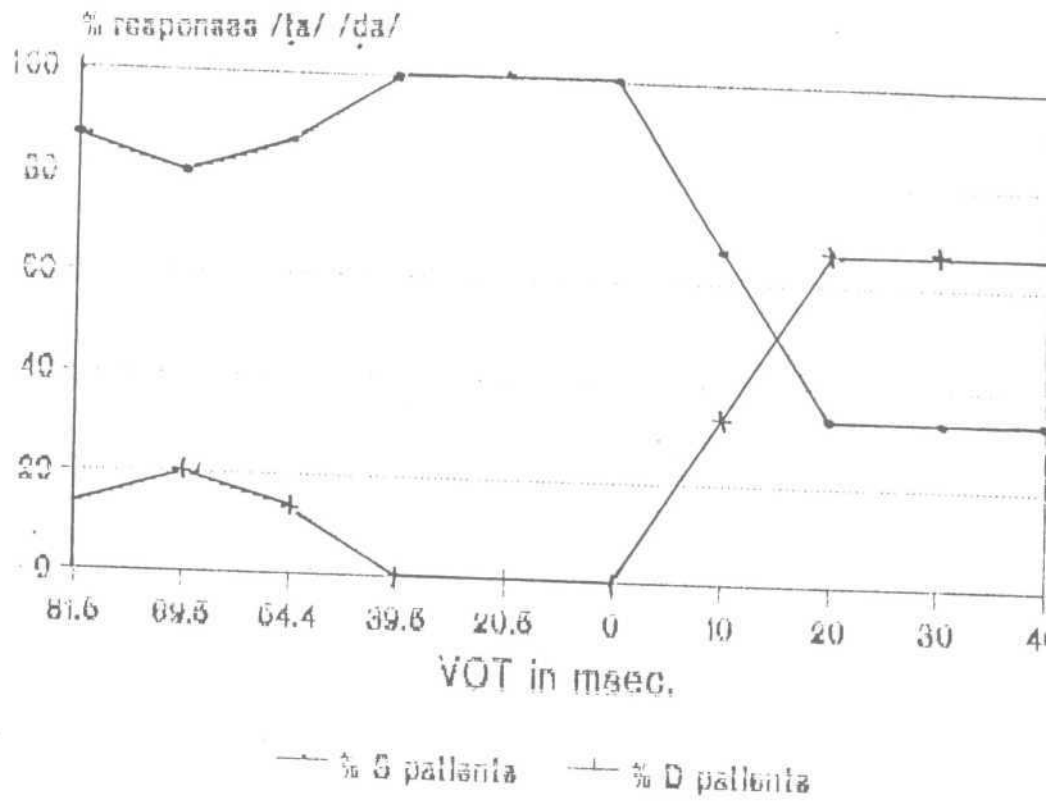
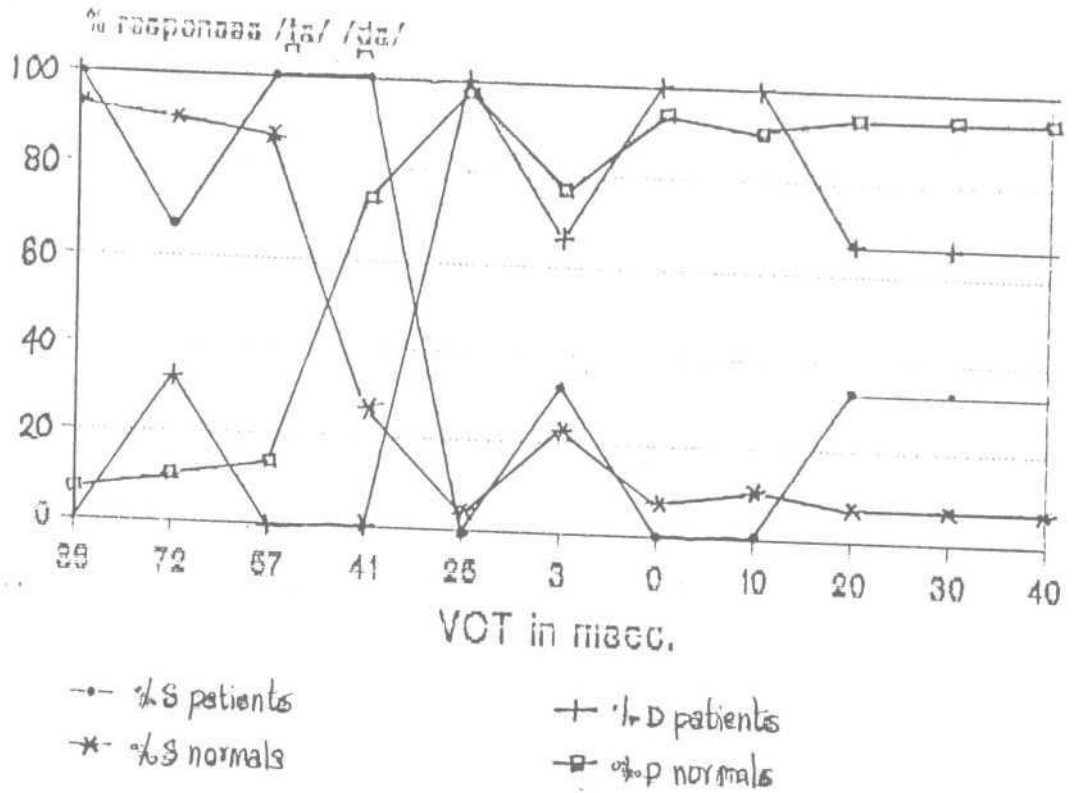
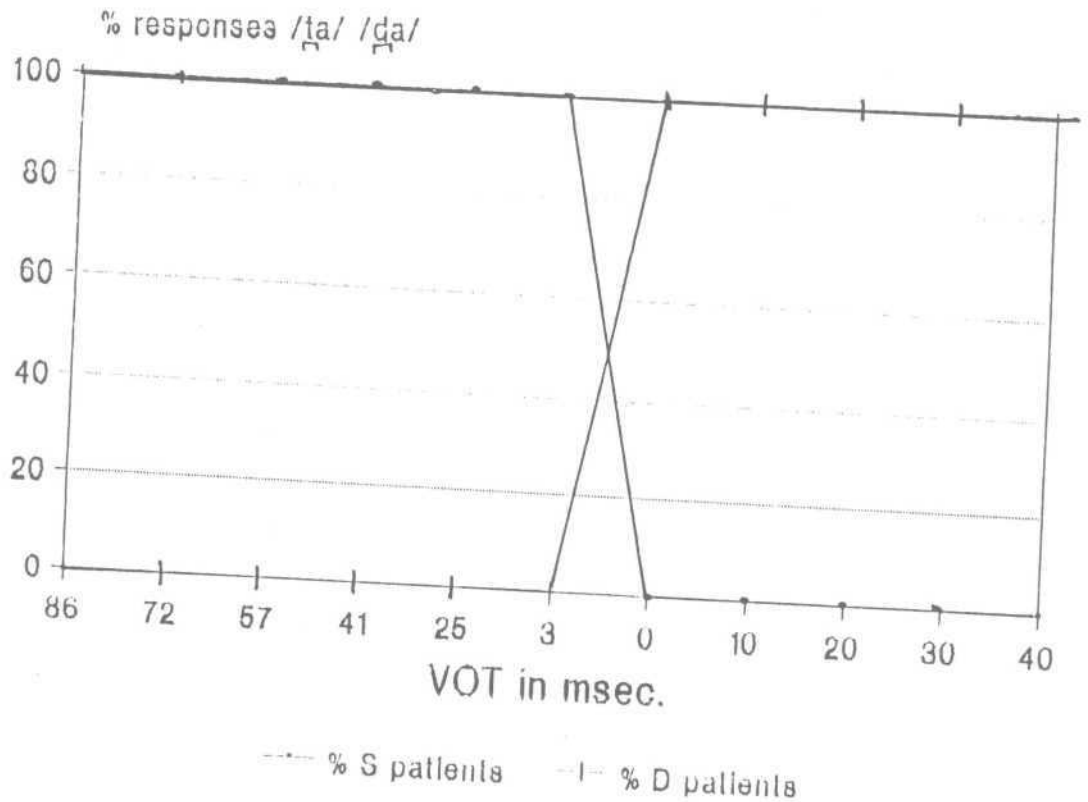


Fig. 4.3 50% Cross-over for /t̪a - d̪a/ - VOT in patients

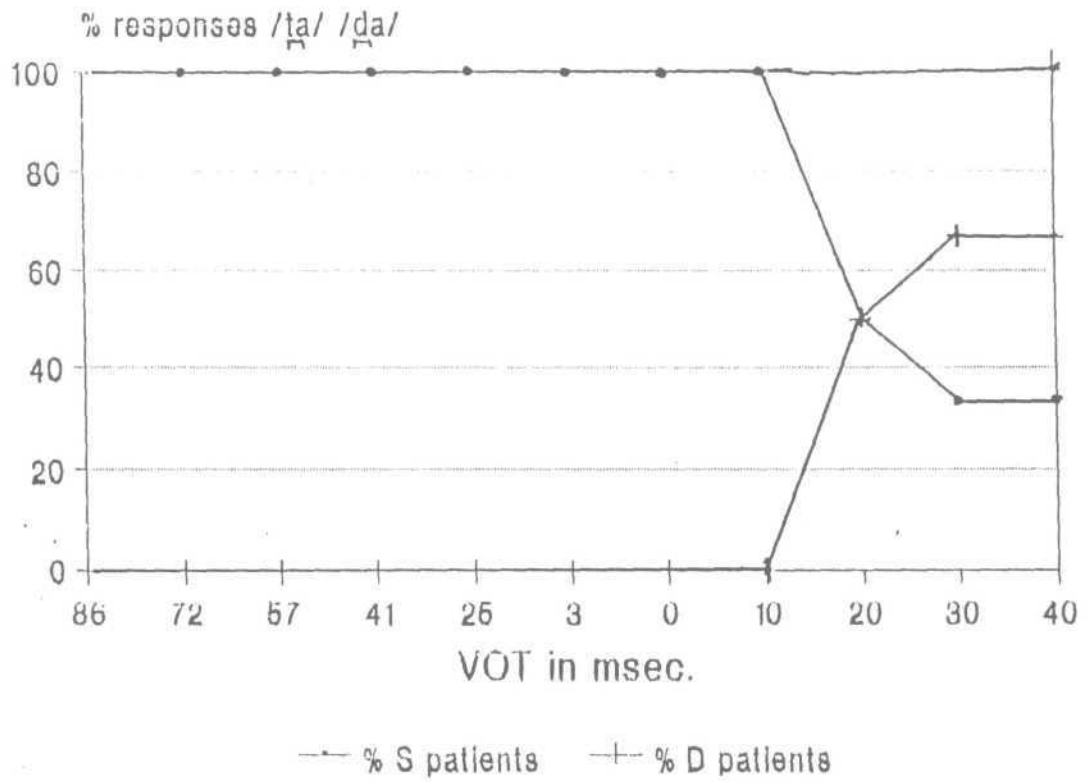
41c
Patient No.9



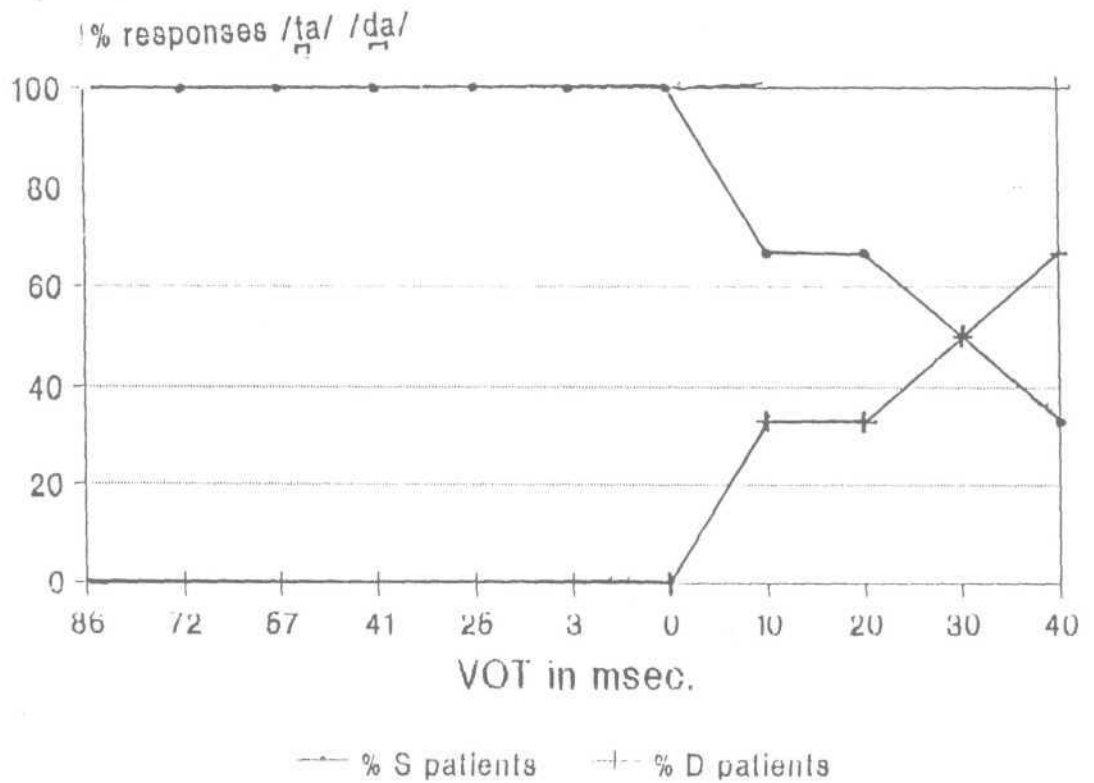
Patient No.7



Patient No.2



Patient No.1



Patient No.4

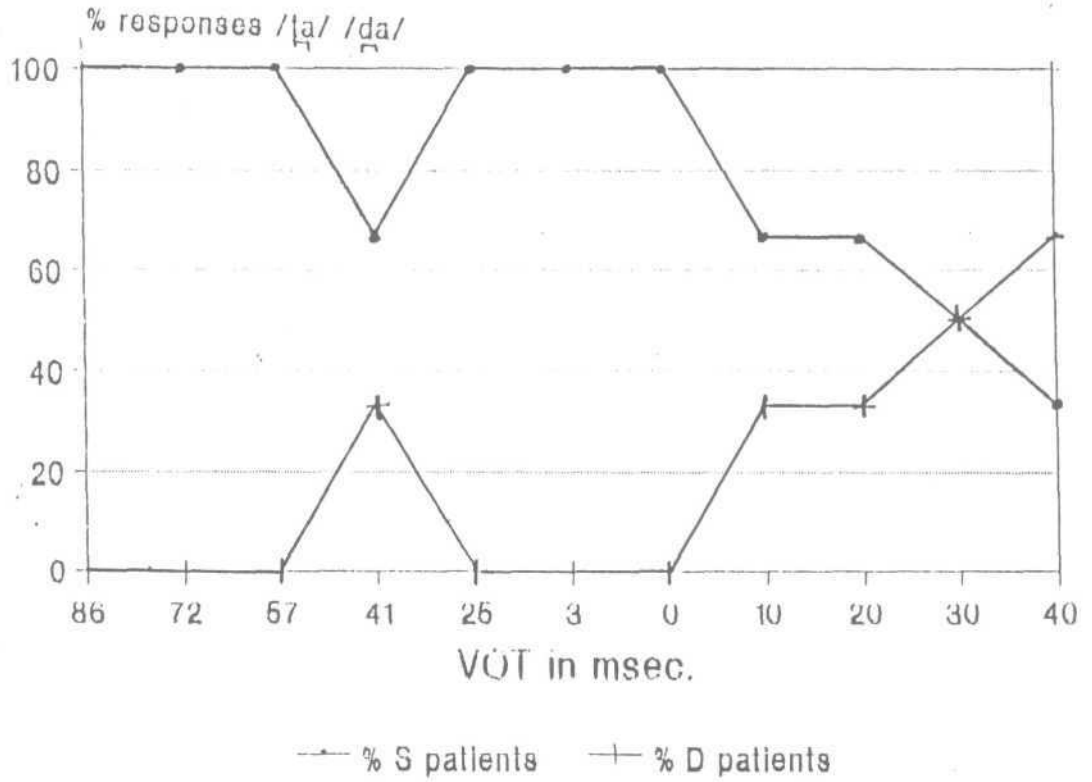
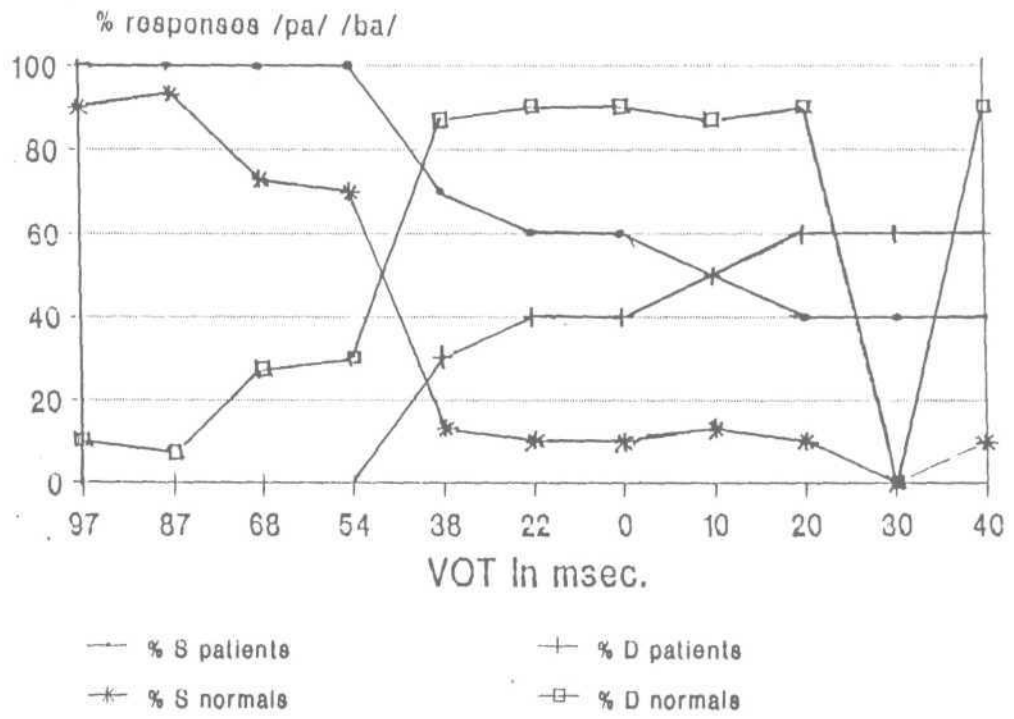
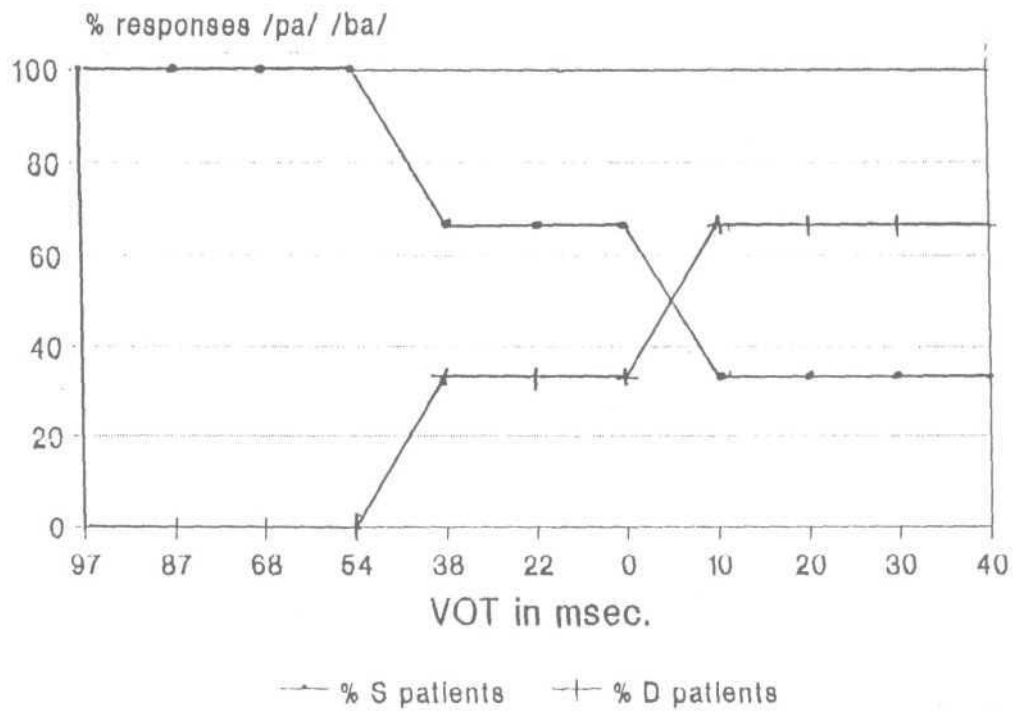


Fig. 4.4 50% Cross-over for /ta - da/ - VOT in patients

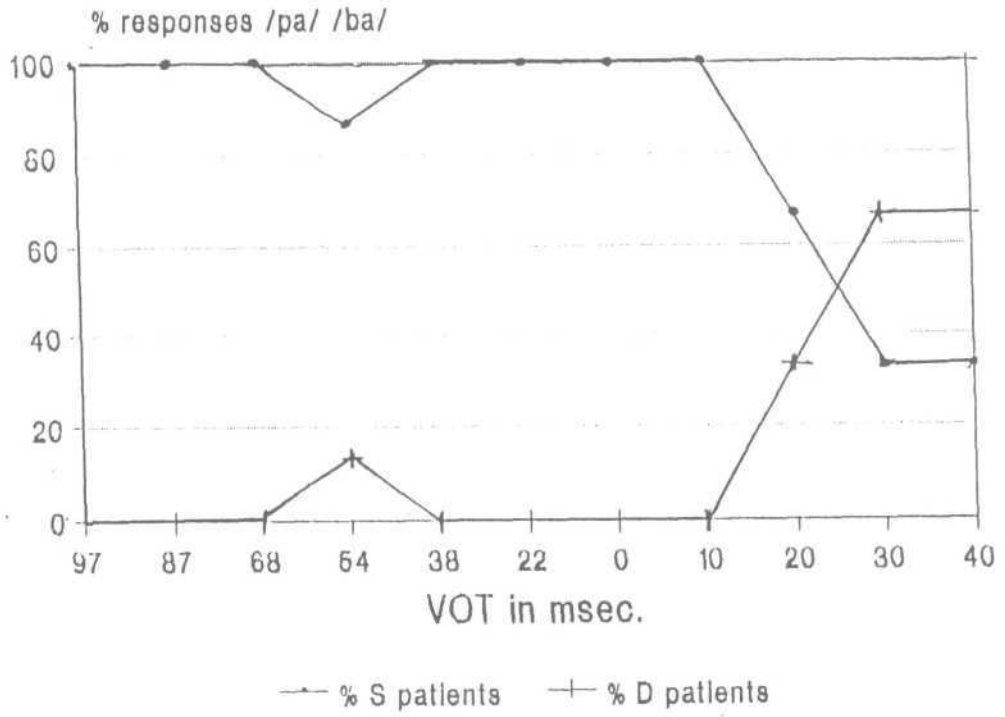
41 d .
Patient No.9



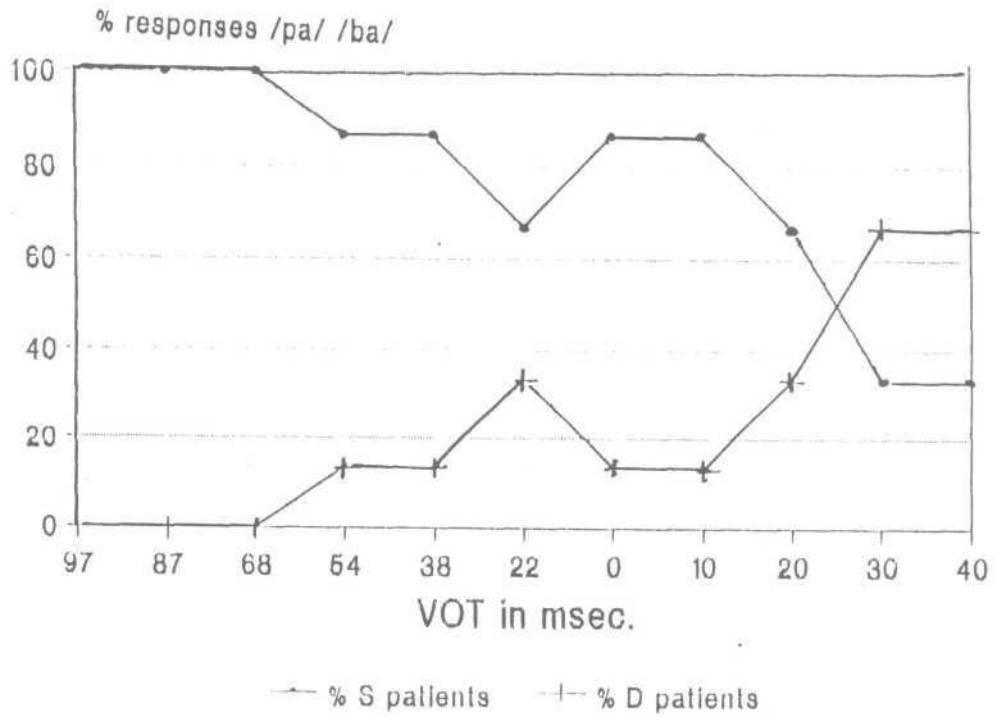
Patient No.7



Patient No.2



Patient No.1



Patient No.4

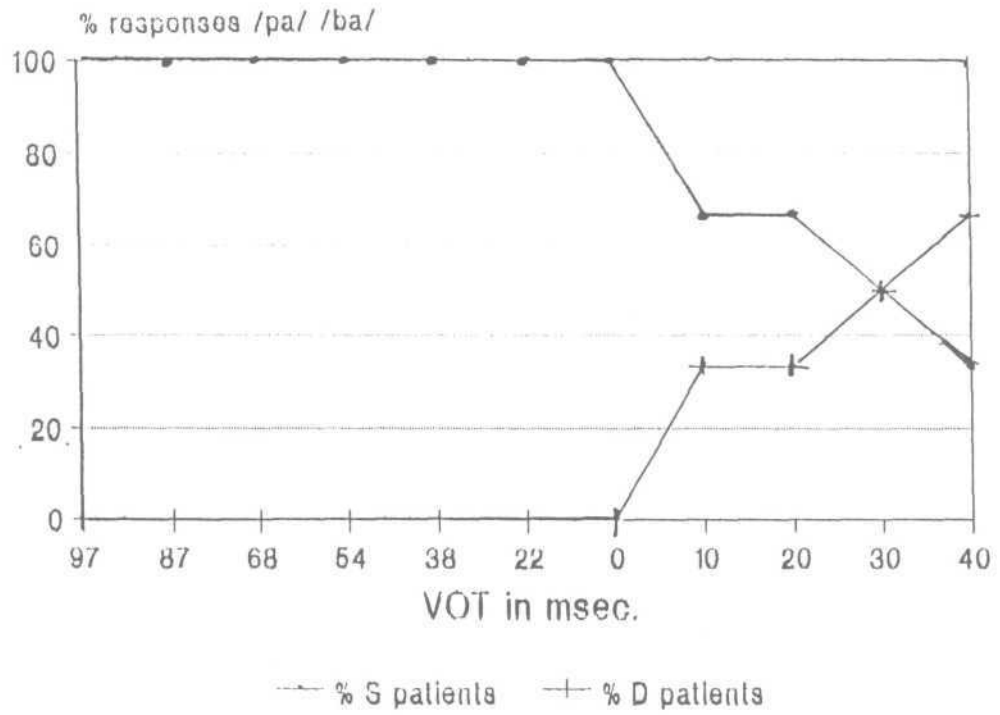


Fig. 4.5 50% Cross-over for /pa - ba/ - VOT in patients

UL, LL, BW

As 50% cross in patients with cerebellar pathologies was not observed UL, LL and BW could not be calculated.

To summarize

For VOT.

- a) Shift in perception from voiced to unvoiced stop consonants was found to occur later in patients with cerebellar pathologies compared to normal controls.
- b) Not all patients perceived a shift in voicing. Only five out of ten patients shifted their percept from voiced to unvoiced, while the other five did not.
- c) UL, LL and BW could not be calculated as none of **the** patients with cerebellar pathologies had greater than 75% of responses.
- d) On the basis of responses of patient to stimulus on a VOT continuum they could be classified as belonging to 3 groups.

Group 1 - Close to normals.

Group 2 - Deviant

Group 3 - No response

For CD

- e) While normals perceived voiced stops at shorter closure durations, patients with cerebellar pathologies did not perceive any shift in voicing.
- f) The identification of the boundary zone between voiced and unvoiced continuum was abnormal or impossible in patients with cerebellar pathologies.
- g) The responses of patients with cerebellar pathologies varied widely and did not maintain group distinction found in normal subjects.

DISCUSSION

The results indicated several points of interest. First of all, shift in perception from voiced to unvoiced stop consonants was found to occur later in patients with cerebellar pathologies compared to normal controls. This was observed when both VOT and CD was used as parameters.

First of all shift in perception from voiced to unvoiced stop consonants was not present in patients with cerebellar atrophy. This was observed when both VOT and CD were used as parameters. This is partly in contrast to the results of the study by Ackermann et al. (1997) who found that the shift in perception for

VOT in patient with cerebellar pathology was similar to that of normals and shift in perception for CD was later than normals in patients with cerebellar pathologies. They attributed the performance of patients with cerebellar pathologies for VOT continuum to other than temporal cues available for the initial stop consonant voicing perception.

However, it can be argued that even for stop consonants in medial position, F2 transition and spectral cues are available. Thus, CD cannot be considered as a better temporal parameter compared to VOT. In Ackermann et al's study the task was identification of the phoneme while in the present study the task was to identify whether the two stimuli were the same or different. This difference in task might also have led to contrasting results. Also, in Tamil the word-initial unvoiced stop consonants are not aspirated, while they are in English. Thus, in English for the VOT continuum, aspiration and spectral energy are additional cues for word -initial stop consonants, which are not in Tamil (Fig.4.6). While *Ackermann et al.* (1997) considered VOT continua as control stimulus, it can be considered as a temporal parameter in the present study.

Second, not all patients with cerebellar pathologies performed similarly. Patients with diffuse cerebellar atrophy and those with surgical removal of left cerebellar hemisphere could not perceive the shift in voicing with both VOT and CD changes. Whereas, patients with removal of right cerebellar hemisphere performed similar to normals.

CHAPTER V

SUMMARY AND CONCLUSIONS

One of the ironies of work on the cerebellum is that, its uniformity of architecture would seem to imply a uniformity of function, whereas its diversity of input and output means that it has many different roles in many different neural processes. The role of cerebellum, in motor functions is well established, but in the new line of research, attributing non-motor functions to cerebellum is taking its turn to attract the centre of importance in research. Thus, one of the non-motor functions, cognition, and its relation with cerebellum seems to be less researched. Role of cerebellum in higher mental functions is found as one of the more neglected areas.

Perception, is one of the higher mental functions. Thus speech perception, a branch of the over all science of perception, is widely studied in most population.

Timing functions, has been attributed to cerebellum (*Irvy and Keele, 1989*). In line with this view, patients with cerebellar dysfunction have shown impairments in motor as well as perceptual timing tasks, which required rhythmic tapping or the judgement of time intervals (*Irvy and Baldo, 1992; Irvy and Keele, 1989; Irvy, Keele and Diener, 1988*). The classical conditioning deficits described earlier have also been attributed to deficient timing mechanism (*Irvy, et al. 1988*).

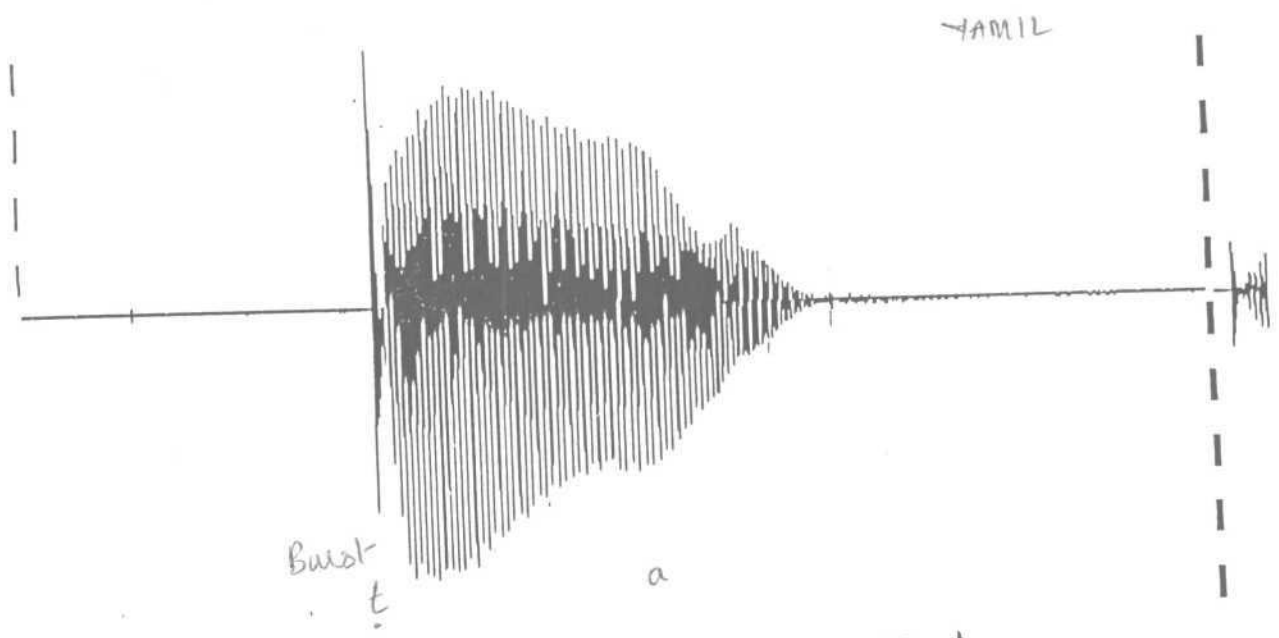
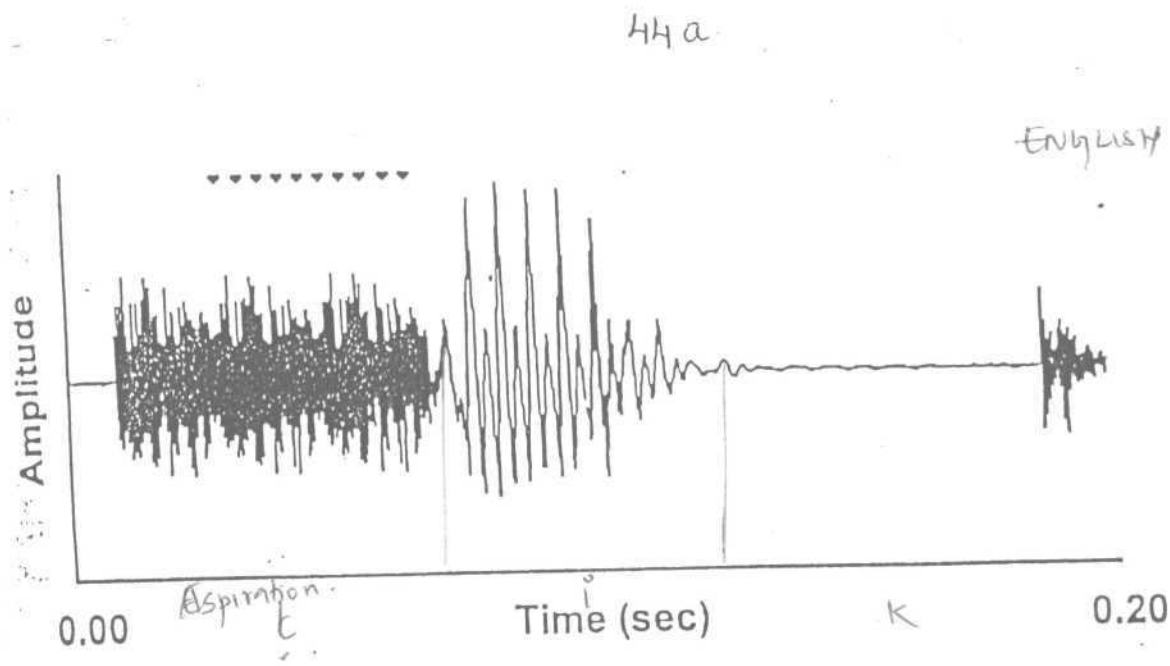


Fig.4.6 Waveform of /t/ in English and Tamil

This result is in contrast with *Ackermann et al. (1997)* who reported no phoneme-boundary in patients with bilateral cerebellar atrophy and similar performance to normals in patients with unilateral cerebellar lesion. It could be hypothesized that the left cerebellar hemisphere plays a role in perception of temporal features compared to the right cerebellar hemisphere. However more data is needed to test such speculations.

On the basis of response of patients to stimuli on VOT continuum, they could be classified as belonging to three groups.

- Group-1 : Close to normal responses
(Unilateral right cerebellar lesion)
- Group-2 : Deviant responses
(Cerebellar atrophy)
- Group-3 : No response
(Cerebellar atrophy, left cerebellar dysfunction,
cerebellitis)

Third, normals perceived voiced stops at shorter closure duration. However, patients with cerebellar pathologies did not perceive any shift in voicing.

The performance of patients with cerebellar pathologies to VOT and CD continuum reflects the fact that CD may be a better temporal parameter than VOT. Perception of linguistically relevant intervals, seems to be impaired in patients with left cerebellar pathologies. These findings are compatible with the hypothesis that the cerebellum represents an "internal clock", a prerequisite for temporal computation also in the perceptual domain (*Keele and Irvy, 1991*).

CHAPTER V

SUMMARY AND CONCLUSIONS

One of the ironies of work on the cerebellum is that, its uniformity of architecture would seem to imply a uniformity of function, whereas its diversity of input and output means that it has many different roles in many different neural processes. The role of cerebellum, in motor functions is well established, but in the new line of research, attributing non-motor functions to cerebellum is taking its turn to attract the centre of importance in research. Thus, one of the non-motor functions, cognition, and its relation with cerebellum seems to be less researched. Role of cerebellum in higher mental functions is found as one of the more neglected areas.

Perception, is one of the higher mental functions. Thus speech perception, a branch of the over all science of perception, is widely studied in most population.

Timing functions, has been attributed to cerebellum (*Irvy and Keele, 1989*). In line with this view, patients with cerebellar dysfunction have shown impairments in motor as well as perceptual timing tasks, which required rhythmic tapping or the judgement of time intervals (*Irvy and Baldo, 1992; Irvy and Keele, 1989; Irvy, Keele and Diener, 1988*). The classical conditioning deficits described earlier have also been attributed to deficient timing mechanism (*Irvy, et al. 1988*).

As the results of the present study are partly in disagreement with those of *Ackerman et al.* (1997), it is suggested that large data is required before concluding regarding the role of cerebellum in speech perception. With the present data, it is too early to confirm such hypothesis.

Assuming the timing function of cerebellum, *Irvy and Keele* (1991) conceptualized the cerebellum as an '*Internal Clock*' required for temporal computations both in the motor and the perceptual domain.

Hence, in order to find the role of cerebellum in perceptual domain, the present study examined ten patients with cerebellar pathologies on a speech perception task.

A total of ten cerebellar dysarthrics diagnosed by Neurologists based on the symptoms, CT and MRI reports formed the experimental group. Their age ranged from 24 to 69 years. All the subjects were native Tamil Speakers. The control group constituted often age matched normal (normal speech and hearing abilities) Tamil speakers.

Two temporal parameters, VOT and CD were chosen for the study. For VOT, four voiced unaspirated stop consonants in the initial position of the CV syllable consisting vowel /a/ were selected. They were the bilabial /b/, retroflex /ɖ/, dental /d/ and the velar /g/.

These as uttered by a Kannada speaking normal female aged 24 years were recorded in to the computer memory at 16000 Hz sampling rate using a 12 bit A/D converter. Using the waveform display of the SSL-VSS Software, VOT for all the syllables were measured. VOT continuum from the original (-118 to -91 msec.)

to +40 msec. were generated. VOT was truncated in steps of four pitch pulses till the burst and when the VOT was zero, silence in steps of 10 msec. was inserted between the burst and the following vowel. Twelve stimuli for each syllable and a total of 48 synthetic stimuli were generated.

Tokens for each phoneme were considered as a set, and within each set, the tokens were paired with the others. The paired tokens were randomized within each set, iterated thrice and audio-recorded using the 'playbat' program of the SSL-VSS Software. A total of 223 pairs of stimuli formed the material for VOT.

For closure duration, two unvoiced unaspirated stop consonants in the medial position of VCV syllables:- bilabial /p/ as in /apa/ and velar /k/ as in /aka/ were selected. The CD continuum was generated by truncating the original CD (113 to 96 msec.) in steps of 10 msec using the waveform editor of SSL-VSS software.

A total of 22 stimuli, 12 and 10 each for /p/ and /k/ were generated and tokens for each phoneme were considered as belonging to a set. All the tokens paired within a set were randomized, iterated thrice and audio recorded using the '*Playbat*' program. A total of 150 paired stimuli formed the material for closure duration. These stimuli formed the material.

Patients were individually tested in the Institute of Neurology in patient wards of Chennai Government Medical College, Chennai.

The stimuli were audio presented through headphones of the tape recorder (Aiwa-HS-GSI22) and the subjects were instructed to say whether the two stimulus in the pairs, were the same or different. The responses were recorded by the experimenter immediately on the response sheet.

The responses of the subjects were tabulated and percent same and percent different for each token for each subject was calculated. The mean percent same and percent different for patients with cerebellar atrophy and normals were calculated. The mean percent same and percent different were plotted on a graph against the stimuli for each set of tokens and the parameters a) 50% crossover, b) Lower limit of Phoneme Boundary Width c) Upper Limit of the Phoneme Boundary Width d) Phoneme Boundary Width (PBW).were measured from the curve. These measures of normal adults and patients with cerebellar pathology were compared to bring about the differences between the groups.

It was found that while normals shifted their percept from voiced to unvoiced, patients with cerebellar pathology did not shift their percept from voiced to unvoiced stop consonants for both VOT and CD. Thus, it was observed that identification of boundary zone between voiced and unvoiced stop consonants in patients with cerebellar atrophy was abnormal or impossible for VOT and CD continuum.

It was also found that not all patients with cerebellar pathologies performed similarly. Patients with cerebellar

atrophy and those with surgical removal of left cerebellar hemisphere could not perceive the shift in voicing for both VOT and CD changes. Whereas patients with surgical removal of right cerebellar hemisphere performed similar to normals.

The performance of patients with cerebellar pathologies for VOT and CD continuum reflects the fact that CD may be a better temporal parameter than VOT. Perception of linguistically relevant intervals, seems to be impaired in patients with cerebellar atrophy. These findings are compatible with the hypothesis that the cerebellum represents an "*internal clock*", a pre-requisite for temporal computation in the perceptual domain (*Keele and Ivry, 1991*). However, with the present data it may be too early to confirm the role of cerebellum in speech perception. A large data base may reveal the function of cerebellum.

REFERENCES

- Ackermann, H., Graber, S., Hertrich, I. & Daum, J. (1997). Categorical Speech Perception in Cerebellar Disorders. *Brain and Language*, 60, 323-331.
- Allen, G., Azzena, G.B. & Ohno, T. (1972). Contribution of the Cerebro-Reticulo-Cerebellar Pathway to the Early Mossy Fibre Response in the Cerebellar Cortex. *Brain Research*, 44, 670-675.
- Allen, G., Azzena, G.B. & Ohno, T. (1974). Cerebellar Purkinje Cell Responses to Inputs From Sensorimotor Cortex. *Experimental Brain Research*, 20, 239-254.
- Aolmes, G. (1939). A Form of Familial Degeneration of the Cerebellum. *Brain*, 30, 466-488.
- Appollonio, I.M., Grafman, J., Schwartz, N., Marsaguvi, S. & Hallett, M. (1993). Deficits in Word Retrieval in Patients With Cerebellar Disorders. *Neurology*, 43, 1536-1544.
- Askshoomoff, N.A. & Courchesne, E. (1992). Cognitive Behaviour in Cerebellar Disordered. *Behavioural Neurosciences*, 106, 731-738.
- Barso, A., Casati, G. & Vignolo, L.A. (1977). Phonemic Identification Defect in Aphasia. *Cortex*, 13, 85-95.

Bellugi, V, Wang, P.P. & Jerningam, T.L. (1994). A typical Cognitive Deficits in Developmental Disorders. *Brain Research*, 34, 19-25.

Blumstein, S.E., Cooper, W.E., Zurif, E.B. & Caramazza, A. (1977). The Perception and Production of VOT in Aphasia. *Neuropsychology*, 15, 371-383.

Botez, M.I., Gravel, J., Attig, E. & Vezina, J.L. (1985). Reversible Chronic Cerebellar Trauma After Phenytoxin Intoxication, Causing Disturbances in Cognitive Thought. *Neurology*, 35, 1152-1157.

Botez, M.I., Leveille, J., Lambert, R. & Botez, T. (1992). Single Photon Emission Computed Tomography (SPECT) in Cerebellar Disease: Cerebello Cerebral Diachisis. *European Neurology*, 31, 405-421.

Bracke-Tolkmitt, R., Linden, A., Canavan, A.L., Rockstroh, B., Scholz, E. & Wessel, K. (1989). The Cerebellum Contributes to Mental Skills. *Behavioural Neurosciences*, 103, 442-446.

Brodal, A. Jansen, J. (1969). The Ponto-Cerebellar Projection in the Rabbit and Cat. Experimental Investigators. *Journal of Comp. Neurology*, 84, 31-118.

Brodal, A. & Szikla, G. (1972). The Termination of Brachium Conjunctivum Decendents in Nucleus Reticularis Tegmentipontis. A Experimental Anatomical Study in the Cat. *Brain Research*, 39, 337-351.

Bruckmoser, P., Hepp, C.M. & Wtesendanger, M. (1969). Conical Influence on the Lateral Reticular Nucleus of the Cat. *Brain Research*, 15, 556-58.

Clendenin, C, Chambers, W.W., & Sprague, J.M. (1955). Functional Localization in the Cerebellum. *Archives of Neurology and Psychiatry*, 74, 653-680. .

Day, R.S. & Vigorito, J.M. (1973). In G.J.Borde and K.S. Harris (1980) (Eds.) *Speech Science Primer - Physiology, Acoustics and Peception of speech*. Wilkins and Wilkins, Baltimore, USA.

Dibrell, J. (1977). Apraxia of Speech : VOT in Initial Stop Perception and Production. In Holt, et al. (1982). VOT Perception and Production in Apraxic Subjects. *Brain and Language*, 18, 318-323.

Fant, G.M. (1960). The Acoustic Theory of Speech Production. Mouton, The Hague.

Fiez, J.A., Peterson, S.E., Cheney, M.K. & Raichle, M.E. (1992). Impaired Non-Motor Learning and Error Detection Associated with Cerebellar Damage. *Brain*, 115, 115-178.

Gandour, T. & Dardarananda. (1982). VOT in Aphasia : Thai I. Perception. *Brain and Language*, 17,24-33.

Grafman, J., Litvan, I., Marsaquoi, S., Stewart, M., Sirigu, A. & Hallett, M. (1992). Cognitive Planning Deficit in Patients With Cerebellar Atrophy. *Neurology*, 42, 1493-1496.

Haggard, M.P., Ambler, S. & Callow, M. (1975). Pitch as a Voicing Cue. *Journal of Acoustical Society of America*, 47, 613-617.

Hoit, J., Kopp, P., & Murray, T. (1982). VOT Perception and Production in Apraxic Subjects. *Brain and Language*, 18, 318-328.

Holmes, G. (1939). The Cerebellum of Man. *Brain*, 62, 1-30.

Honk, J.C. & Wise, S.P. (1997). Distributed Modular Architectures Linking Basal Ganglia, Cerebellum and Cerebral Cortex : Their Role in Planning and Controlling Action. *Cerebral Cortex*, 5, 95-111.

Irvy, R., Baldo, T.V. (1992). Is Cerebellum Involved in Learning and Cognition? *Current Opinion in Neurobiology*, 2, 212-216.

Irvy, R., & Gopal, H.S. (1992). Cited in Ackermann, M.O., Graver, S., Hertrich, J. & Daum, T. (1997). Categorical Speech Perception in Cerebellar Disorders. *Brain and Language*, 60, 323-331.

Irvy, R., Keele, S.W., & Diener, H.C. (1988). In Ackermann, H., Schugens, M.M., Reimold, C, Daum, J., Dichgans, J. & Birbaumer, N.(1993). *The Cerebellum and Cognitive Functions in Humans*, 107,411-419.

Irvy, R., & Keele, S.W. (1989). Timing Functions of the Cerebellum. *Journal of Cognitive Neuroscience*, 1, 132-150.

Irvy, R., & Keele, S.W. (1991). Does the Cerebellum Provide a Common Computation for Diverse Tasks? A Timing Hypothesis. *Annals of the New York Academy of Sciences*, 608, 179-211.

Ito, M. (1984). *The Cerebellum and Neural Control*. New York: Raven Press.

Keidal, W., Kallert, S., Korth, M. & Humes, I. (1983). In F.E. Musiek & J.A. Baran Tutorial: Neuroanatomy, Neurophysiology and Central Auditory Assessment, Part-I :Brainstem. *Ear and Hearing*, 7(4), 214, 1986.

Kim, S.G., Ugurbil, K. & Strick, P.L. (1994). Activation of a Cerebellar Output Nucleus During Cognitive Processing. *Science*, 265, 949-951.

Kish, S.J., Schut, L., Leach, L., Oscar-Berman, M. & Freedman, M. (1988). Cognitive Defects in Olivoponto-Cerebellar Atrophy : Implications for the Cholinergic Hypothesis of Alzheimer Dementia. *Annals of Neurology*, 24, 200-206.

Kittai, J.A., DeFrance, L., Hatada, K. & Kennedy, L. (1967). Cited in Allen, G., Azzena, G.B. & Ohno, T (1974). Cerebellar Purkinje Cell Responses to Inputs From Sensorimotor Cortex. *Experimental Brain Research*, 20, 239-254.

Leiner, H.C., Leiner, A.L. & Dow, R.S. (1986). Does Cerebellum Contribute to Mental Skills. *Behaviour Neurosciences*, 100, 443-4544.

Leiner, H.C., Leiner, A.L., Dow, R.S. (1995). The Underestimated Cerebellum. *Human Brain Mapping*, 2, 244-254.

Lieberman, A.H., Eimas, R. Lisker, C. & Bastian, J. (1961). An Effect of Learning on Speech Perception. The Discrimination of Directions of Silence With and Without Phonemic Significance. *Language and Speech*, 4, 175-195.

Lisker, L. & Abramson, A.S. (1964), A Cross-Language Study of Voicing in Initial Stops : Acoustical Measurement. *Word*, 20, 384-422.

Miller, J.W., Wier, C.C., Pastove, R.E., Kelly, W. & Dooling, R.J. (1976). Discrimination and Labelling of Noise-Buzz Sequences With Varying Noise Lead Times : An Example of Categorical Perception. *Journal of the Acoustical Society of America*, 60, 410-417.

Motonubu, H., Tatsumi, F. & Sasanuma, S. (1986). VOT Perception in Japanese Aphasic Patients. *Brain and Language*, 21,412-417.

Pasual-Leone, A (1993). in Leiner, H.C., Leiner, A.L. and Dow, R.S. (1994). Cognitive and Language Functions of the Human Cerebellum. *Trends in Neuroscience*, 16, 444-454.

Peterson, S.E. & Fiez, J.A. (1993). Cerebellar Activation During Mental Imagery. *Annual Reviews in Neurosciences*. 16,509-530.

Repp, B.H., Liberman, A.M., Eccardt, T. & Pesetsky, D. (1978). Perceptual Integration of Acoustic Cues for Stop, Fricative and Affricative Manner. *Journal of Experimental Psychology: Human Perception and Performance*, 4, 621-637.

Rosen, H. & Scheid, A.E. (1969). Cited in Allen, G., Azzena, G.B. & Ohno, T. (1974). Cerebellar Purkinje Cell Responses to Inputs from Sensorimotor Cortex. *Experimental Brain Research*, 20, 239-254.

Ryding, E., Decety, J., Soholm, H., Stenberg, G. & Ingvar, D.M. (1993). Cerebellar Activation During Word Processing. *Cognitive Brain Research*, 1, 94-99.

Sanes, J.M., Dimitrow, B. & Hallett, M. (1990). Motor Learning in Patients With Cerebellar Dysfunction. *Brain*, 113, 103-120.

Sasaki, K., Oka, H., Matsuda, Y., Shimo, T, Mizuno, N. (1979). Electrophysiological Studies of the Projections from Parietal Association Area to the cerebellae Cortex. *Experimental Brain Research*, 23, 91-102.

Schmahmann, J.D., Sherman, J.C. (1998). The Cerebellar Cognitive Affective Syndrome. *Brain*, 121, 561-579.

Silveri, M.C., Leggio, M.G., & Molinari, M. (1994). The Cerebellum Contributes to Linguistic Production : A Case of Agrammatic Speech Following a Right Cerebellar Lesion. *Neurology*, 44, 2047-2050.

Solomon, P.R., Lewin, J.L., LoTurco, J.J., Steinmetz, J.E., & Thompson, R.F. (1986). The Role of the Middle Cerebellar Peduncle in Acquisition and Retention of the Rabbit and Classically Conditioned Nictitating Membrane Response. *Bulletin of the Psychosomatic Society*, 24, 75-78.

Solomon, P.R., Stowe, G.T & Pendlebury, W. W. (1989). Disrupted Eyelid Conditioning in a Patient with Damage to Cerebellar Afferents. *Behavior Neurosciences*, 103, 898-902.

Thompson, R.F. (1988). The Neurobiology of Learning and Memory. *Science*, 233, 941-947.

Thompson, R.F. (1991). The Neurobiology of Learning and Memory. *Science*, 329, 161-170.

Van Dongen, H.R., Catsman-Berrewets, C.E., Van Mousik, M. (1994). The Syndrome of 'Cerebellar' Mutism and Subsequent Dysarthria. *Neurology*, 44, 2040-2046.

Wallesh, C.W. & Horn, A. (1990). LongTerm Effects of Cerebellar Pathology on Cognitive Functions. *Brain and Cognition*, 14, 19-25.

Weiner, M.J., Hallett, M. & Funkenstein, H.H. (1983). Adaptation to Lateral Displacement of Vision in Patients With Lesions of the Central Nervous System. *Neurology*, 33, 766-772.