AN INVESTIGATION OF SPEECH MOTOR PLANNING ABILITIES IN TAMIL SPEAKING CHILDREN BETWEEN 5 TO 8 YEARS OF AGE

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A Dissertation submitted in part fulfillment for the
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MAY - 2002

Dedicated to

Karan, *Avi,* ***Aditya*** and ***Sneha*** . . . . the foursome who had opened a new horizon in me

&

My dear guide, ***Manjula ma'm*** . . . . . .

For all the faith, the challenges and the wider perspectives which you have all given me. . . . and for the knowledge that you've all given me, (not just technical) but the MORE essential, life's lessons!

CERTIFICATE

This is to certify that the dissertation entitled **"An investigation of Speech Motor Planning abilities in Tamil speaking children behveen 5 to 8 years of age"** is the bonafide work in part fulfillment for the degree of Master of Science (Speech and Hearing) of the student with Register No. M2K09.

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CERTIFICATE

This is to certify that the dissertation entitled **"An investigation of Speech Motor Planning abilities in Tamil speaking children between 5 to 8 years of age"** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in any other University for the award of any Diploma or Degree.

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DECLARATION

I hereby declare that this dissertation entitled **"An investigation of Speech Motor Planning abilities in Tamil speaking children between 5 to 8 years of age"** is the result of my own study under the guidance of **Dr. R. Manjula,** Reader in Speech Pathology, Department of Speech Pathology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier at any other University for the award of any Diploma or Degree.

Mysore
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ACKNOWLEDGEMENT

/ would like to express my sincere gratitude to my guide, ***Dr. R. Manjula,*** *Reader, Department of Speech Pathology, All India Institute of Speech and Hearing, Mysore for her constant guidance and support in the completion of the study. Thank you ma'am, for EVERYTHING that you've given me - knowledge, faith and constant encouragement. I owe a lot to you and I only hope that someday, I 'II live up to your expectations.*

I thank ***Dr. M. Jayaram,*** *Director, All India Institute of Speech and Hearing, Mysore, for allowing me to conduct this study.*

1 am thankful to ***Mr.*** *R.* ***Elangaiyan*** *for his thought provoking ideas and critical comments in the preparation of the material for the study.*

I thank all (he sweet little ***children*** *who enthusiastically participated in the study.*

I also take this opportunity to thank (he Correspondent, Principal and Staff of both the schools, ***Bharathi Vidya Bhavan*** *and* ***Prasanthi Vidya Bhavan, Erode, Tamil Nadu*** *for allowing me to collect data from their schools.*

I thank ***Dr. S. Venkatesan,*** *for helping me with grouping and analysis of (he data.*

Animesh *sir, you have taught me "to think - question and learn ", one of the most essential things in any education. You have really helped* *me to believe in myself right from audio till shuttle! Thank you, sir, for all the faith and encouragement.*

I thank Ms. ***Rathnafor*** *giving this work its final form.*

Amma, *you are my strength in all my weak points and whatever I am today, 1 owe it to you and your blessings, support, optimism and the infinite faith you have in me.*

Anna, *no matter what happens, I know you WILL be there for me, with your reassuring smile and ideas. You have always believed in my potentials and given me the space I needed to function. Hope we both shall continue to GROW together and scale the great heights waiting for us.*

Ananthi, Anitha, Anu and Krupa, *when friends like you are around there is always scope for strength, smile and spirits. Throughout not only have we laughed, teased, shared and cared, but also fought and hurt and learnt.........in short, "Grown" to be better individuals! Memories of our time together are some of my dearest possessions. No matter where the life takes us, the heart knows to "hold on forever"- especially those who are dear and special.*

Anna *and* ***Siddo*** *- thanks for all the good times we've shared together!*

Finally, thanks to all my classmates and others who have made my A11SH life complete in their own sweet and significant ways.

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INTRODUCTION

Speech is a goal directed and afferent guided motor skill. The neural mechanisms which are used to produce speech and the speech motor control, are achieved through neuronal activities that initiate and regulate muscle contraction for speech production. A speaker generally uses a highly flexible motor program with motor equivalence, while achieving maximum precision (clarity) in production.

The theoretical basis for understanding the processes underlying normal speech (including both flexibility and precision) is generally explained by models. Models represent ways of conceptualizing the many different facets of a particular phenomenon and among the speech production models, some authors have viewed speech motor control as a whole, while others have described specific phases of the speech production, like execution / programming etc., Traditionally, a minimum of 3 phases have been described as being involved in speech motor control, namely planning stage, programming stage and execution. (Eg: Serial Order Models by Rosenbek, Kent and LaPointe, 1984; Hierarchical Model by Roy, 1978; Cognitive based reconceptualization by Whiteside and Varley, 2000; Vander Merwe's Model by Vander Merwe (1997). All these models reinstate the fact that speech should be planned appropriately for its parameters like adequate spatial precision at the appropriate instant in time. This is also reconfirmed by the fact that apraxic speakers exhibit deficit in these areas, leading to erroneous speech production. (Kent & Rosenbek, 1982; Zeigler & Von Cramon, 1986; Skenes, 1987).

Need for the Study

Although theoretically, models explain the speech motor planning (both in normals and in the clinical population), there have been very few reports of any emperical data to support these concepts in the literature. But unless such theoretical concepts are verified, the clinical utility of these concepts in diagnosing or treating cases with motor speech disorders will remain uncertain. Hence this study attempts to investigate the nature of the planning stage (as described by various models) through certain behavioural tasks.

Review of literature suggests that there is a developmental trend in speech motor control and the concept of "speech motor age" has been proposed by various authors. (Morris, 1980; Miller, Rosin, and Netsell, 1979). Speech motor age is a concept wherein developmental age in months in assigned for functional expression of the child's expressive performance of the selected speech motor acts. In other words, it attempts to describe the early expressive speech as a sequentially acquired motor event consequent to neuronal maturation. Speech motor planning abilities which will have a direct influence on the expressive speech, can be correlated with the spatial and temporal approximation of the final end product, speech. Akin to such observations, the speech motor planning, which is an internal phenomenon can be inferred by the spatiotemporal approximations of certain linguistic material. Such a study would provide insights in to the nature of the planning system, its accessibility to tests and other related factors.

Studies have often discussed the nature of speech motor control by employing acoustical or physiological means of analysis. But in this study, such observations are hypothesized to be accessible and replicable even by psycholinguistic means under appropriate performance load condition. Hence, this study attempted to investigate the speech motor planning abilities in children between 5 years and 8 years of age through an appropriate psycholinguistic task, by inferring about the spatio temporal skills achieved by these children.

An effort has also been made to report any evident maturational pattern in the planning abilities. Psycholinguistic task was selected for the study because there is evidence cited in the literature that spatio temporal coordination ability is reflected in the segment duration of an utterances, which in turn is conditioned by the linguistic content of production. (Netsell, 1986; Gilbert and Purves, 1979). These investigators have proposed that the accuracy and durational features of speech utterances indicate the integrity of spatiotemporal coordination ability. Netsell (1986) suggests that this ability is refined as the child matures and that, among the other aspects of speech motor control such as acquisition of force dynamics, precision of movement etc., it is the spatiotemporal coordination abilities which is dominant over a period of 3 years to 11 years.

In the present study, Tamil was used in which children are reported to acquire all the phonemes by 4 ½ years. (Thirumalai, 1972). For these reasons, the study was conducted on children between 5 and 8 years of age, as it was evident that children of this age group would have acquired all the phonemes and would be in the process of refining their speech motor abilities in terms of better spatio temporal coordination.

Aims of the Study

- To investigate the speech motor planning abilities, specifically* the spatiotemporal coordination abilities in normal Tamil speaking children between 5 to 8 years of age through psycholinguistic means.
- To analyze for any evident maturational pattern in the speech motor planning in the selected groups of children.

Methodology

30 children each in the age group of 5-5.11 years, 6-6.11 years and 7-7.11 years will be selected for the study and they will be asked to repeat 8 tongue twisters of Tamil language, "as fast and as clearly as possible". The speech sample will be analyzed for

a) Temporal abilities.
b) Spatial abilities,
c) The combined spatiotemporal abilities.

Implications of the study

This study is a preliminary attempt to investigate the nature of the planning system in the children between 5 and 8 years of age. Many studies in the past have employed physiologic or acoustic analysis of the speech motor task performed by the children. In contrast, this study has employed a behavioural analysis paradigm (by perceptual means), employing rating scales. This study will:

- yield data on the normal speech motor planning abilities in the form of a range of values (as in the rating scale) and this can be further modified as a clinical tool.

- Open avenues by further investigations on the functional abilities in the motor planning skills in children through behavioural means. This would further help us in delineating the stages of processing like planning / programming, which in turn, will help in improving the focus of rehabilitation.

Limitations of the study

- Due to time constraints the analysis was restricted in its extent. A more extensive error analysis / performance analysis might have yielded more information on the precise nature of the breakdown of the planning system.

- The method of analyzing time in the temporal abilities was by use of a stopwatch by the experimenter. So the reaction time of the experimenter could have affected the results. In this study, this variable was assumed to have affected all the sampled data equally, as it was not controlled.

- To draw and generalize inferences, more number of children from different samples of the population need to be tested.

REVIEW

Introduction

Spoken language is one form of communication that enables humans to convey information with specificity and detail. The physical act of speaking can be viewed as a series of transformations beginning with a set of neural effector commands that control more than 100 muscle contractions. These muscle contractions move the various peripheral structures involved in speech production. (Netsell, 1986). Understanding the functional nature of the neuromotor mechanisms involved in the production of speech is in the frontier of the current research programs on normal speech physiology. Research is directed at explaining the complex neurophysiological and physical processes involved in speech production. They aim to further our understanding of normal speech motor processes which in turn helps in the diagnosis and treatment of the motor speech disorders.

Speech Production

Speech is an externalized expression of language, and the sensorimotor control for speech can be defined as "the motor afferent mechanisms that direct and regulate speech movements"(Netsell, 1982). As a motor skill, speech is described as a "goal directed" and "afferent - guided" event. Such a definition envisages that speech is a fine motor skill, which includes the following features. It is an activity which (1) is performed with accuracy and speed (2) uses knowledge of results (3) is improved by practice (4) demonstrates motor flexibility in achieving goals and (5) regulates all of these to automatic control, where "consciousness is freed from the details of action plans" (Wolff, 1979). From a linguistic psychological point of view, speech is described as a sequence of temporally non-overlapping and invariant units eg. Phonemes, syllables, words. However, presence of features like coarticulation, reduction and omission of phonemes indicate that the physical correlates of linguistic units are neither temporally discrete nor independent of context. To resolve this paradox, Lindblom, Lubker and Gay (1979) proposed that in successful speech communication, linguistic units meet a condition of "perceptual equivalence" rather than one of acoustic invariance. That is, linguistic units need to be realized in physically explicit form only to the extent that they cannot be perceptually restored by the listener, suggesting that the execution of speech is a highly flexible act.

In summary, speech can be considered as a goal directed motor skill wherein the goal is to produce the appropriate acoustic pattern via flexible motor actions. These motor actions are not fixed movement routines or stored patterns of muscle contractions. The speaker uses a highly flexible motor program to achieve the same acoustic result. The theoretical basis for understanding the processes underlying normal speech production (incorporating both flexibility and precision), is provided by various models.

Models of Speech Production

Models represent ways of conceptualizing the many different facets of a particular phenomenon and hence, to hypothesize and explain disordered conditions. A number of models have been put forth to explain speech production and speech motor control.

During the production of speech, the intended message has to be changed from an abstract idea to meaningful language symbols and then to a code which can be handled by a motor system. There is a gradual appearance of new formations out of pre-existing ones, in many phases. Most neurophysiologists opine that the motor control process involves several phases or hierarchical levels of organization (Jakobson and Goodale, 1991). These phases are generally identified as planning, programming and execution. (Brooks, 1986; Gracco and Abbs, 1987)

Some authors have described speech motor control as a whole, with mere suggestions of the phases involved. Later studies however have described specific phases like the speech execution / programming and describe the specific features of these phases. The various models are reviewed as follows.

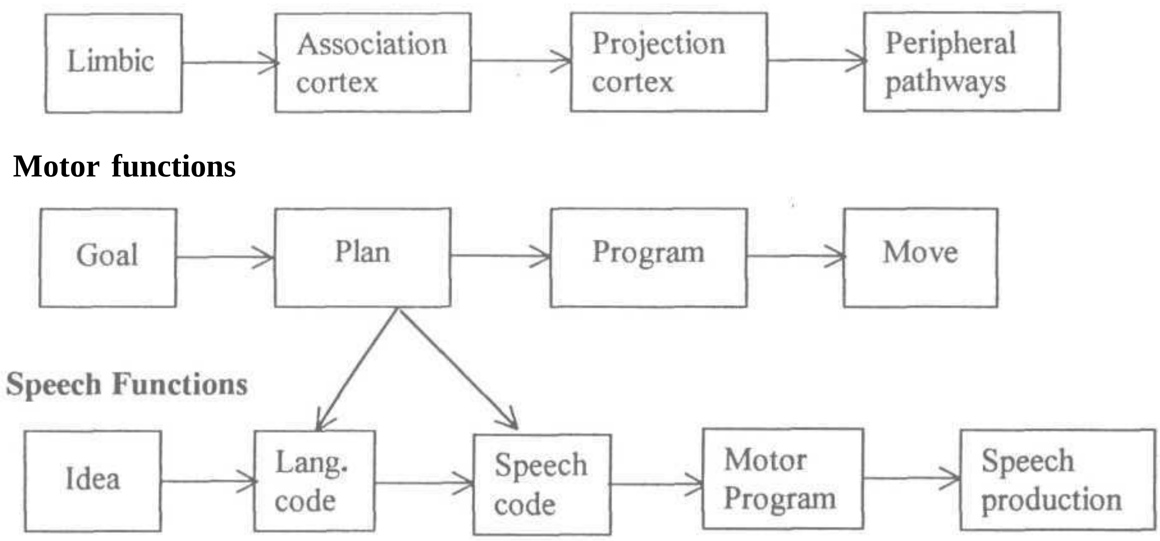
- The models describing the speech motor control in general.
- Models explaining the specifics of the speech motor control.

Models describing the speech motor control in general

Model proposed by Brooks (1986b) describes the execution of any motor behaviour in the same way as Kent and McNeil (1987). Motor behaviour starts with a goal or idea which is organized into a plan, coded into a specific motor program, and executed. Brooks (1986b) described these activities with reference to potential systems of neural regulation. From an emotive base, the limbic system demands movement. Activity in the association cortex (eg: prefrontal, parietal, and temporal) analyzes these demands and formulates a strategy or plan of action. This plan a forwarded to projection cortex, which in combination with various subcortical and brainstem structures formulates specific motor tactics or programs that are to be executed.

Likewise, in favourable circumstances, speech production begins with an idea. To communicate this idea, the speaker must organize it into a linguistic code that contains meaning (semantics) and form (syntax). The form of the message then must be shaped into units of speech production. These units must be organized according to their own rules of appropriate combination (Phonology). Because speech is a "physical phenomenon", these organized speech units must be transformed or coded into a motor program. Subsequently this motor program is used to execute movements of the vocal tract that result in production of the organized speech units. In this frame work, speech begins as a mental concept that becomes linguistically organized, is transformed into a motor behaviour, and is executed as a movement. Activity at any step along the process will influence the next step and possibly the preceding step. Schematically, this can be represented as

Neurological system



Kent and McNeil (1987) offered the conceptual model of speech processing. According to this model, the auditory speech processor (ASP) functions as a phonetic analyzer. Output from the ASP is considered as phonetic representation of the intended utterance. At this point, the analyzed auditory information is believed to contain little meaning. ASP output is directed either to the central language processor (CLP) or to the articulatory coder (AC). The CLP is responsible for semantic interpretation. It is also thought to transform semantically interpreted information to the motor areas. This may be the general area where lexical items (words) are selected and phonologically organized (Cappa, Cavolotti, and Vignolo, 1981). This information is forwarded to the AC which is thought to convert phonetic (information derived from the ASP) or possibly phonological (information derived from the CLP) information into articulatory specifications. This area (the AC) seems to be the architect of motor speech programming. Hence plans or blueprints for speech are developed. The information guiding these plans may be semantically potent, arriving from the CLP, or semantically void, arriving from the ASP. The articulatory plans generated by the AC are forwarded to motor speech programmer (MSP). The MSP converts the articulatory code into motor programs. These programs (possibly a complex set of neuromotor instructions) are enacted via the primary motor area (PMA).

Thus, the above two models suggest that there are many potential information processing steps applicable to speech production between the selection of target and the execution of movement.

Models which explain specifics of speech motor control

Some investigators explain how speech is executed / produced after the occurrence of "conceptualization". These models and theories have tried to explain various features and properties of the speech production system like its ability to self correct through feed back, the phenomenon of coarticulation, its ability to sequence the various articulatory movements and the ability to plan the various dynamics of motor events like force, velocity of movement etc,. There seems to be a hierarchy in the evolution of theories, as they try to define this complex motor control phenomenon. This is evident from the properties that each model addresses. Most of the former models explained whether speech is dependent on sensory feedback or not (a very basic and broad property of the system) through closed loop and open loop models respectively.

This was followed by attempts to explain finer properties namely, the coarticulatory and other speech production abilities. This led to the contemplation of how initially these units are planned for their dynamics like force, velocity etc., and how each of these planned units get altered due to the influence of preceding and following sound. So, the models that were proposed later believed that both open and closed loop features are essential for speech control and also, they try to incorporate planning and execution of these planned units. Keeping these issues in mind, the review would be restricted to the recent models which explain all the properties of speech motor control system. A brief description of the models will follow in the order of,

1. Serial order models.
2. Roy's Hierarchical model.
3. Schema theory.
4. Task Dynamic model.
5. Vander Merwe's model.

1) Serial Order Models

Rosenbek, Kent and La Pointe (1984) have attempted to explain the sequencing of movements as they occur in time. In one version, based on Lashley's (1951) model of serial order in behaviour, an attempt has been made to relate movement to three stages of production (1) determining tendency (2) priming of expressive units, and (3) schema of order. The determining tendency represents the idea to be expressed. The priming mechanism is used to alert the expressive language system and then select the appropriate linguistic units in the correct locations in an output unit. Thus, in these models, the existence of some planning ability is suggested in the first two stages. However it has not really explained the stages or properties of this ability i.e. where and how the parameters are coded etc.,

2) Roy's Hierarchical Model

This is a form of programming model which was specifically developed to explain apraxic errors seen in limb movements of adult patients with neurologic disease. Roy (1978) postulated that motor skill performance is based on hierarchically organized motor programs. This model has two major components : a "planner" and an "executor". The planner comprises the goal selector and the sequencer. The highest level of Roy's model is the goal selector, which functions to select the goal for a given action. The model postulates that the goal selector is not operative for movements that are highly habituated. Thus, the more automatic a movement, the less it relies on the goal selector.

The next level of the system in Roy's model is the sequencer, which functions to order motor output. It has cognitive and perceptual components. The cognitive component makes decision about the elTcctor units (musculnture) and the sequencing of the movements. The perceptual component provides sensory information to assist in decision making by way of feedback loops.

The executor comprises a programmer, movement subroutines, and individual movement units. The programmer functions to work out the specifications derived from the planning component and programs the combinations of movements that will be required to accurately achieve a movement. The movement subroutines are programs that contain the various movements that need to be evoked to achieve a goal, while the individual movement units are single movements that make up a given pattern used by the subroutine component.

3) Schema Theory

This model proposed by Schmidt (1988), was originally developed to explain speech motor control including both open and closed loop features. This theory postulates that there are three components of motor control systems; generalized motor programs, recall schema, and recognition schema.

Generalized motor program

According to Schmidt, a motor program is an abstract memory, that when activated, causes movement to occur. It suggests that the components of **a** movement are stored centrally and hence does not rely on feedback mechanisms to operate or to execute a movement. But unlike a pure open loop model, there are numerous ways to execute a generalized motor program.

In this program, various movement parameters (e.g. force, velocity and displacement) are determined prior to execution. The program contains some abstract notion of which components make up a movement, but the actual physiological variables that are employed for a given task may vary. Hence this suggests one generalized motor program for various other tasks.

Recall Schema

A recall schema is defined as a rule based on past experience (i.e. related to previous attempts to achieve the movement goal). The development of recall schema requires information pertaining to the initial conditions used to execute a given movement such as specific physiological parameters, relative positions of structures, and knowledge of the results. A logical extension of this premise is that the greater the number of experiences with a given generalized motor program, the more developed are the recall schema.

Recognition of Schema

This is used for the evaluation of the target response. Recognition schema comprises of initial conditions, past and current outcomes of movements, and the sensory consequences of actions. As additional variability is encountered with a given task, the scope of the recognition schema is expanded. This expansion increases the strength of the recognition schema, which is also enhanced by the expanding knowledge of results. Evaluation of a movement may occur during the production of movements and / or after its completion. Outcomes of novel responses may be predicted because their development is dependent on the variability of past experiences. Knowledge of results is an extrinsic feedback, (i.e.) information about the achievement of a task in regard to the environmental goal. This is different from the knowledge of performance which is information about the movement, not the environmental goal. Schmidt (1988) notes that this type of information may be related to aspects of a complex movement that a person is only vaguely aware of, even aspects of movements that they may not be consciously aware of, such as that provided by biofeedback.

So, this model has attempted to explain more details with respect to motor control, i.e. a "planning" stage depending more on the generalized motor program recalled from memory. The experience and also the "adaptive" nature of the motor system for novel responses is emphasized. Thus, some attempt towards explaining "motor equivalence", a unique capacity of the motor control system has been done. However the details of either the planning stage or how the motor equivalence is achieved has not been explained.

4) Task Dynamic Model

This model has been proposed by Saltzman and Kelso (1983) to give a dynamical account for skilled activity. This model characterizes as much as possible, a relatively autonomous, self organizing dynamical system.

Speech production through this model has been explained through two dynamics (i.e.).

- Dynamics of interarticulatory coordination within single speech gesture eg: coordination of lips and jaw to produce a bilabial closure.

- Dynamics of intergestural coordination with special attention being paid to periods of "coproduction", when the blended influences of several temporally overlapping gestures are evident in the ongoing articulatory and acoustic patterns of speech. For isolated gestures, invariant control structures are defined in this model that give rise to constriction specific and contextually variable patterns of articulator movements. This is accomplished in two basic steps:

  1) To define the invariant dynamical control regime at an abstract, task specific level of system description.

  2) To use these invariant dynamics to generate the contextual variation observed for articulatory trajectories.

An additional construct considered here is the "Gestural Activation" which refers to the strength with which a gesture attempts to shape vocal tract movement at a given point in time. Each gesture activation coordinate reflects the ongoing strength of that gesture's control in shaping the vocal tract. Invariant gestural units are in the form of context independent sets of dynamic parameters, and are associated with corresponding model articulator coordinates. Each gestural unit's influence over the vocal tract waxes and wanes according to the activation of units. Variability emerges in the unfolding of articulatory movements as a result of both utterance - specific interleaving of gestures and the accompanying process of coproduction and blending.

Each of these construct has been tested through experiments by the investigators and the components have been described. One such report in 1993 by Saltzman has summarized the essential qualities of the system as seen in the following description.

Inter Articulatory Coordination - (Single speech Gesture)

In the task dynamic model, "Coordinative dynamics" suggests appropriate gesture and contextually variable patterns, at the level of the articulatory motions. Since one of the major tasks in speech is to create and release constrictions in different local regions of the vocal tract, the abstract dynamics are defined in coordinates that represent the different configurations of different constriction types. Example, the bilabial constrictions used in producing /p/, *Ibl* or /m/, the alveolar constriction producing /d/, *I\J* or /n/.

Typically each constriction is associated with a pair of so called "tract variable'" coordinates, one that refers to the location of the constriction along with longitudinal axis of the vocal tract and one that refers to the degree of constriction measured perpendicular to the longitudinal axis in the midsagittal plane. Example, bilabial constrictions are defined according to the tract variables of lip aperture and lip protrusion.

Just as each constriction type is associated with a set of tract variables, each tract variable is associated with a set of "model acticulator" coordinates that comprises an articulatory subset for the tract variable. The model articulators are defined according to the articulatcry degrees of freedom of the Haskins software synthesizer. The model articulators are controlled by transforming the tract variable dynamical system into model articulator coordinates. This coordinate transformation creates a set of gesture specific and articulatory posture - specific coupling functions among the articulators. These functions create a dynamical system at the articulatory level whose modal, cooperative behaviours allow them to flexibly and autonomously attain speech relevant goals.

Tract Variables	Model Articulators
LP Lip protrusion	Upper and lower lips
LA Lip Aperture	Upper and Lower jaw
TDCL Tongue dorsum constrict location	Tongue body, Jaw
TDCD Tongue Dorsum constrict Degree	Tongue body, Jaw
LTH Lower Tooth Height	Jaw
TTCL Tongue Tip constrict location	Tongue tip, body, Jaw
TTCD Tongue Tip constrict degree	Tongue tip, body, Jaw
VEL Velic Aperture	Velum
GLO Glottal Aperture	Glottis

Cognitive Based Reconceptualisation

One of the major drawbacks of the task dynamic model, lies in its inability to account for the variance that is planned at higher levels. But this is being explained by concepts as proposed in the "Cognitive based reconceptualisation" by Whiteside and Varley (1998). In this concept, the authors have tried to explain the phenomenon by pooling various studies and their conceptualizations. Finally they have tried to explain the features of apraxia of speech, a condition which affects planning.

According to this concept, movement parameters of frequently used syllables are stored and those of phoneme sequences which are used less frequently are calculated when the need arises, suggesting two encoding routes that is, direct and indirect routes respectively. Here they incorporate concepts of Browman and Goldstein (1992) and that of the task dynamic model and explain that the direct route contains abstract gestural scores which are then passed on to the "articulatory network" which is a coordinative motor system that includes feedback mechanisms. (Kelso, Saltzman & Tuller, 1986). This motor system contains coordinative structures, (Kelso and Tuller, 1981) which become established through the cumulative storage of verbo-motor patterns. The route is therefore computationally more efficient as it relies more on storage and less on on-line computation. It is proposed that this route would operate for high frequency syllables and words. (Levelt and Wheeldon, 1994). In contrast, the 'indirect route' relies heavily on on-line computation and is utilised for novel and very low frequency words. They also believe that this route would be used when greater "care" and hence more conscious on-line control of speech production is required, like when delivering a lecture / speech. This factor suggests that the source of data is an important variable considering the unit of planning in speech. Speech error data drawn from samples of careful speech, is likely to contain bias towards the sub-syllabic, indirect route encoding mechanism.

A factor that is crucial in considering the processes of speech production is the issue of degree of freedom. This phenomenon arises from the fact that there are around 60 muscle groups in the human vocal tract. These muscle groups cooperate to produce 10 to 15 phonemes a second. This, therefore, places the speech production system under great and highly complex computational demands with large degrees of freedom (Keller, 1987). In order to reduce computational complexity and therefore the degrees of freedom, the physiological system will link variables to form self- regulating autonomous subsystems. (Kelso and Tuller, 1981). This results in generating programs of "movement synergies" or verbo-motor patterns which incorporate sequential, overlapping and parallel relationships between muscle commands and thereby simplifying the task of the speech production system through learned links between muscle commands. The result of this is that by reducing the system's degrees of freedom, movements become more stereotyped and faster (unless the system is deliberately "set" for slowness), because repeated complex calculations of sequential organisation and the degree of muscle contractions have been eliminated (Keller, 1987). The authors on this basis have predicted that syllables / words produced via the direct phonetic encoding route would show more cohesion through higher degrees of coarticulation. In contrast, syllables / words produced via the indirect route would show less cohesion and therefore lower degrees of coarticulation. From this concept we understand that there exists the possibility of different routes for different functions and depending on the demand (linguistic complexity, time etc,.) on the system, a particular route's efficiency may be improved / decreased. Although it accounts for higher level equivalence, the details of conversion from the "verbo patterns" to the "motor patterns" and the stages in which this occurs has not been explained in detail. Thus details about the "motor planning" has been clearly differentiated from the other stages of programming and execution (which probably becomes more relevant with respect to the indirect - ongoing encoding route in the Whiteside and Varley's (1998) concept rather than the direct accessing of stored patterns).

5) Vander Merwe's Model

The control of movements is taken to be exerted through a command (or sensorimotor) hierarchy that can be portrayed as highest, middle, and lowest levels. At the highest level, overall invariant motor plans are created which are converted to motor programs in the middle level,, when specific parameters of movements (eg: amplitude and speed) are defined. At the lowest level, programs are translated into muscular activity and motor execution occurs. (Brooks, 1986a). Hence, this implies a very clear demarcation between the planning and programming processes from a neurophysiological view point. But such a delineation has not been done in many of the speech production models. Moreover, there has not been very clear differentiation between the motor planning stage (referred to by the neurophysiologists) and the linguistic symbolic stage that these authors describe as "planning". For example, Darley, Aronson, and Brown (1975) suggest that the phase of spatial temporal planning of movement corresponds to syntactic planning during speech production. More often, however the motor planning stage is equated to phonological planning during speech production. For example, Gracco and Abbs (1987) propose that motor programming and execution would seem to lie immediately down stream from linguistic planning stages and hence reflect the implementation of phonological goals. The true nature of motor planning is therefore not adequately contemplated and not differentiated from phonological planning. However, it is imperative to view speech as a sensorimotor function of the human brain.

Hence, a theoretical framework was proposed by Vander Merwe (1997) which delineates planning itself into a linguistic symbolic stage and a motor planning stage. This is further followed by stages of programming and execution. A clear differentiation of these processes is necessary to comprehensively define the different sensorimotor speech disorders and their intervention. In the following section, only the planning stage of the model would be described as this is the stage that is relevant to the present study.

The different phases of this model are identified as linguistic - symbolic planning which is a non-motor (or premotor) process, motor planning, motor programming, and execution. The differentiation of the three motor levels is in accord with the motor hierarchy as accepted by most neurophysiologists. (Allen and Tsukaherra, 1974; Brooks, 1986a). The serial analytic model is implicit in many contemporary theories of motor control. (Alexander and Crutcher, 1990). It would be wrong to assume multi level processing as strictly hierarchical and thereby implying one - way information flow. It will be noticed in the framework that information flows in both directions and in loops, indicating sensory motor interaction.

In the proposed framework, the initial intention to communicate verbally closes the links with affective input, as the needs and motivation of the speaker influence the drive to communicate. Therefore, there has to be limbic support of sensorimotor processing.

Linguistic Symbolic Planning

During verbal communication, semantic, syntactic, lexical, morphological, and phonological planning have to take place. This phase in the process of verbal communication requires linguistic symbolic planning based on knowledge of the linguistic rules of the language. The term linguistic symbolic planning indicates the non motor nature of this level of processing.

The intention to communicate verbally originates in the internal biological / cognitive needs of the person or in the external demands exerted by the environment. A message is compiled which reflects both the internal and external sources of input. There is interaction between these areas.

Research indicates that planning of the complete utterance occurs simultaneously and not word for word (Holmes, 1984). Semantic construction of the message, recall and selection of lexical units, and syntactic, morphological and phonological planning occur in coherence. The phonological plan is invariant (Linell, 1982), and changes therein influence the meaning or intelligibility of the utterance. Phonological planning, which is also referred to as the covert aspect of phonology (Edwards and Schriberg, 1983), entails the selection and sequential combination of phonemes in accordance with the phonotactic rules of the language and it is portrayed as a linguistic symbolic function in the proposed framework.

Motor Planning

During the planning stage of the production of articulated speech (versus for instance, type - written language), a gradual transformation of symbolic unit (phonemes) to a code that can be handled by a motor system has to take place.

Motor planning entails formulating the strategy of action by specifying motor goals.

Motor plan is goal oriented and motor goals for speech production can be found in the spatial and temporal specifications of movements for sound production. The sounds or phonemes in every language can be described in terms of place and manner of articulation. Each sound has its own specifications, and these core features can be considered as invariant (Stevens and Blumstein, 1981). The core features determine the invariant core motor plan with spatial (place and manner of articulation) and temporal specifications for each sound. The specifications for movements constitute the motor goals. Invariance can therefore be found in the ultimate goals of production.

The core motor plan is attained during the development of speech and the motor specification and sensory model (what it feels and sounds like) are stored in the sensorimotor memory. While mastering the core motor plan, propioceptive, tactile and auditory feedback is implemented. This feedback loop is indicated in the model.

During speech production, the core motor plans of the sequences of phonological units / phonemes are recalled from the sensorimotor memory. The context within which this motor plan has to be implemented is monitored and sometimes adapted, if the complexity is found too high. Examples of such adaptation can be found in the phenomena of shorter chunks of utterances which are produced as units, (eg: syllabic speech), phonological changes like shortening of a word or duplicating sounds in a word, or slowed rate of speech.

Following recall of the core motor plan, planning of the conservative movements necessary to fulfill the spatial and temporal goal commenses. The different motor goals for each phoneme are to be identified, and the movements that are necessary' to produce the different sounds in the planned unit are then sequentially organized. Interarticulatory synchronization is to be planned for the production of a particular phoneme. At this stage, the potential for coarticulation is created. When the different motor goals for the sounds in the planned unit, which presumably consists of a few words in the normal speaker are specified, a certain movement such as lip rounding can be temporally prepositioned if there is no other opposing movement prior to it.

An invariant core motor plan is recalled from the sensorimotor memory and the motor goals specified, but the "realized speech" violates the linearity and invariance condtions. (Wanner, Teyler and Thompson, 1977). On the articulatory level, speech movements are variant and context dependent, and the boundaries between discrete phonological units fade away (Calvert, 1980; Perkell and Klatt, 1986).

Variance manifested in the spatial and temporal aspects of speech movements originates from various sources. Adaptation of articulatory movements to the sound environment (Borden and Harris, 1984), coarticulation of more than one articulator but for different phonemes (Borden and Harris, 1984), motor equivalence of speech targets with variations in the individual components (Hughes and Abbs, 1976), phonetic and linguistic influences on segmental duration (DeSimoni, 1974; Walsh, 1984) and changes in speech rate (Gay, 1981) are all factors that contribute to variance in speech production.

The core motor plan of the phoneme therefore has to be adapted to the context of the planned unit. Adaptation of the spatial specifications to the phonetic context and to the rate of production has to occur. Adaptation of the temporal specifications to the segmental duration, coarticulation potential, and interarticulatory synchronization takes place. The adaptation of movements, however has to be kept within certain limits of equivalence to ensure that the critical acoustic configuration is reached. Adaptation cannot be guided by response feedback, as the movement has not yet taken place at the moment of planning. It is, however, conceivable that internal feedback (Kelso, 1982) or predictive simulation (Lindblom, Lubker & Gay, 1979) guides adaptation.

Following the identification of motor goals in accordance with the necessary adaptations to the core plan, the different subroutines that constitute the motor plan are specified. Co-occurring and successive subroutines such as lip rounding and velar lift are specified and temporally organized. Systematic feed forward of temporally arranged structure specific motor plan subroutines to the motor programming system then occurs.

The next phases explained are the programming and the execution phase. From the available data, the programming of speech movements entails the selection and sequencing of motor programs of the muscles of the articulators (including the vocal folds) and specification of the muscle - specific programs in terms of spatiotemporal and force dimensions such as muscle tone, rate, direction and range of movements. During the execution phase, the hierarchy of plans and programs is finally transformed into non learned, automatic (reflex) motor adjustments.

Thus the various phases of speech production has been explained by this model. It may be noted that the last phases of the model (programming and execution) are also subdivided into smaller phases and explained thoroughly by the model. (Vander Merwe,1997). Since planning alone is considered in this study, the substages of planning alone has been described.

Development of Speech Motor Control

Speech motor development can be defined as the changes in the structure and functions of the system that controls the production of speech. Like any other biological process of development, speech motor development also consists of growth and maturation. Growth is an increase in size, function or complexity upto some point of optimal maturity. Maturation refers to the emergence of organism's, genetic potential. It consists of a series of preprogrammed changes which comprises alterations not only in the organism's structure and form, but also in its complexity, integration, organisation and function.

Anokhin (1964) hypothesized that motor behaviour was governed by a number of functional systems within the nervous system. A functional system is made up of a group of nervous system structures that developed an "action-system specificity". For example, the neuroanatomy and neurophysiology subserving swallowing would be one such functional system and that subserving speech production could be a second functional system. Given this scheme, swallowing and speech could share certain neuroanatomic structures while maintaining separate neural functional systems. These systems are said to develop on different schedules, according to the needs of the organism. Therefore, the functional system for swallowing is developed in utero, so that it can be ready for use at birth. The functional system for speech motor control on the other hand, is not present at birth. The neural functional system for speech is not in place until near the end of the second year of life. (Netsell, 1986).

Concepts related to speech motor development

The temporal courses and eventual attainment of adult speech motor control seem most dependent on the individual's nervous system maturation. Generally, according to many authors, the following criteria are used in discussion of neural maturation. They are myelination, axonal - dendritic growth, nerve cell proliferations, synaptogenesis, changes in the electroencephalogram (EEG), status of the primitive reflexes (Capute, Accardo, Vining, Rubenstein and Harryman, 1978), movement associated with vegetation (like sucking, swallowing, chewing etc.,) sound production (crying, vocalization, verbalization etc.,) and walking.

The nature of speech and vegetative movement

There are certain commonalities and differences in speech and vegetative movement patterns. One common feature of both types of movement is that they are highly stereotyped and automated. (Netsell, 1982) This had led some investigators to categorize both activities as "reflexive" and this raises the issue as to whether reflexes are used in speech movements. Others contend that reflexes must be inliibited or suppressed in order for normal speech movements to occur.

Again, there is an intermediate view (McClean, 1978; Netsell and Abbs, 1975) suggesting that we use some reflexive motor patterns that would be competitive with the speech movements. Even though the neural commands for speech and vegetative movements are suggested to share certain elements, it is clear that the command centers have different origins at some place in fhe nervous system. It is generally assumed that the speech commands originate in the cerebral cortex and the vegetative commands are triggered from external stimuli or subcortical neurons. Regardless of their loci, the speech and vegetative neural commands our conceived as parallel inputs that would compete at some level of the neuraxis for the 'final' effector neurons, if issued simultaneously. It follows that the vegetative command neurons might be inhibited or otherwise quieted during speech activity. (Netsell, 1982).

Fetal development represents critical periods in infants maturation. According to Netsell's (1986) review, the acquisition of speech motor control is a continuous but a non linear process. Sensitive periods of nonlinearity occur, when certain neural, musculoskeletal, environmental, and cognitive changes combine ("or get together") in the individual organism. The points in time at which a particular number of these combine can result in jumps in performance that appear incremental.

Critical and Sensitive Periods

Clearly, embryogenesis and other fetal developments represent critical periods in the infant's maturation. As Ferry, Culbertson, Fitzgibbons, and Netzky, 1979 (p-10) point out,

"The concept of various critical periods in neurologic development has been proposed to indicate finite items in which specific events must occur **to** provide the substrate for subsequent developmental achievements. This *now-or-ncvcr* hypothesis is based up on imprinting studies in animals and psychological studies of sensorimotor development leading to cognitive skills in children. More recently, however, the concept has been challenged Wolff in 1970, suggested that child behaviour depends upon the complex interaction of many biologic and environmental factors. The concept of "sensitive" periods has been proposed as an alternative, referring to periods when a child may learn particular skills more easily than others.

Based on the early precocity of brain development and the highly complex interaction between neurogenesis, synaptogenesis, and myelination, as described, all phases of early brain development are critical. The most important (if not critical) period of neurologic development is the first 10 weeks of intrauterine life, when the anatomic, physiologic, and biochemical substrates of future developmental progress are being formed".

Speech Motor Age

The child's speech motor age (SMA) can be developed as a measure to represent an age, in which the individual functional components are assigned a particular month based on the child's performance of selected speech motor acts. The acts were selected as minimal sets to represent increasing control of a particular part. A comprehensive chart is being developed by Morris (1980) that includes developmental aspects of pre-speech activities and feeding as well as vocalizations of the first 24 months.

A more complete speech motor age would extend to perhaps 14 years and the long term goal would be to include speech motor acts that capture the essence of minimal change or development in both the speech emergence and speech refinement periods. It is implicit that the final chart will be built from a large body of perceptual, acoustic and physiologic data taken from normally developing children. Given this necessity for a variety of studies, this study is taken up as an attempt to identify and capture the above said minimal speech motor control change (if evident) within a specific age group of 5 to 8 years within the speech refinement period through perceptual means. That is, by using a linguistically controlled material of increasing complexity, the spatial temporal planning, which forms an essential part of speech motor control is implied and studied in detail.

This is in confirmation with the models of speech production reviewed earlier in this section.

The available data and methods of studying them

Traditionally, linguistic approaches, such as phonetic or phonological analyses, have been used to study speech development. However, in addition to psycholinguistic processes, speech production involves skilled motor behaviour. There has been relatively little work focussing on the capabilities and constraints of the developing motor system for speech (Kent, 1981). An improved understanding of speech motor development may stimulate ideas about the organization of motor processes in the adult speaker.

- There have been many studies, (Bruner, 1973; Kent and Moll, 1975; Smith, 1978; etc,.) which use a motor approach to examine the development of a child's skill in producing a given perceptual output. Most of them have selected cross sectional groups of subjects and occasionally some have depended on longitudinal data. These studies have studied the variability in performance before these children reach adult like pattern along with the level of skill development. In the following section, a review of motor based approaches and the data they present will be reviewed.

Motor based approach

Bruner (1973) viewed the development of skilled action as the construction of serially ordered acts, the performance of which is modified to achieve diminishing variability, increased anticipation, and improved economy. These attributes seem highly appropriate to describe the development of motor control of speech. An adult's speech movement patterns are characterized by precise timing (Kent and Moll, 1975), considerable anticipation, which results in extensive coarticulation, or overlapping of articulation for phonetic segments (Daniloff and Hammarberg, 1973; Kent and Minife, 1977), and economy.

A fairly consistent result of studies on children's speech production is that children below 6 years have longer speech segment durations than adults and older children (Subtenly, Worth and Sakuda, 1966; Hawkins, 1973). Smith (1978) reported that durations of nonsense utterances were 15% longer for four year olds than for adults and 31% longer for 2 years olds than for adults. Because limited data is available on the durations of segments in children's connected, meaningful speech, it is not clear if the lengthening of segments is a uniform property of children's speech. This issue is of interest for atleast two reasons.

1) Reduction of segment duration with age may be a consequence of neuromuscular maturation and hence durational measurements may be one way of characterizing a child's developmental progress in attaining adult like speech motor control.

2) Developmental patterns in the control of duration are a necessary substrate for research on the acquisition of phonological processes.

Another developmental pattern, emerging from studies of children's speech is an age dependent decline in variability of performance. (Eguchi and Hirsh, 1969). Taking variability as an index of maturation of motor control, Kent & Forner (1980) assumed that a child's speech production continues to improve in precision until at least 11-12 years of age. In order to study the developmental aspects of segment durations of connected meaningful speech, they selected children from three age groups, four year olds, six year olds, 12 year olds and young adults (college age), for a simple task of sentence recitation. Wide band spectrograms were obtained from the recorded acoustic signal and a variety of time intervals were measured from the spectrograms. The data was in agreement with earlier results, that young children atleast, younger than about six years, tended to have longer speech segments than adults. In addition, these longer mean segment durations often were accompanied by greater speech variability in the repeated productions of the segments. The results indicated that both lengthening of mean segment duration and increased variability of segment duration were more likely to occur under (or interact with) some segmental - suprasegmental combinations than others. For example, the increased mean and variability of VOT seen in /k/ in "cat" but not /t/ in "took" were related to the fact that "cat" is a stressed, utterance final word containing a vowel of inherently long duration.

Variability of timing control is important in characterizing both developing and disordered motor control, whether for speech or motor behaviour generally. But it has been reported that variability of timing may vary with segment duration. Klatt (1974) suggested in a study of duration of friction for /s/ that the precision of timing in speech production may vary with speaking rate, such that the variance of temporal measure decreases as speaking rate increases (and as segment duration is reduced). Lehiste (1972) also reported data in which durational variance clearly declines as the base duration decreases. When variability of timing is used to describe developing or disordered speech, it is important to recognize the possibility that increased variability may be related simply to a slower speaking rate (hence longer segments) and not necessarily to neuromuscular immaturity or neurologic damage. Some reports showing heightened variability for young children or persons with speech disorders may serve as evidence for the general rule that slow speakers are more variable in timing control than fast speakers.

Smith, Kenney and Hussain (1996) report a longitudinal investigation of several temporal characteristics of speech of 12 children of various ages who were seen twice, approximately 1½ years apart. All these children were asked to produce the target words "saucer" and "sissy" 25 times in succession in isolation and then 25 times each in the carrier phases, "say - again". These 100 productions (i.e. 2 words and 2 sentences x 25) by each of the 12 children were audiotaped and subsequently digitized and analysed. The longitudinal analysis of certain acoustic characteristics resulted in some interesting observations that could not have been obtained using a cross sectional design. For the group, durations decreased on average from the initial to followup recordings by approximately 10%, and temporal variability decreased by about 40%. For the individual children however, it was found that some of them showed few, if any, changes in some of the temporal measurements made at two different times, whereas others showed substantial differences. Younger children also did not necessarily show longer durations or greater variability than older children nor did the younger children always show greater changes across time than older children. Thus, although cross - sectional studies indicate that there is a general tendency when comparing groups for increased age to be associated with shorter durations and reduced variability, individual children may not evidence such patterns or changes across time. Similar findings have been reported by Smith and Kenney in (1999) also.

Sharkey and Folkins (1985) present data on the variability of lip and jaw movements in children and adults and draw implications on the development of speech motor control, when they produced [mae] and [bae] 20 times each. Groups of five adults and children at ages 4, 7 and 10 years were taken and the duration of lip-opening movements, jaw - opening movements, lip open postures, jaw open postures and the timing between the onset of lower lip opening and jaw opening were studied, using a strainguage system and a recorder. The recorded signals were displayed with an optical oscillograph. Results showed that all the parameters studied decreased in variability between the child and adult groups. No significant differences were observed in the variability of these measures across the groups of children. The variability of lower lip displacement decreased significantly between the 4 years old, and 7 years old groups, but not between other age groups. Jaw displacement variability did not change significantly between any groups. No significant differences in variability were found between [bae] and [mae]. It was hypothesized that different developmental motor processes affect the variability of speech movements at early, intermediate and older ages. They speculate that there are early processes in the development of the speech motor skill occurring prior to the intermediate ages usually explored through the acoustic studies. Refinement of speech motor skill at each stage might involve tightening the coordinative structures. At other stages, it may not involve tightening the structure, but rather find new motor patterns within it. Thus, different parameters change variability at different ages.

Thus, the above review suggests that the development of speech motor control can be inferred through parameters like variability in production. But the above studies have used either acoustical or physiological means to measure this, whereas there has been limited attempt to elicit the same behaviourally or psycholinguistically. Review of literature also shows that the implications drawn about motor control from these variability measures also varies from investigation to investigation. This suggests that depending on the understanding (from models and other literature) about speech motor control, the variability data (elicited through any means like acoustic or physiological or behavioural) can yield data about normal processes underlying the motor control and also infer on any evident maturational pattern. The following section reviews the differences in the type of the analysis done and subsequently implications drawn from them in various studies.

Variation in variability studies

A number of studies have explored the token-to-token variability of speech motor processes by extrapolating the motor system from acoustic measurements (DeSimoni, 1974; Eguchi and Hirsh, 1969; Kent and Forner, 1980) and analyses of intra oral air pressure (Flege, 1982). In general, these studies have shown that variability of many of the parameters studied decreases with age up to puberty. These studies have interpreted the decline in variability not only within Bruner's (1973) construct of skill development, but they have equated increased variability with movement imprecision or error (Kent, 1976). It is implicit in this approach that there are certain best movement patterns that are refined from a repertoire of less efficient patterns.

Bernstein (1967) has developed ideas of motor skill acquisition that contrast with the variability-as-error perspective. Bernstein stressed that, regardless of the level of skill development, multiple repetitions of a task are seldom repeated with the same movement parameters. Instead, motor tasks employ sets of coordinative structures which produce many functionally equivalent movement patterns. As skill is increased the child may learn new ways to exploit his / her coordinative structure organization to accomplish the task. In this case, token-to-token variability for some parameters might be reduced by refinement in the structural organization, but in other parameters it might be increased by greater flexibility.

Furthermore, even when token-to-token variability decreases as the motor system develops, it may not necessarily reflect refinements in precision. For some motor tasks which may become more regular with age (eg. Locomotion, respiration, and mastication), it may not be reasonable to posit that children make movement errors. Instead, the decreased token-to-token variability in the adult may reflect a decrease in flexibility or it may occur because older subjects prefer habitual patterns. Purves and Lichtman (1980) have pointed out that many tasks are performed with less variability as individuals mature. They have suggested that this occurs through a selective elimination of synapses which may be a general feature of neuro-ontogeny.

It has also been proposed that purposeful tasks develop from modifications of elementary motor processes which may be tapped by eliciting reflexes (Wyke, 1975) or primitive spontaneous movements, for example, the development of walking from the infant's spontaneous kicking. (Thelen and Fisher, 1983). Such a perspective might suggest that the movement patterns for a task initially would be consistent as they evolve from the relatively rigid primitive patterns and would slowly become more variable as the child improves control and exploits the ability to fit motor patterns to variations in the specific needs of the task.

A final perspective is that the variability of movement patterns may play an exploratory role that aids motor learning. This perspective is related to the conventional idea that sensory information plays a more important role in processes of motor learning, than in the performance of highly learned tasks. (Hoyle, 1979).

Thus, there are a number of different interpretations of changes in variability of movement parameters relative to the process of speech motor development. However this does not necessarily detract from the experimental utility of studying movement variability. This is because the changes in variability of movement parameters may signal when in the maturational scheme atleast one of the developmental processes discussed above, such as imprecision, flexibility, habit formation or learning facilitation is occurring. Furthermore, movement variability (when considered relative to the size of movements) is probably not directly influenced by structural growth. In contrast, movement parameters such as displacement, velocity or even timing may be influenced by developmental changes in the anatomy of the speech structures as well as changes in the motor skill.

Furthermore, the various developmental processes may be expected to influence movement parameters differently. An analysis of variability in many movement parameters across ages spanning the development of speech motor skills may allow differentiation among the processes. For example, it has been hypothesized that a coordinative structure organization of speech movement would allow more flexibility in the structural parameters of speech movement (e.g. displacement, velocity) than in the temporal parameters (eg. The duration of a single movement without an overall shift in rate) (Fowler, Ruben, Remez and Turvey, 1980). This approach also suggests that the timing between articulators would be as structured (i.e. consistent) as that within an articulator. (Tuller, Kelso and Harris.,1982).

The study of variability by Sharkey and Folkins (1985) indicates at least three different types of developmental motor processes for speech. One type of processes is part of the organization of the motor system that produces relatively consistent duration parameters by approximately 4 years of age. A second type of process may be involved in refining movement organization at intermediate ages. A third type of process may be related to the decline in variability of all movement duration's studied between the child and adult groups. This third type of process may relate to precision shaping, a preference for habitual patterns or even a reduced involvement of variability in motor - learning processes. A similar finding (i.e) primary phases in the development of lip and jaw coordination for speech integration, differentiation, and refinement, along with existence of distinct coordinative constraints on early articulatory movement has been reported by Green, Moore, Higashikawa and Steeve (2000).

Smith and Goffman (1998) studied children between 4 and 7 years and young adults while they produced a six - syllable utterance 15 times, and calculated the spatiotemporal index (STI). STI reflects the degree to which repeated perfonnance of a task produces movement trajectories that converge on a single pattern. They also report that children produced less stable movement trajectories, as reflected in higher values of STI. Also, measures of amplitude and peak velocity of lip opening and closing movements of children suggested that they have large movement ranges in speech. They also agree that this large amplitude, low-velocity movement style may reflect different underlying control processes. Another analysis of result revealed that children and adults produced equally distinctive movement trajectories which suggests that non linear and non uniform changes occur in components of speech motor system during development.

Based on the above review, two main conclusions can be drawn about speech motor control development:

- Spatial temporal control is improved till around puberty.
- The underlying process responsible for this has not been clear and may present individual variations across various components of motor control in a given individual, suggesting non linearity in development.

In summary, the various studies have employed acoustic and physiological means to arrive at these conclusions. An attempt has been made in the present study to infer similar conclusions about speech motor maturation through behavioural (linguistic) means. Simultaneously, by introducing definite linguistic control (i.e. complex linguistic stimuli to be produced with a specific rate) an attempt has been made to infer about the underlying planning process, during the speech production.

METHODOLOGY

Aims of the Study

To investigate the speech motor planning abilities, specifically the spatio temporal coordination abilities in normal Tamil speaking children in the age group of 5 to 8 years through psycho linguistic means.

To analyse for any evident maturational pattern in the speech motor planning in the selected group of children.

Subjects

30 normal children each in the age group of 5-5.11 years, 6-6.11 years and 7-7.11 years constituting a total of 90 children, whose mother tongue was Tamil, were selected for the study. The subjects were selected from I, II and III grades of 2 randomly selected schools in Tamil Nadu. The male : female ratio of the sample was as shown in the following table

Age group	No. of male children	No. of female children
5-5.11 years	25	5
6-6.11 years	21	9
7-7.11 years	23	7

The ratio is not equal because the subjects were selected on the basis of their ranks (i.e. first 15 rank holders were selected for the study from grades I, II and III) and one of the school had very few girls in each of these grades. First 15 rank holders were selected as the academic performance was suspected to affect the performance,from the results of the pilot study.

Age Range

Based on the review of literature on the development of speech motor control (Netsell, 1982; Wolff, 1979 and Morris, 1980) it was assumed that spatio temporal coordination is dominated in the speech motor development over a period from 3 to 11 years of chronological age and that children whose mother tongue **is** Tamil acquire all the phonemes of Tamil by 4 ½ years of age. (Thirumalai, 1972). So, in order to study the developmental trend in the speech motor planning (in terms of spatio temporal abilities), subjects were selected from 3 age groups, namely, 5-5.11 years, 6-6.11 years and 7-7.11 years.

Test Procedure

Step I: Preparation of the test material and pilot study

Initially 20 phrases, representing tongue twisters in Tamil (which increased in length and complexity) were prepared for the purpose of the study. This was administered to 3 adults and 3 children (between 5 to 8 years of age) in a pilot study to check for the complexity of the material and to try and arrange them in the increasing order of complexity.

After the pilot study, the material was short listed to the following 8 phrases, omitting both the very easy and very difficult ones. These phrases were arranged in the order of increasing length (defined in terms of number of syllables, namely from 6 to 8 syllables) and complexity (defined as concurrent occurance of proximal phonemes eg: /*t/* & /t|/). Accordingly, the 8 phrases were categorized into two levels, namely, level -1 (easy) and level - 2 (difficult).

Level 1 - Easy

1) /muganaga natpu/

2) /Karka kasadara /

3) / doladola t attai / .

Level 2 - Difficult

4) /ta:ta: tatjtja tjattai/

5) /tatjtjar seida tjakkaram/

6) /tjinnandz tjiru silandi/

7) /minnit tiriyum minmini/

8) /ta:ta tanda ja:nait thandam/

Step //: *Data collection and recording of the sample*

Before the actual recording, the children were screened for structural and functional integrity of their oral mechanism. The Tamil Articulation Screening Test was also administered, to ensure good peripheral articulation abilities. Those children who failed in either of these criteria were dropped and excluded from the study. Then the children were given 5 practice trials with the following material, before the actual recording, to familiarize them with the procedure.

1) /rodza dza:di / (2) / maja ma:mbalam/

They were given the following instructions for practise before the recording of each utterance.

"I shall be telling you a phrase. Repeat the phrase after me as fast and as clearly as possible for 5 times". But this was not recorded.

For the actual data recording, the following instructions were given:

"Now, repeat the following phrase 3 times as fast and as clearly as possible. I will be recording whatever you are saying" and the test phrase was told.

The above instructions were repeated before the recording of each phrase and for each child, the recording was done individually in a quiet room set up. The sample was recorded on a portable tape recorder, National Panosonic, LI20.

Analysis

This was carried out in 3 phases, one for temporal abilities and another for spatial abilities, and lastly, the spatial and temporal combined rating.

Phase I: Temporal measure

The first trial of the recorded utterance was measured for its time interval using a stop watch. Only the first trail was considered because it was postulated that by second or third trial, adaptation might occur, in which case the spatio temporal abilities would not be reflected. The analysis of this section included the experimenter measuring the time taken for each utterance using a stop watch and hence, there is a possibility for a human error, that is, the reaction time for switching on / off the stop watch, which could have affected the results. But because this variable could not be controlled and it was common for all the data, it was assumed to have affected all the data samples equally. The raw scores of the temporal data were tabulated for each age group as follows.

y

Subjects	1	2	3	4	5	6	7	8
1.								
2.								
3.								
4.								
30								

Then the range of values obtained for each sentence (after ignoring the extreme values) was determined. This range was divided into 3 ratings namely, for level 1 (easy), any value between 1 second to 1 ¾ seconds was rated as "a"; values between 2 seconds to 2 ¾ seconds was rated as "b" and any value above 3 seconds was rated as "c". Similarly, for level 2 (difficult), values between 2 secs to 2 ¾ sees were rated as "a", those between 3 and 3 ¾ seconds were rated as "b" and those above 4 sees were rated as "c". Any value between 1 ¾ sec and 2 sec / 2 ¾ sec and 3 sec in level 1 and between 2 ¾ sec and 3 sec / 3¾ sec and 4 sec in level 2 was considered in the corresponding higher rating.

Phase II: Spatial measure

Initially, all the utterances were transcribed. Then the samples were analyzed at syllable level for (S) substitution errors, (O) omission errors (D) distortion errors, (A) addition errors, and word preservation errors. Whenever there was preseveration, the sample other than the persevered words were analyzed for SODA errors.

Eg: /ta:ta la:(a tatt a tattai/ (ta:ta - One word perseveration ; t - One substitution error)

Finally the total number of error syllables (including all types) was calculated. The range of errors was calculated for each utterance and then the sentences were classified as

Level 1 (Easy)	0 errors	1 error	≥ errors
Level 2 (Difficult)	0/1 error	2/3 errors	≥4 errors

The total number of individual type of errors namely substitution or omission or distortion or addition or word perseveration were also calculated. With the above values, the mean percentage error at each level was calculated by finding percentage for the mean error value for each type of error. Eg: For addition error (at level 1)

$$\text{Mean \% error} = \frac{\text{Total No. of addition errors}}{540} \times 100$$

where 540 is the total number of syllables uttered by children of each age group in level 1.

For addition error (at level 2)

$$\text{Mean \% error} = \frac{\text{Total No. of addition errors}}{1080} \times 100$$

where 1080 is the total number of syllables uttered by children of each age group in level 2. Similarly, for perseveration errors, mean % error was calculated with the total number of words, namely, 180 words at level 1 and 480 words at level 2 spoken by the children.

Phase III: Spatiotemporal (ST) abilities

To assess this, both the individual ratings of spatial and temporal measures were combined to form one common 5 point rating scale as follows.

Name	*scale*	*Description*
Very good ST skills	0	Combination of "a_1" (in spatial) and "a" (in temporal) scale.
Good ST skills	1	Combination of "b_1" or "a_1" (in spatial) and "b" or "a" (in temporal) scale.
Average ST skills	2	Combination of "b_1 or C_1 or a_1" (in spatial) and "a or b or c" (in temporal) scale.
Partially imprecise ST skills	3	Combination of "c_1 or b_1" (in spatial) and "b or c" (in temporal) scale
Completely imprecise ST skills	4	Combination of c_1 (in spatial) and c (in temporal) scale.

The total number of children falling under each of the 5 categories of scores were calculated and tabulated. Due to time constraints, analysis was limited to this level. However, the data provides scope for further detailed analysis on

1) The type of substitution error, namely which phoneme is substituted more often for a particular target phoneme.

2) Types and distribution of metathetic errors / spoonerisms

3) Whether adaptation is present or not (by analyzing the difference between 1* and 3rd trial)

4) By analyzing the distortion and perseveration errors in a more detailed manner.

Analysis, and inferences were drawn about the planning abilities in terms of spatial and temporal approximations and any evidence for the developmental trend. Results are discussed in the following chapter under the following sections:

- Temporal abilities
- Spatial abilities
- Spatio-temporal (ST) abilities.

RESULTS AND DISCUSSION

The aim of the study was to investigate the speech motor planning abilities in children between 5 and 8 years of age, through psycho linguistic means. Thirty Tamil speaking children in each age group of 5-5.11 years, 6-6.11 years and 7-7.11 years were selected for the study. A task of repeating 8 tongue twisters was selected. After the pilot study the 8 tongue twister which were selected were divided into 2 levels of complexity as, easy (consisting of 3 sentences) and difficult (consisting of 5 sentences) after the pilot study. Children were asked to repeat them as fast and as clearly as possible and the samples were recorded. The recorded speech samples were analyzed in terms of temporal abilities, spatial abilities, and spatio - temporal abilities using appropriate rating scales. The results are discussed under the following subsections.

I. Temporal abilities

II. Spatial abilities and

III. Spatio - temporal abilities

I. Temporal Abilities

The time taken by the subjects to utter each sentence was recorded using **a** stop watch. Based on the range of values obtained by them, the entire sample was grouped into "a", "b" and "c" categories according to the following criteria.

Level 1 - Easy :	1-1 ¾ sec	*2-2 ¾* sec	3 sec & above
Level 2 - Difficult:	2-2 ¾ sec	3-3¾ sec	4 sec & above

(any value between 1 ¾ and 2 sec / 2 ¾ and 3 sec in level 1 and between 2¾ and 3 sec / 3 ¾ and 4 sec in level 2 was considered in the corresponding higher rating).

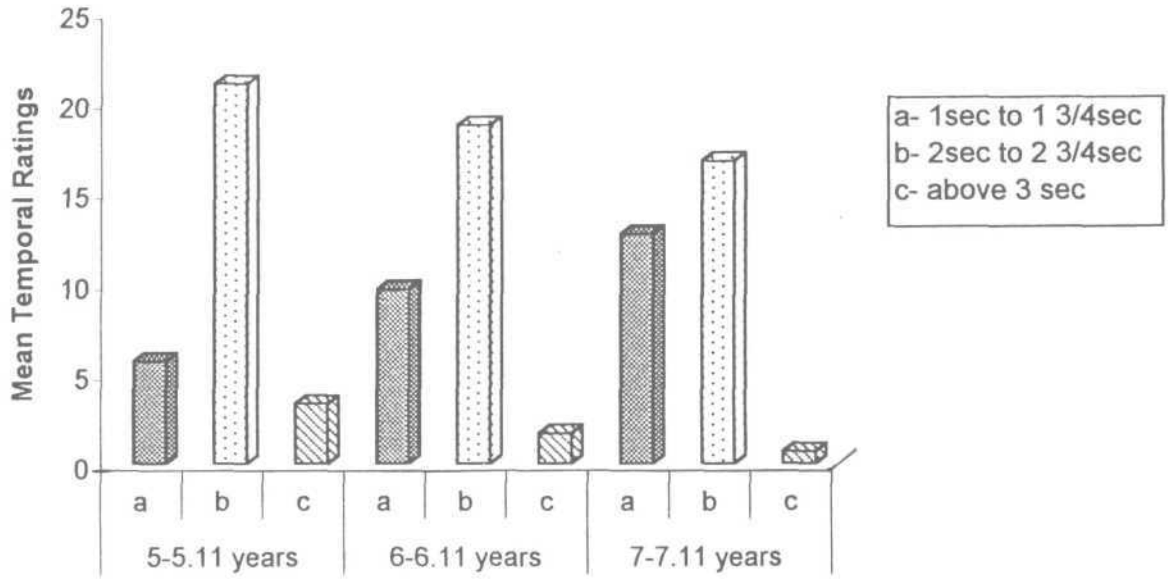
The results obtained is summarized in Table (1)

Table - 1: Temporal abilities in different age groups for levels 1 & 2.

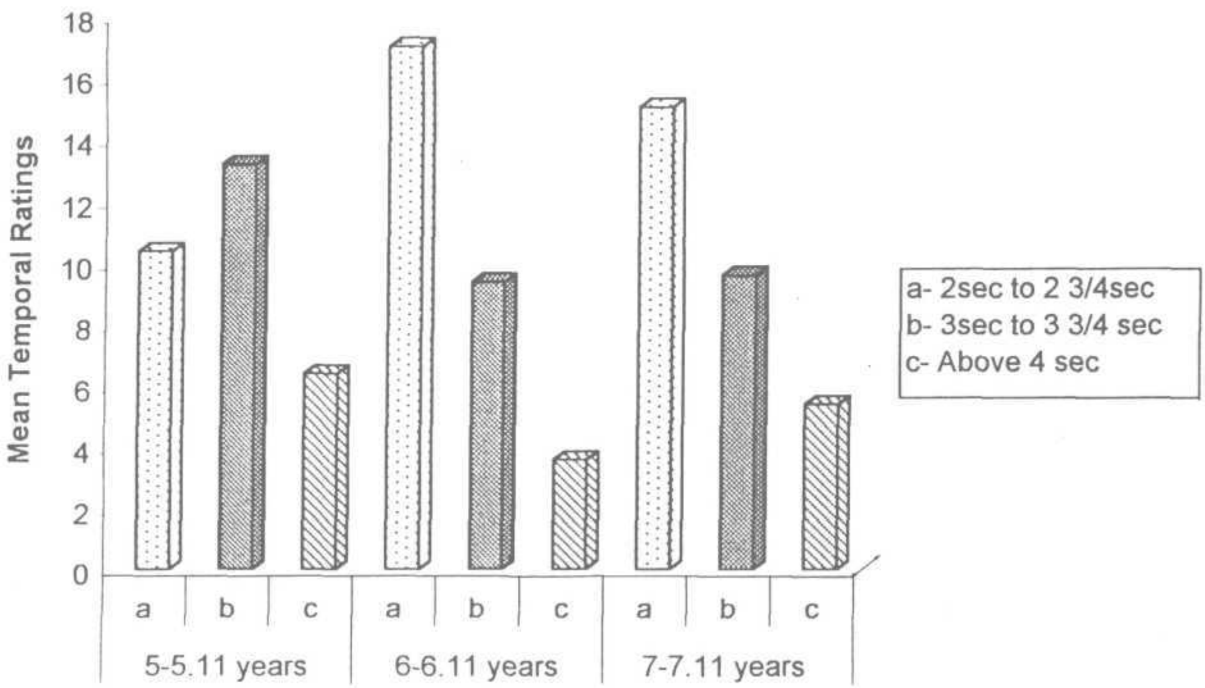
Level	Phrase No. & mean	5-5.11 years (No. of subjects = 30)			6-6.11 years (No. of subjects = 30)			7-7.11 years (No. of subjects = 30)		
		a	b	c	a	b	c	a	b	C
1. Easy	1	8	17	5	10	18	2	18	12	-
	3	6	21	3	9	20	1	9	19	2
	2	3	25	2	10	18	2	11	19	-
	Mean	5.67	21	3.33	9.67	18.67	1.67	12.67	16.67	0.67
2. Difficult	4	9	10	11	16	10	4	10	10	10
	5	12	12	6	19	10	1	16	9	5
	6	12	13	5	17	8	5	22	7	1
	7	15	12	3	22	6	2	18	7	5
	8	4	19	7	11	13	6	9	15	6
	Mean	10.4	13.2	6.4	17	9.4	3.6	15	9.6	5.4

TEMPORAL ABILITIES

Graph 1 : Mean temporal ratings of a, b, c for all the children in the 3 age groups for level 1 (easy)



Graph 2 : Mean temporal ratings of a, b, c for all the children in the 3 age groups for level 2 (difficult)



Level I - Easy

From Table (1) and Graph (1), the mean values of a, b and c scores for all 3 phrases of this level indicates a clear developmental trend. The mean number of children who have obtained "a" scores (which represents the least time taken) has increased from 5.67 in 5-5.11 years age group to 9.67 in 6-6.11 years age group and 12.67 in 7-7.11 years age group. Consequently, the mean number of children who have obtained "b" or "c" scores has also reduced from 21 and 3.33 (in 5-5.11 years age group) to 18.67 and 1.67 (in 6-6.11 years age group) and 16.67 and 0.67 (in 7-7.11 years age group) respectively.

This pattern indicates that the temporal skill undergoes refinement with age (i.e.) as children grow, more children tend to use lesser duration for an utterance of specific complexity. Similar developmental trend has been reported by Smith (1978), who suggests that reduction in segment duration with age may be a consequence of neuromuscular maturation. Others who report of similar results are Subtenly, Worth, Sakuda, 1966; Hawkins, 1973; Smith, Kenney and Hussian, 1996; Smith and Kenney, 1999 . It may be noted that these studies report of reduction in segmental duration of simple and complex syntactical structure. However, the results in Table I and graph 1 of this study suggests generalization of this feature to tongue twister sentences which are grouped as being easy.

Level 2 - Difficult

As observed from Table (1) and Graph (2) the mean values for a, b and **c** scores in this level of complexity is slightly variable, although an overall developmental trend is still evident. The mean 'a' value increases with age except for the 7-7.11 years age group. The mean 'a' scores of 5-5.11 year olds is 10.4 which increases to 17 in the 6-6.11 years age group and decreases to 15 in the 7-7.11 years age group. Consequently, the "b" and "c" scores also show similar trends as they decrease from 13.2 and 6.4 respectively (in 5-5.11 years age group) to 9.4 and 3.6 respectively (in 6-6.11 years age group). However there is a slight increase in scores, i.e., 9.6 and 5.4 respectively in 7-7.11 years age group. The variability in mean values of 7-7.11 years age group has been contributed because of decrease in "a" scores and increase in "c" scores in phrases 4, 5, 7 and 8 and decrease in "b" scores in phrases 5 and 6.

In summary above pattern simply reflects that not all children of a particular age group refine their temporal abilities to the same extent, suggesting some kind of a stagnation or nonlinearity in maturity of a skill. The concept of nonlinearity has been well documented in the literature of speech motor control development by studies involving both physiological and acoustic means of analysis of target behaviour. (Wolff, 1979; Morris, 1988; Sharkey and Folkins, 1985; Smith and Goffinan, 1998; Green et al, 2000). According to Netsell (1982), speech motor control is a continuous but a nonlinear process because of which spurts / increment in performance can be seen. He suggests that sensitive periods of non linearity occur when certain neural, musculoskeletal, environmental, and cognitive changes combine or "get together" in an individual at specific points in time. It is quite possible that such a spurt was evidenced in the performance of 6-6.11 years old children in the present study.

11. Spatial Abilities

For analyzing these abilities, the utterances of the children were transcribed and the syllables were analyzed for the errors in terms of substitution (S), addition (A), omission (O) and distortion (D). Whenever there was perseveration, the word perseveration scores were counted. In the utterances with perseveration, the final attempt was analyzed further for SODA errors.

The results obtained in spatial abilities has shown that a normal planning system can be assessed through psycholinguistic means that also that it can breakdown under performance load. That is, the material used being novel and complex (tongue twisters), it elicited erroneous performance under the loaded task of "speedy execution". Although a trend is evident with respect to the independent variable of the study, that is, age,the actual percentage of errors especially omission / addition / distortion / word perseveration is very less. Hence, in spite of the fact that no inference can be drawn regarding the actual functioning of the planning system, in the selected age group, the trend can still be discussed with the obtained data. The probable reason for such a performance of the planning system (inspite of the sporardic and variable errors evidenced in the results) will be discussed in the light of the ideas proposed by various models of speech production. Hence, in future, extension of such studies with larger samples size in each age group are required to comment on such a trend and draw inferences.

Table (2) shows the total number and the mean percentage value of omission, distortion and addition errors exhibited by the children at both the levels. The results show that the percentage omission / addition / distortion errors are very less. This indicates that in spite of its developing nature, a "normal" planning system can handle loaded task effectively. Few omission and addition errors suggest that the children seem to be aware of the total number of syllables that can constitute even a "novel / complex" word, at a young age itself, (probably from their knowledge about the phonological rules of the language).

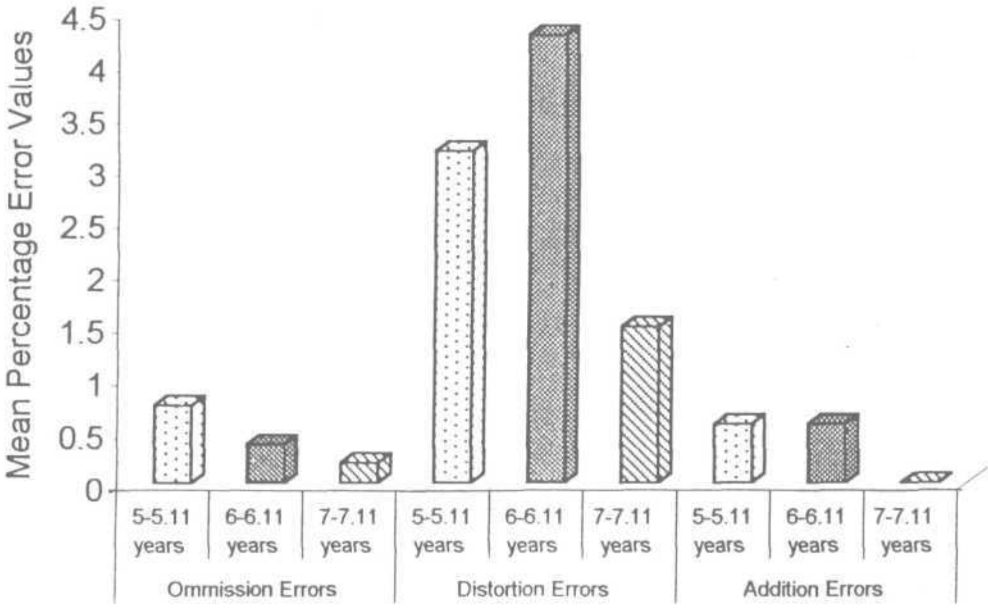
Reduced distortion errors indicate that even during the loaded task (since they had already acquired all the phonemes of the language), their performance was not very grossly affected. This can be interpreted in the light ofLTask Dynamic Model (Saltzman & Kelso, 1983). The model suggests that the speech system has the ability to precisely specify the independent sets of gestural parameters (eg : tract-variable targets). The results in Table (2) suggests the presence of such an ability even in the younger age group studied. Although the error percentage of omission / distortion / addition are very less, a maturational pattern can still be evident from the data and this is discussed henceforth.

Table - 2 : Omission, distortion and addition errors in different age groups for levels 1 &2.

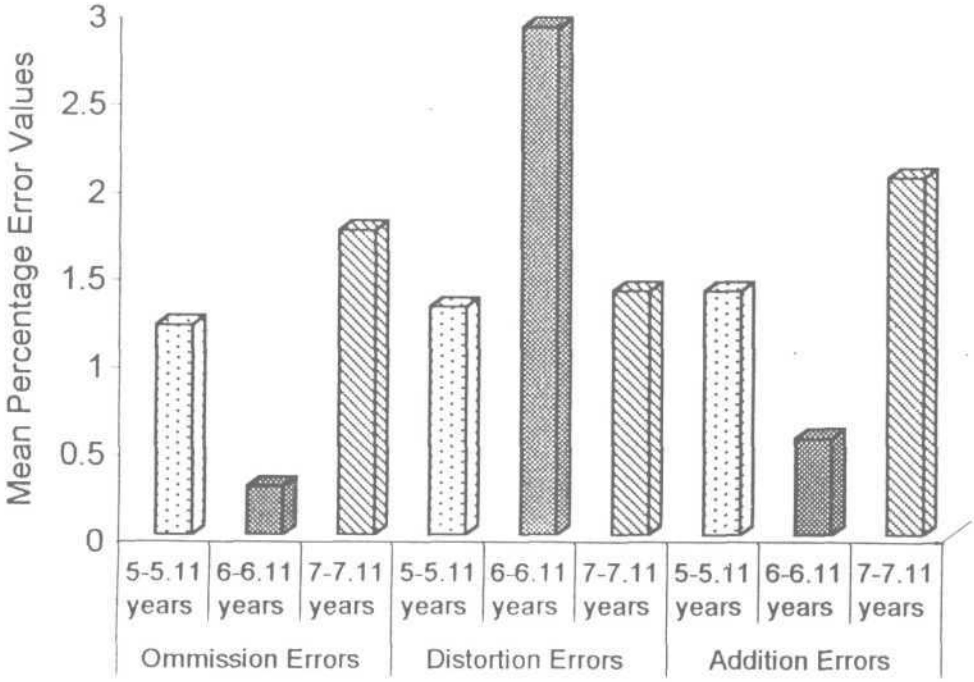
Level	Utterance No. & mean % value	Omission errors			**Distortion errors**			Addition errors		
		5-5.11	6-6.11	7-7.11	**5-5.11**	6-6.11	7-7.11	5-5.11	6-6.11	7-7.11
Easy	1	0	0	0	3	**5**	**1**	**1**	0	**0**
	2	**2**	2	0	12	17	7	0	2	**0**
	3	**2**	0	**1**	2	1	0	2	**1**	**0**
	Mean (total No. of syllables =540)	0.0074	0.0037	0.0019	0.0315	0.0426	0.0148	0.0056	0.0056	**0**
	Mean % value	0.74	0.37	0.19	**3.15**	4.26	1.48	0.56	0.56	0
Difficult	4	**2**	0	0	**2**	10	1	2	2	**12**
	5	1	2	2	2	9	4	4	**1**	5
	6	2	0	3	7	7	3	5	3	**2**
	7	5	1	3	3	1	1	1	0	1
	8	3	**0**	**0**	**0**	**4**	6	**3**	0	**2**
	Mean (total No. or syllables =1080)	0.012	0.0028	0.0074	0.013	0.029	0.0139	0.0139	0.0056	0.0204
	Mean % value	1.2	0.28	0.74	1.3	2.9	1.39	1.39	0.56	2.04

SPATIAL ABILITIES

Graph 3 : Mean percentage error values for omission, distortion and addition errors in level 1 (easy)



Graph 4 : Mean percentage error values for omission, distortion and addition errors in level 2 (difficult)



Level 1 - Easy

The mean percentage value of the total number of omission, distortion and addition errors from Table (2) and Graph (3) indicates an overall decreasing trend except for 6-6.11 years olds in distortion errors. Mean percentage omission errors decrease from 0.74 in 5-5.11 years olds to 0.37 and 0.19 in 6-6.11 and 7-7.11 years olds respectively. Similarly percentage addition errors decreased from 0.56 in 5-5.11 years olds and 6-6.11 years olds to 0 in 7-7.11 years olds. But, the mean percentage distortion errors decrease from 3.15 in 5-5.11 years olds to 1.48 in 7-7.11 years olds, and the 6-6.11 years old age group shows an increase in values to 4.26 because they had more distortion errors for phrases 1 and 2.

The general decreasing trend in omission, addition and distortion suggests an improvement in the planning abilities and neuromuscular coordination abilities.[1] (Omission and addition errors may reflect the phoneme selection abilities in the linguistic plan of the utterance at the highest level, especially because the stimuli used was a tongue twister. According to Vander Merwe (1997), an overall invariant motor plan is created as a first step for good execution. But considering Whiteside and Varley's (1998) concept, such a plan is created / computed only during novel utterances and the verbo-motor pattern for execution is retrieved from storage during the production of familiar utterances. So, novel and complex utterances can evoke additional phonemes / omission of the necessary phonemes under the condition "speed / fast production", which is the experimental condition. This can result in a "weak / erroneous" production, due to the variant motor plan especially in terms of number of syllables involved. Hence, addition and omission represent a break down in the highest level of planning abilities. The finding of the present study shows that this breakdown goes on decreasing, indicating a mature planning system in older children which can handle fast online computation of complex materials. Even Roy's model (1978) supports such a concept of increasing dependence of non - habituated movements on the goal selector.

Distortion errors may reflect imprecise neuromuscular coordination skills at the peripheral level, that is imprecise spatial approximation. The stimuli being unfamiliar and a novel one, il could have elicited more distortion. This is a relevant observation based on the cognitive based reconceptualization proposed by Whiteside and Varley (1998). They propose that syllables / words produced via the indirect route (which is meant for novel and low frequency words that are computed on line), would show less cohesion and low degrees of coarticulation. This could have led to imprecise execution of the computed motor pattern, resulting in distortion, especially when speed is involved.

Imprecise spatial approximation could have also resulted because of the perceived task load by the 6-6.11 years olds who have compromised on the spatial abilities while performing better in the temporal abilities, (as evident from the increased "a" scores as in Table (1)). Fowler et al., (1980), Linville (1982), Tuller, Kelso and Harris (1982), hypothesized that spatial equivalence can occur only with constant or stable temporal performance (i.e., consistent timing between the articulators). So, when the 6-6.11 year olds of this study have altered the duration, they seemed to have lost their spatial precision ability.

Level 2 - Difficult

The mean scores in Table (2) and Graph (4) are in general greater than level - easy and the variability is more on distortion errors, indicating that more complex tongue twisters have elicited more errors. In this level, mean scores do not reflect any trend. However, when we consider the raw data in isolation, omitting the extreme cases and considering the majority, a pattern emerges. That is, omission, distortion and addition errors go on decreasing with age. The decreasing trend of omission and addition errors could indicate a precision in phoneme selection, even during the loaded task of increased rate and increasing length and complexity of tongue twisters. This again suggests that the planning system of older children could handle faster online complex computations, than children of younger age group.

There is some variability in this trend seen in some instances by older children (7-7.11 years) and this can be attributed to increased addition errors for specific phrases like 4 and 5. This could have been because of their awareness of their wrong productions. Eg: /ta: ta: tat t a t t attai/. This inappropriate selection of *lit* instead of /t / has contributed to increase in addition errors especially in these phrases. This kind of self correction through awareness is less evident in younger age group. This is more clearly reflected by increased substitution errors in the younger age group, without any subsequent increase in addition errors. This kind of a concept has been discussed by Schema theory proposed by Schmidt (1988), where the author suggests that the "recognition schema" is dependent on initial, past and current outcomes of movement, and the sensory consequences of actions. As additional variability is encountered with a given task, the scope of recognition schema is increased. Thus, the planning system seems to learn to adapt with experience and this is more in children of the older age group. Vander Merwe (1997) also suggests the existence of feedback at all the levels of planning, programming and execution of a linguistic utterance.

From Table (2) and Graph (4), distortion errors which reflect the imprecise neuromuscular coordination, is seen to be generally decreasing. But there is variability in scores especially for phrases 5 and 8 and general increase in distortion errors in 6-6.11 year old age group. The increased error shown by this age group could be explained as a compromise in the spatial ability to accommodate for their non - linear development in the temporal abilities. The atypical results observed in phrases 5 and 8 by older age group children shows the inability of these children to maintain both spatial and temporal precision at all instances, or that it is conditioned by the utterance complexity, and it might simply indicate an immature developing system, that is, development is not completed even by 7-7.11 years of age. Utterance complexity of phrases 5 & 8 could have affected the data because:

a) phrase 5 demanded a transition from affricate to fricative and back to affricate (/t /-/s/-/t /). Such a transition would be difficult to maintain, especially when these children were exhibiting a trading relationship in spatial ability to accommodate for their temporal skills.

b) In phrase 8, the complexity was more because of the length (which consisted of 8 syllables).

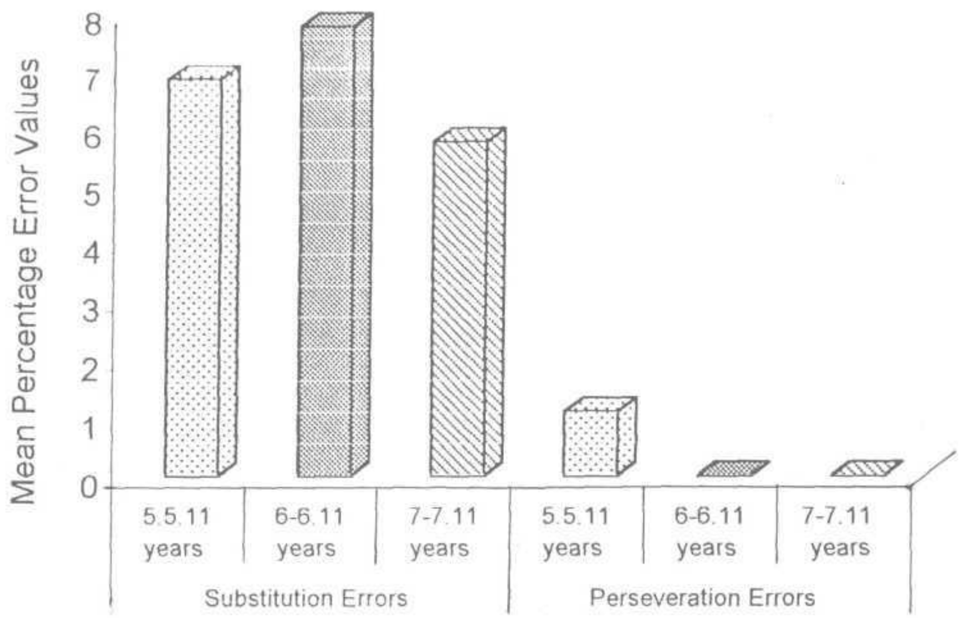
That distortion errors reflect some planning ability, is explored by the Task dynamic model proposed by Saltzman & Kelso (1983), where it is described that variability emerges as a result of both utterance specific, temporal interleaving of gestures (articulatory) and the accompanying process of co-production and blending. They have explained that when coproduced gestures use the same sets of tract variables, all articulators are shared in common, and there is a potential for mutual interference in attaining competing phonetic goals. In this situation, gestures compete for control of tract variables, resulting in the contextual variation. Thus, although invariant cues are specified in the form of context independent sets of gestural parameters (eg: tract - variable targets), variability can emerge which can lead to some degree of erroneous productions.

Table (3) shows the other two types of errors exhibited by the children namely, the substitution and perseveration. It is seen that substitution errors are relatively more common than other error types like omission / distortion / addition. This implies that although children had acquired all the phonemes, their ability to access the right one with speed is yet not completely mature. So, whenever a breakdown in planning tended to occur, an increase in substitution errors were evidenced. It could also indicate that whenever a breakdown in planning tended to occur, the sequencing skills seemed to be the most likely ability to be compromised than the highest selection abilities / peripheral execution skills. Further an in depth analysis of the type of substitution errors might have thrown some light on the pattern of the selection and sequencing abilities. But due to time constraints, the analysis and discussion in the study are restricted to the frequency of occurrence of the substitution errors.

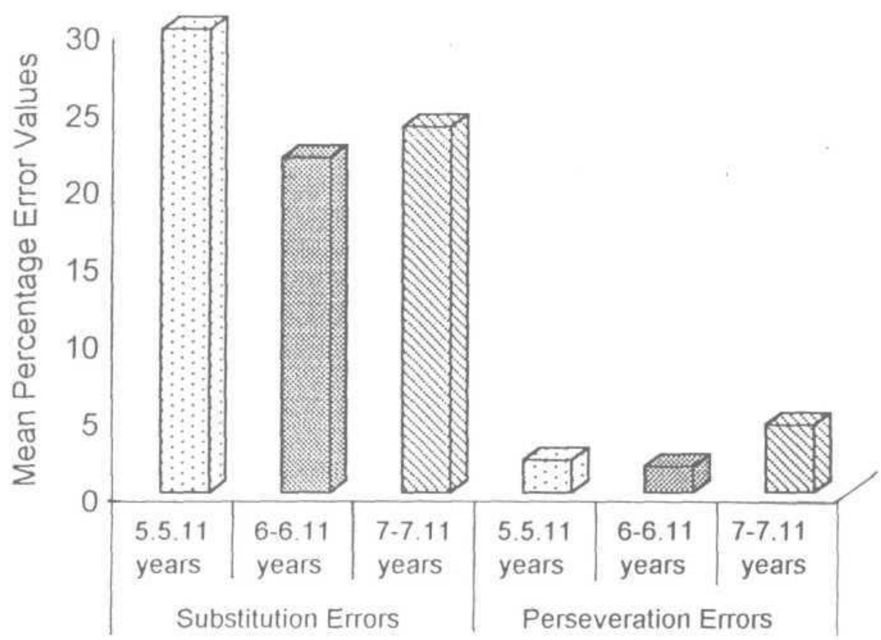
Table 3 : Substitution and perseveration errors in different age groups for levels 1 &2.

Level	Utterance No. & mean % value	Substitution errors (SE) Mean = total of no. SE / 540 syllables in level 1/ 1080 syllables in level 2			Perseveration errors (PE) Mean = total of no. PE / 180wordsin level 1/ 480 words in level 2		
		5-5.11	6-6.11	7-7.11	5-5.11	6-6.11	7-7.11
Easy	1	12	9	1	1	0	0
	2	16	18	11	1	0	0
	3	9	15	19	0	0	0
	Mean	0.0685	0.0778	0.0574	0.0111	0	0
	Mean % value	6.85	7.78	5.74	1.11	0	0
Difficult	4	34	34	32	5	5	6
	5	16	27	16	1	0	5
	6	41	29	18	3	1	2
	7	63	13	58	1	0	3
	8	8	14	4	0	2	5
	Mean	0.30	0.2167	0.237	0.0208	0.0167	0.0438
	Mean % value	30	21.67	23.7	2.08	1.67	4.38

Graph 5 : Mean percentage error values for substitution and perseveration errors in level 1 (easy)



Graph 6 : Mean percentage error values for substitution and perseveration errors in level 2 (difficult)



Level 1 - Easy

From table (3) and Graph (5), the mean percentage scores and raw scores for substitution errors is seen to decrease with age except for 6-6.11 years olds, and the score in the 3rd phrase. These results reflect the child's performance to the task load from his / her own mastery of phonemes. While 1st and 2nd phrase involved phonemes which are acquired early (stops and nasals) and mastered by older children, the younger children were still in the process of mastering although they had acquired them. Mastery at this level could indicate faster / easy access of phonemes at the time of demand. Hence they tended to substitute them with other phonemes when they could not easily access the target phoneme at that moment of performance especially with speed, (instruction given was as fast and as clearly as possible).

In the 3rd phrase, the structure of the phrase involved a slightly more complex organization of phonemes than in phrases 1 and 2 as it consisted of more proximal phonemes occurring concurrently (d, 1, t) than phonemes in 1st and 2 . Also, the errors, that is, substituted phonemes were mainly the voiced affricate /dz/ and */j/* for /t 7 and /]/ respectively, those which are acquired and hence mastered later in age. It could be postulated that since the older children had more (mastered) phonemes in their reportoire, which could be easily accessed there was more confusion during the task performance than younger ones, especially when the task required precise selection of spatial location in a quick succession at an appropriate time. Hence, it can be concluded that substitution errors reflect the selection and sequencing of planning phenomenon. Vander Merwe (1997) explains selection and sequencing as part of the highest level of planning in the linguistic planning stage.

Word perseverations were in general absent at this level except for one sporadic case in the age group of 5-5.11 years, for both utterance 1 and 2. No conclusions can be drawn from such a rare occurrence.

Level 2 - Difficult

The mean percentage values from Table (3) and Graph (6) shows that substitution goes on decreasing with some variability in both the older age groups. That is, the errors are more in 6-6.11 years age group than 7-7.11 years age group for all utterances other than phrase 7. But the type of errors seen in this level of complexity were mostly transposition (metathetic errors) which directly reflects on the errors in sequencing skills, (Vander Merwe, 1997).

This kind of picture shows that children develop sequencing abilities across time, but not uniformly. It may also depend on variables like how the child perceives the instructions given to him / her. For example, the 6-6.11 year olds gave more importance to timing aspect. Their awareness towards wrong selection of phonemes / self correction abilities, (generally mediated through slower transition to subsequent phonemes) was reduced. This resulted in increased substitution errors.

Perseveration errors seem to increase with age [an evidenced from Table (3) and Graph (6)] except in phrase 6 and the mean percentage scores of 6-6.11 year old age group. Yet the overall trend seem to suggest that programming abilities are improving with age. That is, as children grow older, they try to plan even novel / difficult utterances correctly through conscious and appropriate transitions to the following word and thereby repeat the previous word. This^inturn^ reduces substitution errors. For eg : Eg: /ta:ta: **ta:ta:** tat t a t attai/. This is evident from the fact that there are less substitution errors shown by the 7-7.11 years olds in comparison to 5-5.11 years children. The 6-6.11 years old children have presented more substitution errors and very less perseveration errors in this level of complexity, representing a reduced ability to consciously self correct. Thus, self correction ability seems to be one of the variables which can influence planning, thus laying importance on external feedback also. (Schema theory by Schmidt, 1988; Vander Merwe, 1997). But the well established proposition of non linearity in the temporal measure and the psychological perception of the task can all influence the performance of planning system and hence, result in some kind of either maturational / performance non linearity in the planning system.

In summary, an indepth analysis of spatial approximation behaviour gives us interesting insight about the speech motor planning system and some of the variables that may affect it. An error analysis could give us a better idea about the stages in planning abilities namely, distortion errors reflects neuromuscular coordination, omission and addition errors reflect on the ability to select phonemes (or linguistic planning) and substitution or word perseveration about sequencing (or referred to as programming by authors like Vander Merwe, 1997). A further detailed analysis of the type of substitution error (i.e. which phoneme most often was substituted with which phoneme / whether they were simply metathetic / anticipatory - transposition error etc.) might give more detailed idea about the functioning of the planning system. It can help in resolving the controversy of whether it is due to a non linearity in the development that is reflected in the results or the perception or the psychological importance given to the instructions or merely a chance variable. But due to limited time, such an analysis has not been undertaken and the underlying phenomenon are proposed merely as hypotheses.

III. Spatio Temporal Abilities

After the samples were analyzed in terms of SODA, the total number of error syllables were counted and based on the range of values obtained (after omitting the extreme values), the samples were classified as a_1, b_1, and c_1, as follows:

	a_1	b_1	c_1
Level 1-easy	0 error	1 error	$\geq$ 2 error
Level 2-Difficult	0/1 error	2/3 errors	$\geq$ 4 errors

The above two levels were determined based on the sentence complexity, that is, level 2 involved more proximal phonemes occurring concurrently (like /t/ - /t / etc.), and also based on the results of the pilot study. The pilot study was conducted to select the material to be used for the study, and to arrange it in the increasing order of complexity. Initially a list of 20 tongue twisters were prepared which was short listed to a set of 8 stimuli after the pilot study, omitting the very easy and very complicated ones. These 8 stimuli were also divided into easy and difficult levels based on the performance of the subjects in the pilot study.

Then, they were analyzed together with the temporal rating of "a", "b", and "c" and a combined 5 point rating scale was formulated to infer, in general about spatio temporal (ST) abilities. The 5 point scale used was:

Name	*Scale*	*Description*
Very good ST skills	0	Combination of "a_1" (in spatial) and "a" (in temporal) scale.
Good ST skills	1	Combination of "b_1" or "a_1" (in spatial) and "b" or "a" (in temporal) scale.
Average ST skills	2	Combination of "b_1 or c_1 or a_1" (in spatial) and "a or b or c" (in temporal) scale.
Partially imprecise ST skills	3	Combination of "c_1 or b_1" (in spatial) and "b or c" (in temporal) scale
Completely imprecise ST skills	4	Combination of C_1 (in spatial) and c (in temporal) scale.

Table (4). Shows the distribution of children of various age groups for the above ratings.

Table 4 : Distribution of spatiotemporal abilities across different age groups in levels 1 & 2.

Phrase No. and Mean	5.5.11 years					6-6.11 years					7-7.11 years				
	0	1	2	**3**	4	0	1	2	3	4	0	1	2	3	4
Easy															
1.	6	12	9	2	1	6	17	4	1	2	18	11	-	1	-
2.	4	8	10	7	1	5	9	6	9	1	5	15	8	2	-
3.	2	20	2	4	2	8	12	7	3	-	**7**	13	7	3	-
Mean	4	13.3	**7**	4.3	1.3	6.3	12.67	5.67	4.3	1	10	9.67	5	2	0
Difficult															
4.	6	9	9	5	1	14	7	5	3	1	7	8	6	5	4
5.	11	12	4	3	-	14	7	8	1	-	15	7	3	3	2
6.	4	12	8	3	3	14	7	5	2	2	17	7	6	-	-
7.	4	12	9	3	2	22	6	-	-	2	5	14	6	2	3
8.	4	17	7	1	1	11	11	5	2	1	8	15	3	3	1
Mean	5.8	12.4	7.4	3	1.4	15	7.6	4.6	1.6	1.2	10.4	10.2	4.8	2.6	2

Level 1 - Easy

In this level, the spatio temporal combined abilities (henceforth referred as S-T abilities) shows a clear tendency in the children to improve as age increased. This is evident from the fact that the children of 7-7.11 years age group have good ST abilities than younger age group. But even in this age group not all children fall above average (although more than 50% children get above average scores, i.e., above a score of "2"). This indicates that development of ST abilities is not uniform across all children of same age group and that there could be better scope for such children with increasing maturation. A complementary observation is the reduction in the number of children in the extreme range of 3 and 4 as the age increases. The variability of scores amongst subjects decreases as the age advances. In other words, the intersubject variability decreases with age. This could be because, the system is able to manage to produce more stable responses at older age groups for "easy" utterances. Such a variability decrement has been demonstrated in just the temporal measure (like segment duration) by Smith, Kenney and Hussain (1996) and on lip and jaw movements during speech by Sharkey and Folkins (1985).

Level 2 - Difficult

Although a similar trend as in level 1 is evident even in level 2, ST abilities improve as age increases, the variability is also high. In general, the 6-6.11 year old children seem to have better ST scores than 7-7.11 year old and 5-5.11 year old. This suggests that the complexity of the material, the phoneme context and the length of the utterance influence the planning abilities of children. The more complex the material, the greater the variability in the ST scores. This is compounded by the non linearity seen in the development of these abilities. The variability is also supported by the non uniform reduction in the complementary scores 3 and 4. That is, although less number of 6-6.11 year old children had 3 and 4 scores compared to 5-5.11 year old children, there were more number of 7-7.11 year old children with 3 and 4 scores than 6-6.11 year old children.

Another support to the claim that phonetic context influences planning and thus in turn the ST abilities is the fact that the total number of children obtaining score of "o" i.e., good scores, in all 3 age groups in either level of complexity, goes on decreasing (with the exception of some instances) and as the sentences increased in complexity, the scores tended towards 1 and 2, representing average / slightly above average performance. The atypical instances like the performance of 5-5.11 year old children for phase 5 (level 2), 6-6.11 year old children for phrase 3 (level 1) & phrase 7 (level 2), 7-7.11 year old children for phrases 5, 6 and 8 (level 2), reflects or confirms the presence of nonlinearity in development.

Thus, at all levels, this study substantiates Von Hofsten's (1989) observation that "the rate of development is different for different subjects. Some develop quickly, whereas others develop slowly. One and the same child may develop quickly at certain ages and slowly at others". The attempt to investigate planning abilities and measure the ST skills through psycho linguistic means has been justified by the results of this study which closely replicates the other acoustic / physiologic based studies. In addition, analysis of spatial skills (in terms of the errors made by the subjects, of the linguistically controlled material) has thrown light on interesting characteristics of the planning system. It has shown that not only do the peripheral neuromuscular refinement occurs with development, but also there is a maturation evidenced in the higher level linguistic planning capacities and in turn, in its capacity to handle a loaded task such as, the precise execution of a tongue twister. As age increases, more "mature errors" are employed by the children to handle the task load and exhibit increased awareness and conscious control of the performance. That is, a reflexive error in the younger age group becomes a more controlled production in the higher age groups. Also, the planning system seems to be influenced by psychological state and cognitive awareness of the child as a variation in performance was noted with respect to perceived cognitive load about the task. Further analysis of error patterns might lead to better understanding and confirmatory conclusions about the planning system. However due to time constraints, the study is limited to the listed observations.

In conclusion, the following trend can be summarized from the results of the study:

1. Temporal abilities improve with age with evidences of nonlinearity (especially in level 2, the difficult tongue twisters)

2. Spatial abilities improve with age as evidenced from the fact that "reflexive error" patterns of younger age group become more "mature error" because of self correction abilities.

3. S-T abilities also show an overall refinement as age advances with evidences of nonlinearity.

SUMMARY AND CONCLUSIONS

Spoken language is a form of communication through which human beings covey information. Speech is a goal directed and afferent guided motor skill that is controlled by complex neural mechanisms. A speaker uses a highly flexible motor program with motor equivalence, while simultaneously achieving maximum precision (clarity) in production. Various theories explain the process of speech motor control through 3 basic steps, namely planning, programming and execution (Serial Order Models, by Rosenbek, Kent and LaPointe, 1984; Hierarchical Model by Roy, 1978; Schema theory by Schmidt, 1988 and Vander Merwe, 1997). Of these stages, an attempt was made in this study to investigate the nature of the planning stage by employing psycholinguistic means. Review of literature suggests that speech motor control is achieved during development till around puberty (Wolff, 1979; Morris, 1980; Netsell 1986). These studies have employed acoustic and or physiologic means to analyze the spatiotemporal abilities of their subjects. In the present study, the development of spatio temporal abilities of children between 5 to 8 years were assessed behaviourally through rating scales.

The study was conducted on 30 children each in the age group of 5-5.11 years, 6-6.11 years and 7-7.11 years by asking them to repeat 8 phrases constituting tongue twisters of Tamil language, for 3 times. The material (tongue twisters) used was constructed in a hierarchy of increasing order of complexity and after a pilot study it was divided into two levels, namely easy and difficult. The samples were recorded and analyzed for their spatial, temporal and spatiotemporal (ST) abilities.

For temporal abilities, the time taken for each phrase was calculated and rated, selecting the range of values and dividing them into three as :

	a	b	c
Level 1 -easy	1 -1 ¾ secs	2-2 ¾ sec	3 secs & above
Level 2-difficult	2-2 ¾ secs	3-3 ¾ sec	4 secs. & above

For spatial abilities, the material was transcribed and an error analysis for substitution, omission, distortion, addition and word perseverations was done.

The total number of error syllables were calculated and rated as:

	a_1	b_1	c_1
Level 1-easy	0 error	1 error	$\geq$ 2 errors
Level 2-difficult	0/1 error	2/3 errors	$\geq$4 errors

For spatiotemporal abilities, a combined 5 point rating was used, namely:

Name	*Scale*	*Description*
Very good ST skills	0	Combination of "a_1" (in spatial) and "a" (in temporal) scale.
Good ST skills	1	Combination of "b_1/a_1" (in spatial) and "b/a" (in temporal) scale.
Average ST skills	2	Combination of "$b_1/c_1/a_1$" (in spatial) and "a/b/c" (in temporal) scale.
Partially imprecise ST skills	3	Combination of "c_1/b_1" (in spatial) and "b/c" (in temporal) scale.
Completely imprecise ST skills	4	Combination of "c_1" (in spatial) and "c" (in temporal) scale.

The total number of children falling under each of this rating was calculated.

The results of this study is summarized as follows:

1) Temporal abilities

In level one, the number of children who took least time ('a' scores) go on increasing, suggesting a clear developmental trend. But, in level two, although a similar trend is seen, there is a better performance evidenced in 6-6.11 year old, which reflects non linearity in development.

2) Spatial abilities

a) Omission and addition errors

- Omission and addition errors decreased with age and some variability was evidenced in level two.
- Omission and addition errors represent problems in phoneme selection, the highest level of speech motor planning and the decreasing trend in these errors suggests a mature planning system in older children. This is reasoned to be because of their ability to cope with the online computation of novel utterances with speed.
- The variability in level two was due to increased addition errors seen in older children. This was attributed to their increased self correction attempts, suggesting that the feedback system is also developing, and yet to mature.

b) Distortion errors

- Distortion errors also presented a decreasing trend with increasing age, but there was more variability in this data because of increased scores shown by the 6-6.11 year old children. This trend is seen in both the levels.

- Distortion errors in general, reflect the imprecise neuromuscular coordination ability at the execution level, probably due to increased demand on the temporal interleaving of target specific gestural parameters.

- Variability seen in distortion errors in 6-6.11 year olds is reasoned to be because of the non linear increase in their temporal skills or the psychological load they encountered because of the nature of the instructions ("as fast and as clearly"). This probably led to the compromise of gestural parameters which specify the precise target, and in turn has led to increased distortion errors.

c) Substitution errors

- Substitution errors also show a decreasing trend with increasing age, with some variability in both levels.

- In level one, substitution reflects a reflexive error from their reportoire of mastered phonemes. In level two, however, substitution errors reflect more metathetic or transposition phenomenon. In level one, the occurrence of substitution errors shows the ability of the children to access phonemes (mastered ones are easily accessed than unmastered ones) and in level two, it reflects more of sequencing ability, emphasizing that the linguistic content also influences performance.

- Variability in substitution scores indicate non linearity, which might have had occurred as a consequence of non linearity in temporal measures. That is, 6-6.11 years old children have better temporal skills and hence the self correction abilities (generally mediated through slower transition to the subsequent syllable) have reduced. This explains why there is increased substitution errors.

d) Wordperseveration errors

- Word perseveration errors go on increasing with age, suggesting that as children grow older, they try to plan even novel / difficult utterances correctly, through conscious and appropriate transitions to the following word. Due to this phenomena, they tend to perseverate on the previous word.

- The ability to consciously self correct was found to be maximum in 7-7.11 year old children. Between the other two groups, it is comparatively less in 6-6.11 year olds than in 5-5.11 year old. This could be due to the influence of psychological load of the task as perceived by the subjects. That is, 6-6.11 year old subjects have given more importance to temporal / timing aspects.

3) Spatiotemporal abilities (ST)

- More older children have very good ST abilities than younger children in level one, indicating that the "more mature" planning system is able to produce more stable responses (in terms of ST abilities) than younger systems.

- In level two, although similar trend is observed, more variability is also seen.

- Variability is due to the fact that the 6-6.11 year olds have better ST abilities than other two groups, suggesting that temporal stability at this particular age group accounts for better ST abilities, than spatial stability.

4) Other variables that are found to influence the planning system are the linguistic complexity of the material, non linearity in various developing skills and the psychological perception of the instructions / performance load.

In conclusion, this study confirms that inspite of some variability, there exists a maturational pattern in speech motor acquisition and that it can be studied through psycholinguistic means. Although the data has given interesting insights about the planning system in children, the variability evidenced in the results suggests that there is some degree of non - linearity in the development of speech motor planning abilities of children. The data obtained in the study can be further analyzed in detail to describe more variables affecting the planning system. But due to time constraints, the analysis was restricted to above mentioned results.

Recommendations for Future Research

The same data can be analysed further to answer the following questions:

- What is the type of substitution error (which phoneme is most often substituted and the nature of metathetical or spoonerism error presented by the children)?

- What kind of distortion error (description in terms of some form of gestural parameter) or addition or perseveratory error occurs most often?

- Is there any adaptation evidenced between 1st and 3rd trial?.

This study has thrown some light on interesting features of the planning system operating in children aged between 5 to 8 years. This can be further investigated in detail to define the capacity of such a system and the variables that affect its performance, like for example, answering questions like, what happens when the linguistic complexity of the material is increased or decreased.

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