Differential Diagnosis of Stuttering and Normal Non-Fluency

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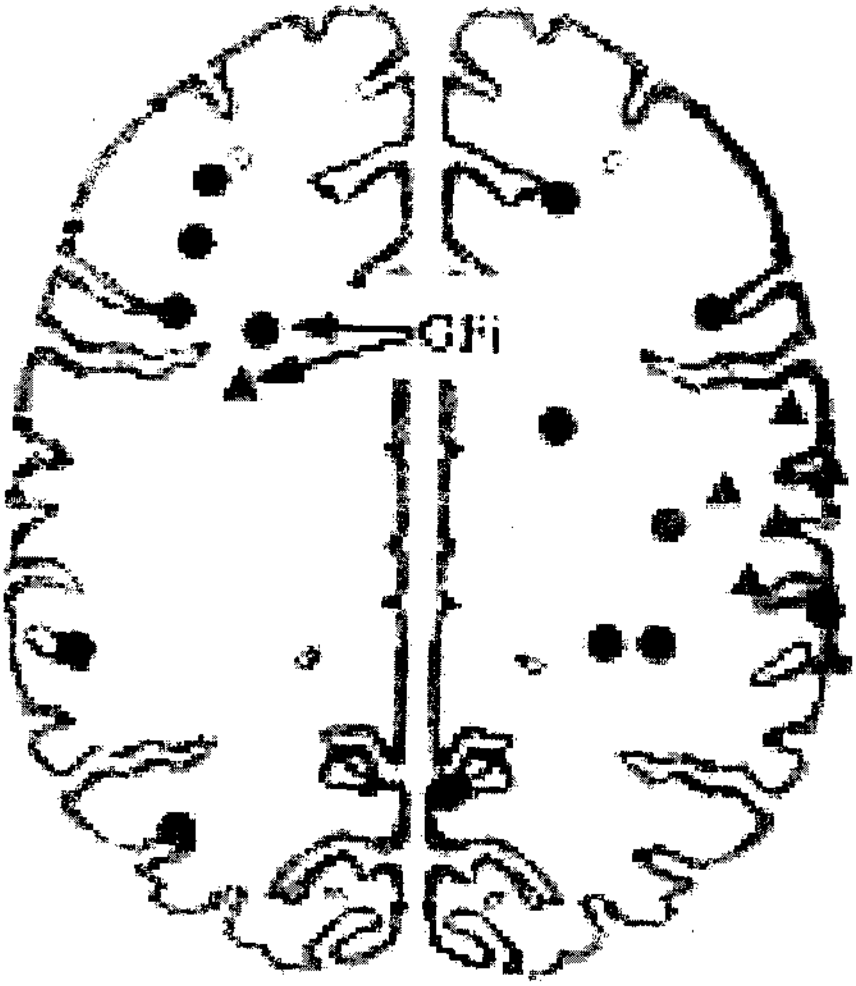

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Department of Speech-Language Sciences
All India Institute of Speech & Hearing
Mansagangothri, Mysore 570 006

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Principal investigator: Dr. S. R. Savithri

Co-principal investigator: Ms. K. Yashoda

Research officers worked in the project:

Mr. S. Shivaprakash, Mr. M. B. Venugopal and Mr. Kunal Ghosh Ms. T. Ananthi

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Chapter I

Introduction

Stuttering is a disorder of fluency, characterized by repetitions, hesitations, prolongations and audible pauses. Interruptions in the flow of speech commonly referred to as dysfluencies are the most obvious feature of stuttering. Stuttering shows temporal disruption of the simultaneous and successive programming of muscular movements required to produce a speech sound or its link to the next sound (Van Riper, 1982). This disruption is characterized by repetitions, hesitations, prolongations and audible pauses. Stuttering usually develops in early childhood when language acquisition is taking place (Van Riper, 1971; Bloodstean, 1981). The possible relationships between stuttering and linguistic variables, however, remain unclear. With regard to childhood stuttering, for example, it has been speculated that pathological disfluencies emanate from the normal non-fluencies in the spontaneous speech of young children. Bloodstein argues in favor of such a relationship and has proposed the "continuity hypothesis", in which, normal non-fluencies of early childhood change over time (perhaps because of the child's concern about speech or language production) and evolve into utterances and fragmentations of words that are perceived by the listener as disfluencies or stuttering. However, the question of whether non-fluencies and stuttering are on a continuum or are separate entities is still debatable.

Many children stutter transiently before developing normal fluent speech. Several studies showed that listeners frequently disagreed on deciding whether speech dis-fluencies of young children were either normal or stuttered (Onslow, Garden, Bryant, Stuckings & Knight, 1992). The rate of development of non-fluencies within the context of normally fluent speech in the early years appears to be a very dynamic phenomenon and one, which probably occurs on a highly individual basis. In contrast to the shifts in rate of development of non-fluencies and situational influences on non-fluencies, the characteristics of non-fluency (interjection, word/phrase repetitions) are reasonably consistent from child to child. Disfluencies have also assumed a central role in descriptions of the development of stuttering and in subgroup differentiation.

Time-related variations in disfluency from easy repetitions to tense sound prolongations, blocks and broken words have been a core feature in developmental models of stuttering (Bluemel, 1932; Bloodstein, 1960a, 1960b; Van Riper, 1971). However disfluencies are also found in the speech of speakers who are not regarded as exhibiting stuttering. Curiously, this fact has resulted in several different ways in which disfluencies played a prominent role in theories of stuttering, especially those pertaining to the inception of the disorder during early childhood. For e.g. difficulties in distinguishing normal from abnormal disfluencies, causes parents to erroneously diagnose interruptions in their children's speech as "stuttering", was at the heart of the diagnosogenic theory (Johnson, Boehmler, Dahlstrom, Darley, Goodstein, Kools, Neelley, Prather, Sherman, Thurman, Trotter, Williams, Young, 1959).

One major problem in the study of what has been termed normal disfluency (Wingate, 1976) is its variability, particularly with adults, making it difficult to observe scientifically. It is well documented that children between ages of 3-5 years experience periods of disfluency, which vary, often depending upon the emotional and linguistic load present in the communicative interaction. However, only a small percentage of these children who are dysfluent actually become stutterers. Perhaps clarifying the similarities and differences between the two types of dysfluencies might add to our understanding of the stuttering mechanism. The question to be explored is the relation between so-called normal dysfluency and the more pathological dysfluency of the stutterer. Two views of seemingly different philosophies regarding these two types of dysfluencies are prevalent in the literature. The first view, initially discussed by Froeschels (1969) suggests that normal disfluencies have a place on the same continuum as stuttering and that the latter is simply a most severe and more frequent manifestation of the former. On the other hand, Bloodstein (1981) hypothesized that the difference between normal non-fluencies and stuttering non-fluencies was one of degree rather than a distinct entity.

Most studies on early childhood non-fluencies examine the following characteristics: interjections, part-ward repetitions, word repetitions phrase repetitions, revision of incomplete phrases, dys-rhythmic phonation (phonation that disturbs the rhythm of a word, such as prolongation, improper stress, a break in the word), and tense pause (barely audible manifestations of muscle tension occurring between words and within words). Undoubtedly, these characteristics still reflect the influence of Wendall Johnson's work on the early childhood non-fluencies (Johnson et. al., 1959).

In a review of literature, Yairi (1997) stated that disfluency counts have been the classic metric of the disorder for both clinical and basic research and have been employed as the dependent measure in numerous studies of stuttering. Clinically, the number of disfluencies especially of certain types has been regarded as the most important index of stuttering severity (Van Riper, 1971). Analysis of disfluency has been weighted heavily in instruments of evaluation and diagnosis of early childhood stuttering, especially in differentiating between normal disfluency and incipient stuttering (Adams, 1977; Curlee, 1980; Pindzola & White, 1986; Campbell & Hill, 1987; Gordon & Luper, 1992). Colburn's (1979) findings were in agreements with those of others (Silverman, 1972; Yairi & Clifton, 1972) in that dys-rhythmic phonation and tense pauses were the least frequently occurring non-fluencies in normal speaking subjects.

Adams (1977) drew from several sources in delineating a strategy to distinguish normally non-fluent children from incipient stutterers. The following qualitative and quantitative criterions were cited.

1. Stutterers were as twice as non-fluent as non-stutterers
2. Stutterers produced 1-5 reiterations of a part word repetition where as non-stutterers produced 1-3 reiterations
3. Stutterers demonstrated an abrupt abnormal cessation of voice or airflow whereas this was not evident with non-stutterers
4. Stutterers displayed schwa intrusion in repetitions whereas non-stutterers did not.

Adams cited research that drew upon subjective listener analysis studies as well as objective spectrographic analysis. Van Riper (1971) cites research that employs both spectrographic and cineflourographic analysis concluding that the dysfluencies of stutterers vs. non-stutterers were different along several dimensions. Agnello (1975) analyzed spectrograms and concluded that the acoustic and pause characteristics of the stutterers dysfluencies differed from their normal speech dysfluencies. Furthermore, stuttering non-fluencies did not show the normal downward shift of the second formant associated with normal articulatory positioning.

Despite divergent opinions, it is universally agreed that the dys-fluencies should be identified early and treated. It is widely accepted that it is better to treat stuttering in its early stages than to wait until adolescence/ or adulthood. Not only early intervention is less time consuming and cost effective, but it also liberates children from a lifetime of frustration and embarrassment about speech (Onslow, 1996). Clinicians do not find it difficult to decide that a child is "normally fluent" if he or she exhibits extremely fluent speech; likewise it is not hard to decide that a child is "stutterer" if he is prominently dysfluent. It is, however, difficult for a clinician to decide about a child whose behavior falls between these youngsters who can be classified as stutterers. Unfortunately these in-between youngsters represent a sizable portion of all children who stutter. Part of this difficulty arises from lack of "objective measures of stuttering" and "norms" to clearly separate "fluent" from "disfluent" speaker.

Howell & Vause (1986, among others) have set a few indicators that show that the fluent and disfluent speech of stutterers and non-stutterers, though perceptually identical, differ acoustically. However, the results of acoustic analysis of the speech of normally non-fluent and stuttering children are equivocal. Frequency of second formant (F2), F2 transition, voice onset time, duration of vowels and consonants and FO perturbation have been investigated as possible differential diagnostic indicators. The F2 transitions in dysfluent speech of normal children and children with stuttering indicate a variable pattern. The F2 transitions are sometimes absent or atypical

(Howell & Vause, 1986; among others) and when they are appropriate they tend to be shorter in duration (Yaruss & Conture, 1993). Klich & May (1982) and Hirsch, Fauvet, Ferbach-Hecker, Bechet, Bouarourou, & Sturm (2007) found that stutterers' Fi and F2 values were more centralized compared to non-stutterers, which were interpreted to reflect restricted articulatory adjustments. This was contradicted by Prosek, Montgomery, Walden & Hawkins (1987) who, failed to find any such centralization.

In spite of several findings, it has not been possible to make a distinction between stuttering and normal non-fluency and that the exact nature of the relationship between normal dis-fluencies and stuttering dys-fluencies remain unclear. In this context, this project investigated the efficacy of acoustic parameters in differential diagnosis of stuttering and normal non-fluency. Specifically, onset and offset of F2 transition, F_2 transition duration, extent and speed of F_2 transition, and pattern of F_2 transition were extracted from the speech of 200 children with stuttering and 200 children with normal nonfluency and compared.

Chapter II

Review of literature

One of the biggest challenges facing speech-language pathologists who treat children who stutter is differentiating between children most likely to continue stuttering into adulthood unless they receive speech-language treatment and those most likely to recover without treatment (Adams, 1980; Conture, 1990). Some reports have shown that some children who stutter recover from their early speech disfluencies without intervention, whereas others continue to stutter and require intervention to overcome their problem. Hence it is required to decide whether the disfluencies in the child are likely to disappear with age (normal nonfluency) or continue and persist (stuttering). The problem arises in differentiating because it is often very difficult to differentiate disfluencies from early stuttering and this in turn has led to controversies about management. From the work of several researchers (E.g. Wexler & Mysak 1982; Indu, 1990; Nagapoornima, 1990; Yamini, 1990) who have observed the frequency and type of disfluencies in young normals, it is evident that a large majority of children aged between 2 - 5 years are likely to exhibit the same. The results also revealed that the percent disfluency remains the same from kindergarten to sophomore years, but the type of disfluency changes. While the *younger children* use *repetitions, pauses and false starts,* at *older age* they use the more sophisticated type of disfluency i.e. *parenthetical remarks.* Thus the clinician requires an understanding of the multidimensionality of fluency to differentially diagnose normal non-fluency/disfluency from stuttering.

Several protocols have been published that are designed to help speech-language pathologists distinguish children who are typically fluent from children who stutter (e.g. Adams, 1977, 1980; Ainsworth & Fraser, 1989; Pindzola & White, 1986); however fewer instruments (Riley, 1984) help clinicians distinguish among children who stutter. Most such protocols are based on informal observation or clinical experience, examining such factors as the frequency, type and duration of speech disfluencies; the number of iterations per sound/syllable repetition (SSR); perception of schwa vowel in place of the target vowel during SSR; the perception of physical tension and/or nonspeech behaviors (e.g. eye blinking) associated with disfluent speech; and children's and parents attitudes towards speaking and/or stuttering. Since most of the protocols have not been verified objectively reliability and validity of these protocols are questionable. These protocols will not be discussed in this review, as they are not relevant to the study.

Several *aspects of* ***stuttering*** have been studied in order to give a clear picture about **the *differences between normal nonfluency and stuttering.*** Widely held assumption (Johnson and associates, 1959) regarding the differentiation is that during early stages of speech and language development, there are more similarities than dissimilarities between children who stutter (CWS) and children who don't stutter (CWNS). These similarities are in terms of type and frequency of disfluencies. Results of studies conducted by authors like Ambrose and Yairi (1999) contradicted this belief that stuttering features are different only during the later years. In their study they held time since onset of stuttering constant. Their results made it clear that even at the earliest stages of stuttering, there are qualitative as well as quantitative differences between children who do and don't stutter. In recent research, several authors have analyzed features of stuttering close to the onset of stuttering (Ambrose & Yairi, 1999; Mansson, 2000; Throneburg & Yairi, 2001; Pellowski & Conture, 2002; Yairi & Ambrose, 2004). The assumption being that at such an early time secondary symptoms are less frequent when compared to older children and adults who stutter. Secondly, analysis of data, collected as close to the onset of stuttering as possible, could demonstrate how early stuttering differs from normal disfluency, which might lead to earlier and more precise diagnoses. The findings of these studies provide more information for evidence-based practice in the differential diagnosis of stuttering and normal nonfluency.

The number, type and duration of within-word disfluencies are important factors in the diagnosis of stuttering in children. The duration of within-word disfluencies has also been used as an indicator of stuttering severity (Conture, 2001; Riley, 1980), and as a means for evaluating stutterers' progress in fluency therapy (Johnson et al., 1959). Some authors (e.g., Bloodstein, 1987) have questioned the diagnostic validity and usefulness of disfluency duration measures. Such questions primarily have stemmed from the lack of objective data concerning the duration of within-word disfluencies produced by children who stutter (CWS) and children who do not stutter (CWNS). Accordingly, several recent studies have investigated the temporal characteristics of children's within-word disfluencies.

Temporal characteristics of disfluencies in children with stuttering

Schaedler (2002) examined the temporal characteristics of speech disfluencies produced by young children during a sentence imitation task. Eleven children who stutter (CWS) and 11 age- and sex-matched children who do not stutter (CWNS) (Mean age = 5.6 years) participated in the study. The subject's repetition of 20 3-syllable-long phrases and sentences (phonetic similarity of the syllable onsets differed) were video recorded. The data was transcribed verbatim and each of the 1-syllable word was coded for phonetic accuracy and fluency. Words featuring articulation errors (e.g. "Snue's snake soup") were coded as "inaccurate". Inaccurate words were then coded as "revised" if the speech error was repaired (e.g. "Snue's-Sue's snake soup."). Syllables featuring within-word disfluencies were coded to reflect the type of disfluency they contained (i.e., SSR, SP, or SSR+SP). All revisions that occurred on non-stuttered words and all stuttered disfluencies that occurred on phonetically accurate words were digitized using Computerized Speech Lab (CSL), so that they could be viewed as amplitude waveforms and sound spectrograms. The duration of within-word disfluencies and speech error revisions were measured. Results indicated that the within-word disfluencies of CWS were significantly longer than those of CWNS, and that the speed at which CWS initiated speech error repairs was significantly shorter than that for CWNS. There was no significant difference between groups for the duration of speech errors.

Natke, Sandrieser, Pietrowsky, and Kalveram (2006) investigated disfluencies in German preschool CWS and compared it with CWNS. The guidelines (provided by Yairi & Ambrose, 1992) of sufficiently long speech samples (a minimum of 1000 syllables), a narrow age range between 2 and 5 years, and proximity to stuttering onset were adhered to. Twenty-four CWS (13 boys and 11 girls) and 24 CWNS in the age range of 2-5 years participated in the study. Two play sessions (minimum of 600 syllables) was video- and audio-recorded for each child. Speech samples were transcribed orthographically and analyzed using the computer program CLAN (MacWhinney, 2000), where a special post-coding system for disfluencies was added. Disfluencies were identified and five types of dysfluencies (prolongations, blocks, and repetitions of sounds, syllables, and one-syllable words) were defined and grouped as SLD. Percentages for each disfluency type (related to the number of syllables) and the number of iterations was calculated for each participant and were used to derive group means. A syllable-based metric was used because it reflects the amount of speech affected by disfluency more accurately than a word-based metric (Yairi, 1997). Results revealed that all disfluency types classified as SLD were produced significantly more often by children who stutter than by children who do not stutter. In other disfluencies, the groups did not differ (multi-syllable repetitions may represent an exception). Repetitive stuttering-like disfluencies shown by both groups differed in frequency and in number of iterations. CWS repeated these disfluencies more often than CWNS. The latter also showed that pause durations between iterations of one-syllable words are shorter in CWS than in CWNS. Though there were cases with up to 10 iterations in CWS, which did not appear in the CWNS group, one iteration is most common. This implied that ranges or upper limits are more informative than means in this context. Results of the study indicate that different causal mechanisms might underlie one-syllable word repetitions shown by CWS and CWNS, indicating types of'stuttered' and 'normal' repetitions.

Motor and acoustic characteristics of disfluencies in adults with stuttering

Results of many motor and acoustic studies appear to lead to an overall conclusion that the speech production process in adults who stutter is different from that of normally fluent controls (Alfonso, 1991; Kent, 2000). The phenomenon of recovery gives rise to important questions pertaining to the nature of the differences between persistent and recovered stuttering. Separating those who will persist from those who recover should increase precision in experiments in various aspects of childhood stuttering and provide databased grounds to reconsider traditional views of stuttering as a unitary disorder (St. Onge, 1963). From a clinical point of view, perhaps the most immediate question involves prognosis; that is, are there means to determine in the early stage of the disorder which of the children who begin stuttering will recover spontaneously? Do they exhibit different speech and/or nonspeech characteristics even before developmental processes separate them? Early prediction of the eventual course of the disorder will allow clinicians to make informed decisions about selective treatment strategies. Inasmuch as variations in formant structure along the temporal and frequency domains reflect articulatory dynamics, especially of the tongue (Gay, 1978), and to the extent that stuttering is a disorder that involves difficulties with temporal programming and with executing complex articulatory movements or maintaining spatial organization of the articulators (Alfonso, Watson, & Baer, 1987; Kent, 1984; Van Riper, 1982), information regarding F2 in individuals who stutter would seem to be relevant. It is also reasonable to hypothesize that those children who are destined to become adults with chronic stuttering present formant abnormalities from early on. These irregularities in children with persistent stuttering would be similar to those found in adults with chronic stuttering but are not exhibited by children who will eventually recover. Two theories with regard to defining stuttering were put forth by Van Riper (1982) and Wingate (1977). According to Van Riper (1982) the production of disfluency is phonetically dissimilar to the onset of fluent production of the target syllable. For example a stuttering disfluency in the context of */kPeitl/* might be */kuh kuh kuh J^eitl/.* Van Riper (1982) explains this phenomenon as a disorder of timing, and suggests that the presence of the perceived schwa in syllabic repetitions may be due to a failure in coarticulation. That is, stutterers articulate schwa when they intend producing some other vowel. When they realize this, they terminate their effort. In contrast, Wingate (1977) discusses stuttering as a phonetic transition defect. Contradicting Van Riper's theory, Fry (1955) has shown that two factors that cause the repeated syllables to sound more centralized are duration and amplitude. That is the unstressed and rapidly articulated vowels being shorter and at a lower level sounds more like schwa vowel. Hence the listeners may judge any speech, which includes short-duration and low-amplitude vowels as more centralized. Hence it is important to resolve the issue of whether true schwas occur in stuttered speech because this has some practical implications. Some studies have been conducted to investigate Van Riper's theory. A series of studies have been conducted to investigate whether the part-word repetitions in stutterers' speech differ acoustically (Fi and F2, F2 transition duration, extent and speed of F2 transition) from their fluent utterance and from that of a fluent speaker's speech. These studies have been conducted in adults and children.

Montgomery & Cooke (1976) assessed acoustic and perceptual parameters of part-word repetitions. Thirty experimental samples (part-word repetitions on the initial CV+ utterance of words) were extracted from 16 English speaking adult stutterers. Five speech pathologists judged these samples and wrote down the vowel heard (condition I) and predicted the vowel of the word that the stutterer was going to produce (condition II). Confusion matrices were generated for both conditions. Consonant duration, vowel-to-end duration and the pattern of Fi and F2 formant transitions were measured using a Voiceprint sound spectrograph. Visual comparisons of the transition patterns of Fi and F_2 in the region of the C-V juncture were made in the stuttered and fluent words. Results indicated that the schwa vowel was perceived in only 25% of the repetitions. Visual comparisons revealed a difference in the rate and/or extent of formant movement in 62% of the pairs of samples. Results also revealed that although abnormal consonant duration and C-V formant transitions characterized the initial segment of the stuttered word, the remainder of the word is identical to its fluently produced counterpart. The authors concluded that the formant deviations may simply reflect the fact that the consonant of the stuttered word was produced with an abnormal posture and the articulatory "path" from this posture to the normally produced vowel was correspondingly disturbed.

Klich and May (1982) analyzed Fi and F_2 in adult stutterers. Seven adult stutterers whose severity of stuttering ranged from moderate-to-severe participated in the study. Subjects' fluent reading in a control (normal) condition and under four experimental condition-masking noise, delayed auditory feedback, rhythmic pacing, and whispering-was audiorecorded. Formant frequencies (Fi and F2) and formant transitions associated with the fluent CVC utterances (with vowels /i/, /ae/ and /u/) were measured. They found that formant frequencies in stutterers (measured by the authors) were different from that of nonstutterers (existing data). The stutterers' Fi and F2 values were found to be more centralized compared to nonstutterers. The formant frequencies were centralized even more in reading, but varied little across conditions despite changes in fluency, speaking rates, and vowel duration. Results suggested that stutterers restrict their vowel articulations spatially as well as temporally during fluent utterances. The authors concluded that vowel reduction may be used by stutterers as a strategy for achieving fluent speech.

Harrington (1987) studied coarticulation in the disfluent utterances of 36 adult male and female stutterers. Each subject read a list of 200 monosyllables one at a time following the offset of a 1 kHz tone. The monosyllables included all phonotactically legal prevocalic consonant sequences followed by the vowels *I'll,* /u: / and *1*1.* Two subjects (one male and one female) were randomly chosen for electropalatographic recording. Results suggested that during the production of the bilabial closure (during production if the monosyllable /pid/), the sides of the tongue were raised towards the palate, indicating that the disfluent utterance is not a schwa vowel. Results of acoustic analysis using spectrogram indicated the following:

1. The acoustic vowel onglide (the initial formant transitions following the release of the consonant) could be realized as part of the disfluency, but not the acoustic vowel target (the point at which the formant frequencies correspond most closely to those of the same vowel when produced in isolation).
2. The acoustic vowel onglide of the disfluency would bend in the direction of the acoustic vowel target, but not reach the frequency values of the acoustic vowel target.
3. Following the release of the consonant in the dissiliency, the formants might remain level (absent transition) in contrast to the clear transition shown in the production of the target syllable; formants at the release of the consonant of the dissiliency would point in the 'wrong' direction (discrepant transition) compared with the formant transitions from the prevocalic consonant(s) to the vowel in the target syllable.

Mohan Murthy (1988) studied acoustic and aerodynamic aspects in a 17-year-old Kannada speaking adult male subject (with chronic stuttering). Dysfluent utterances were elicited in four types of speech tasks (spontaneous speech, picture description, word repetition and sentence repetition). Simultaneous audio and electrolaryngographic (Lx) recordings and concurrent audio and electroaerometric (mouth expiration) recordings were made. Using wideband spectrograms speech sound duration, first and second formant frequencies, and speed of transition were measured. Segment durations and formant transitions were measured at the apparently disrupted instances. When airflow patterns and/or voice bars on the baseline of the spectrogram were appearing abnormal, corresponding Lx and aerometric recordings were analyzed. Results of acoustic measures showed faster transition rate and atypical CV and VC transitions in the dysfluent pretherapy utterances.

Suchitra (1985) studied acoustic parameters in pre- and post-therapy speech of stutterers. Five stutterers (four males and one female) in the age range of 15 to 28 years and five age and gender matched normals participated in the study. Subjects were asked to read four syllables and three words with voiceless stop consonant (p, t., t, k) in the initial position which was audiorecorded. Using wide band spectrogram voice onset time was measured. Using acoustic waveforms spectral parameters were analyzed in VCV segments with vowels /i, u, a/ and consonants /p, b, t, d, k, g/. Results showed that, (i) when the F2 of the initial vowel was falling in normals, it was steady in the fluent utterances of stutterers, (ii) when the F2 of the final vowel was steady in normals, it was rising in the fluent utterances of stutterers and (iii) the F2 was missing in a number of VCV sequences in the fluent speech of stutterers which was not seen in normals. Results also showed that the extent of transition for both initial and final vowel in fluent utterances of stutterers were different from those of abnormals.

Raghunath (1992) studied temporal and spectral parameters in the speech of persons with stuttering. Four adult male stutterers in the age range of 20-30 years participated in the study. Spontaneous speech and reading samples were collected. The perceptually dysfluent and the corresponding fluent utterances were selected for further analysis. Using wide band spectrogram, vowel duration, voice onset time, aspiration duration, transition duration and speed of F2 transition were measured.

Results indicated shorter and longer transition duration of F2 in stuttered events compared to nonstutterers. Results also showed lack of F_2 transition and inappropriate transitions. The author related these findings to errors of coarticulation.

Robb & Blomgren (1997) analyzed F2 transition in the speech of stutterers and nonstutterers. Five English speaking stutterers (M = 28 years) and five nonstutterers (M = 35 years) participated in the study. Material consisted of consonant+vowel+/t/ (CVt), i.e. all the tokens ended with the phoneme *HI.* C consisted of the two bilabial stop consonants /p, b/ and two alveolar fricatives /s, z/ and V consisted of /i, u, a/. Each token was embedded in a carrier phrase. The subjects read the phrase, which was audio recorded. Fluent utterances were considered for further analysis. Formants were identified using a combination of filter-bank spectrographic and LPC techniques. Onset of F2 transition and offset of F2 transition at 30 ms and 60 ms were measured. The onset and offset points for each of the F_2 transition measures were then fit with a polynomial to determine the slope of the F_2 transition. Each subject's CVt coarticulation was evaluated according to the "steepness" of the derived slope coefficient for each token at 30- and 60-msec time-points. Results indicated that the F2 slope coefficients for stops at both 30- and 60-msec time-points were consistently larger (furthest from 0.00) for stutterers compared to nonstutterers. The nonstutterers F_2 slope coefficients for fricatives at both 30- and 60-msec time-points showed a closer approximation to zero compared to stutterers. However, there was an exception to this pattern. The stutterers' production of the /sit/ and /zit/ tokens yielded smaller slope coefficients compared to nonstutterers.

Blomgren, Robb & Chen (1998) studied the vocal tract stability of stutterers' and nonstutterers' fluent speech through the examination of formant frequency fluctuation *(FFF).* Fifteen adult males served as subjects comprising separate groups of untreated stutterers (mean age - 28 years), stutterers enrolled in a fluency-shaping treatment program (mean age - 27 years), and nonstuttering controls (mean age - 35 years). Material consisted of consonant+vowel+/t/ (CVt), i.e. all the tokens ended with the phoneme *Ixl.* C consisted of the two bilabial stop consonants /p, b/ and two alveolar fricatives *Is, zl* and V consisted of /i, u, a/. Each token was embedded in a carrier phrase. The subjects read the phrase, which was audio recorded. The steady-state portion of first (Fi) and second formant (F_2) was examined. Vocal tract vowel space was estimated three ways. The first analysis scheme involved measurement of formant frequency spacing. The second measure involved calculating the area of the vowel space triangle. The third measure was based on calculating the average Euclidean distance from each subject's midpoint "centroid" vocal tract position to the corresponding /i/, *lul,* and /a/ points on the vowel triangle. The untreated stutterers displayed the greater vowel centralization than control group and treated stutterers.

Zmarich & Marchiori (2006) studied prosodic influences on anticipatory coarticulation in adult stutterers. Four adult stutterers and four nonstutterers read aloud declarative sentences with normal (Subject-Verb) and inverted word order (Verb-Subject), as an answer to appropriate questions. The verb was kept constant ("viene"), whereas the subject, a three-syllabic pseudo-name ("dadada" or "dididi"), was systematically varied for lexical stress. Each of the two words could be focussed, and the focus had scope (i) on the whole sentence (informative broad focus), (ii) on the first word (narrow initial contrastive focus), (iii) on the second word (narrow final contrastive focus). The fluent utterances were acoustically analyzed. Results showed that stutterers assign the main prominence to the initial name even when it is not under focus and that they realize the FO peak for the word in narrow focus earlier than nonstutterers do. Stutterers had greater slope coefficient of the regression line for F2C and F2V values (Sussman, Duder, Dalston, & Cacciatore, 1999). The results about coarticulation processes in stutterers indicate faster and wider tongue movements from consonant target to vocalic targets with respect to nonstutterers, i.e. less coarticulation. Authors attribute the results to some subtle dysfunctions of the respiratory, laryngeal, supralaryngeal systems and of their coordination, as found by physiological research on stuttering, which could have been triggered by the variability of the focal accent position in the sentence and by the complexity of its (co)articulatory realization, especially at the utterance initial position.

Hirsch, Fauvet, Ferbach-Hecker, Bechet, Bouarourou, & Sturm (2007) analyzed the formant structures of vowels produced by stutterers at normal and fast speech rates. Nine adult speakers, from 25 to 30 years, included three control subjects without speech disorders, three stutterers and three treated stutterers. Each speaker had to pronounce sentences containing a [CVp] sequence ten times, where C was [p], [t] or [k] and V [i], [a] or [u]. The subjects repeated the sentences in two speech rate conditions: normal and fast. Fluent utterances were selected and using spectrographic data the formant frequencies were measured. Several studies (Lindblom, 1963 among others) done on normals have shown that an increase of speech rate could provoke a compression of durations and a reduction of the vowel space, *i.e.* a certain centralization of vowels in this space. However, in this study, this phenomenon of centralization was only observed for two vowels, *i.e.* for [i] and for [u]. Results showed that the formant structure of vowels [i, a, uj is comparable for treated stutterers and for control subjects, whereas it is different for stutterers. F_2 is especially responsible for this configuration: it suggests fronting of the tongue. Furthermore, an "undershoot" phenomenon was observed for controls and treated stutterers in a fast speaking condition. This centralization was not noticed in non-treated stutterers' speech, since area of the vowel was similar in the two rate conditions. Thus stutterers do not show variations of vowel space when they speak faster. The authors hypothesized that lack of centralization during fast rate of speech could result from reduction of the vowel space of stutterers in normal speech rate itself.

Studies conducted by Klich & May (1982), Blomgren, Robb and Chen (1998), and Hirsch, Fauvet, Ferbach-Hecker, Bechet, Bouarourou, & Sturm (2007) found vowel centralization in the speech of stutterers. The following three studies failed to find vowel centralization in the speech of stutterers.

Harrington (1984) studied the disfluencies produced by a Cantonese stutterer. He studied the spectrograms of two disfluencies produced in the context of target syllables /ssetf and /se/. It was found that in the disfluency in the context of target syllable /sas»y was produced with a greater degree of lip rounding than the context target syllable /se/. Similar results were reported by Harrington (1987), who studied coarticulation in the dysfluent utterances.

Prosek, Montgomery, Walden and Hawkins (1987) analyzed formant frequencies of stuttered and fluent vowels in 15 adult stutterers in the age range of 18-35 years. Subjects read a 120-word reading passage 5 times in succession (adaptation task), which was audiorecorded. Fluent reading of word list was also elicited for further analysis. The fluently produced word list and the first and the fifth readings were considered for further analysis. Fi, F_2, Bl, and B2 were measured and F1- F2 vowel space and normalized, F1- F2 vowel space were plotted. Vowel normalization allowed intertalker differences due to vocal tract length to be eliminated form the comparison. Results showed difference in formant frequencies between stutterers and nonstutterers. The authors attributed these differences to variable vocal tract dimensions. The results did not indicate any difference between the formant frequencies of the fluent and disfluent vowels produced by the stutterers. The results indicated that stutterers do not exhibit greater vowel centralization than nonstutterers. These studies contradicted Van Riper's theory that stuttering is an error of coarticulation.

The aforementioned studies investigated acoustic parameters (especially formants) in adults who stutter. This cannot be generalized to children who stutter (CWS) because the stuttered speech of CWS is speech, which is closest to the onset of the stuttering problem, and consequently is likely to be less habituated than that of adult stutterers. Such lack of habituation, coupled with the young child's incomplete development of physical and psychologic reactions to their stutterings, suggests that the speech behavior associated with young stutterers' fluency is less likely than that of adult stutterers to be influenced by this habituated "stuttering physiology" and associated (non) speech reactions. Therefore, it would be most desirable to study the fluent speech of children who stutter if one wanted to study those aspects of stutterers' actual speech production abilities that are minimally impacted by habituated instances of stuttering and psychogenic or physical reactions to same. Such studies would give a clear picture about the child's speech production which inturn can be considered as a factor for differentiating stuttering children from normally fluent ones.

Acoustic characteristics of dysfluencies in children with stuttering

The first study in this aspect was conducted by Stromsta (1965), who investigated the second formant transitions in 63 children identified by **their parents as** having stuttering. Disfluent segments in their speech was analyzed spectrographically and divided into two categories - (a) displaying formant transitions and normal termination of phonation or (b) displaying lack of formant transitions and/or abnormal termination of phonation. Ten years later, parents' classifications of 38 of these children as either "stuttering" or "not stuttering" were checked against these categories. Results of acoustic analysis showed that the spectrogram of stuttered speech revealed a lack of usual falling or rising transitions shown in spectrogram of normal speech. He also found that experienced listeners judged the formant transitions in the stuttered speech of children to be abnormal. The juncture formants were not present or were very different. Results also indicated that those children whose spectrograms of disfluencies showed anamolies in coarticulation failed to "outgrow" their stuttering and those children whose spectrograms showed normal juncture formants had become fluent in the ten year span since the original recordings were made. His study provided relatively little information about his subjects or about the exact nature of the "abnormal" formant transitions he reported.

Zebrowski, Conture & Cudahy (1985) examined formant transition rates (speed of transition) in the speech of children with stuttering. Eleven young stutterers (mean age = 4 yr, 5 mo) and 11 age and sex- matched normally fluent children (mean age = 4 yr, 8 mo) were considered for the study. Stimulus material consisted of a consonant-vowel-consonant or consonant-vowel test word containing word-initial bilabial stop consonant /p/ or *Ibl* embedded in a carrier phrase. The subjects' repetition of these phrases was audiorecorded. The following temporal parameters were measured - vowel-consonant transition duration (ms) and rate (Hz/ms), stop-gap, frication, and aspiration durations, voice onset time (VOT), consonant-vowel transition duration and rate, and vowel duration. Results indicated no significant differences between young stutterers and their normally fluent peers for any of the temporal measures for either *Ibl* or /p/, although differences in frication duration approached but did not reach significance. The normally fluent children exhibited an inverse relation between stop-gap and aspiration durations for /p/ while the children with stuttering demonstrated a lack of any clear relation between these two temporal variables. In other words, for normally fluent children, longer stop-gap durations correspond to shorter aspiration durations for /p/, this trend was not reported in stuttering children. Findings seem to suggest that young stutterers exhibit some difficulties effecting the relatively smooth, coordinated "compensatory" relations between laryngeal and supralaryngeal behaviors which would allow the system to remain within the "time limits" necessary for optimally smooth, ongoing, fluent speech production.

Howell & Vause (1986) assessed acoustic and perceptual parameters of stuttered vowels. Eight children with stuttering (seven males and one female) participated in the study. Thirty monosyllabic words were used as material, and words consisting of a single voiceless consonant were spectrographically analyzed. The first three formant frequencies were extracted by Linear Predictive Coding (LPC) analysis. The dysfluent vowels were shorter in duration and lower in amplitude compared to the fluently produced vowels. The spectral properties of the dysfluent vowels were similar to the following fluent vowel, indicating that the stutterers are articulating the vowel appropriately. But the formants in the stuttered speech lacked transitions. In the perceptual experiment it was found that if the amplitude is normal and the duration is lengthened they sound more like the intended vowels. This indicates that the stuttered vowels were perceived as schwa vowel due to shorter duration and lower amplitude.

In another study, Howell, Williams & Vause (1987) assessed acoustic and perceptual parameters of stuttered vowels in eight children with stuttering. The material consisted of words having initial voiceless stop consonants followed by a vowel. Thirty spontaneous disfluent utterances that occurred on these words were considered for further analysis. The vowel before the fluent release and the subsequent fluent vowel were selected. The first three formant frequencies and the formant transitions between the initial consonant and the following vowel were measured using model spectrum and spectrogram. For the perceptual test sequences of repetitions and the subsequent fluent word spoken by one of the stutterers were used. The first stimuli were original tokens (repeated syllables) and the second were original tokens increased in duration and amplitude. In the next set the same vowels in normal speaker's utterance was reduced in duration and amplitude. The tokens were formed and given for perceptual judgment. Results showed that the first three formant frequencies were not different between the fluent and the disfluent productions. The disfluent vowels were shorter and lower in amplitude than the corresponding fluent vowels. Normal formant transitions were absent in the disfluent utterances. Perceptual study showed that the listeners perceived the disfluent vowels as closer to schwa vowel. The findings of the study indicated that the acoustic properties of the stuttered vowels have the properties of the following fluent vowel and not schwa. The stuttered vowels were perceived as schwa vowel due to shorter duration and lower amplitude.

Revathi (1989) measured acoustic temporal parameters in the speech of normally non-fluent and stuttering children in two normally nonfluent children and two stuttering children in the age range of 6-8 years. The material consisted of pictures to elicit Kannada words that included all the consonants in initial and medial position as well as pictures for story narration. The children were asked to name the pictures and narrate the story. The following temporal parameters were measured using wide band spectrograms: vowel and consonant duration (for consonants other than stops), closure and burst duration, voice onset time, Fi and F2 transition duration (TD) and speed of transition of Fi and F2. Results indicated significantly longer vowel and burst duration in stutterers, and significantly shorter F2 TD and higher speed of Fi transition. Fricative duration was longer and nasal duration was shorter in stutterers.

In a third study, Howell & Williams (1992) investigated the acoustic and perceptual properties of stuttered vowels. The subjects consisted of 24 children who stutter and eight teenage stutterers. From conversational speech samples the vowel in CV syllable repetitions and the following fluent vowel were excised. The formant frequencies, duration and intensity were measured for the disfluent and the corresponding fluent vowels. Perceptual tests were conducted to assess whether duration and the differences found in the source excitation would make children's vowels sound neutral. Results showed that the formant frequencies of vowels in syllable repetitions were appropriate for the intended vowel and the duration of the dysfluent vowels were shorter than those of the fluent vowels for both groups of speakers. The intensity of the fluent vowels was greater than that of the dysfluent vowels for the teenagers but not the children: For both age groups, excitation waveforms obtained by inverse filtering showed that the excitation spectra associated with dysfluent vowels fell off more rapidly with frequency than did those associated with the fluent vowels. The fundamental frequency of the children's dysfluent speech was higher than their fluent speech while there was no difference in the teenager's speech. The relationship between the intensities of the glottal volume velocities was the same as that of the speech waveforms. The results of the perceptual experiments showed that in children, neither vowel duration nor fundamental frequency differences caused the vowels to be perceived as neutral. The results suggest that the low intensity and characteristics of the source of excitation, which cause vowels to sound neutral, may only occur in late childhood. Furthermore, monitoring stuttered speech for the emergence of neutral vowels may be a way of indexing the progress of the disorder.

Yaruss & Conture (1993) examined the relationship between F2 transitions during sound/syllable repetitions (SSRs) and the predicted chronicity of stuttering. The subjects were 13 Children divided into high-risk group (consisting of 7 boys with a mean age of 50.6 months), and low-risk group (consisting of 5 boys and 1 girl with a mean age of 48.5 months) based on the predicted chronicity of stuttering. Each child's conversational interaction with mother was audio/video recorded for 30-minutes. Ten SSRs per child was acoustically analyzed using spectrograms from Computerized Speech Lab (CSL). Duration of F2 transition, onset and offset frequencies of the F_2 transitions, extent of F2 transition, and rate of frequency change in F_2 transition (speed of F_2 transition) were measured. Results showed missing (25-29%) or atypical (10-16%) formant transitions in children who stutter during the first iteration. There was no significant difference in the frequency of occurrence of these missing or atypical formant transitions for high verses low risk group. Also, there was no significant difference between groups for mean duration of F2 transition, onset and offset frequencies of the F_2 transitions, extent of F2 transition, and rate of frequency change in F_2 transition (speed of F2 transition). In the low-risk group, stuttered F2 transitions were typically shorter compared to fluent transitions. However, their classification of subjects and conclusions were not verified by longitudinal observations of the children.

Walker, Shine & Hume (1994) analyzed the acoustic differences between matched pairs of normally fluent and stuttering children. Two repetitions of ten fluently spoken sentences were selected for the analysis. Fundamental frequency, duration of steady-state portion of vowels, duration of syllabic subsegments, duration of transition of primary stressed syllables, duration of entire utterance, duration of pause preceding the primary stressed syllable, second formant frequency of vowels, total change and ratio of the transition of the primary stressed syllable, and rate of speech were measured. The mean absolute difference in the change of each variable measurement, between the first and second repetition of each of ten sentences, was statistically and descriptively analyzed. The experimental groups of stuttering subjects were found to have statistically and descriptively larger absolute difference scores, than the normally fluent subjects. This difference in variability was found to exist between the two groups despite the normal variability that exists in repetitive utterances spoken by normally fluent children.

Kowalczyk & Yairi (1995) examined speed of F2 transition in eight persistent preschool stutterers. They found that the stutterers exhibited greater speed of F2 transition compared to age-matched groups of recovered stutterers and controls.

Some authors have studied vowel development in very young children at risk to stutter. Fosnot (1997) compared the high front /i/ and high back /u/ vowel in children at risk and not at risk to stutter. Three at-risk and 4 not-at-risk children (15 months old) were selected to participate in this study. Longitudinal video recordings were made of children playing with parents for 10 minutes between 15 and 36 months of age. Anatomical and linguistic influences did not differ across subjects with the exception of the 24-month period. Spontaneous utterances from each child were digitized into a CSL, Model 4300. The F1 and F_2 of the steady state portion of each /i/ and /u/ vowel was measured. Not-at-risk children demonstrated values typical of normally developing children. Repeated measure ANOVA showed that children who were at risk to stutter had significantly higher formant values for F1 for both /i/ and /u/ vowels. These results suggest that the tongue height is lower than it should be for the high vowels. Formant frequencies for F_2 for both /i/ and /u/ were significantly higher also reflecting a more forward tongue position for the front and the back vowels in at-risk children.

Prakash, Saji & Savithri (1998) studied transition duration in the fluent and dysfluent utterances of five children (three with stuttering and two normally nonfluent). Spectrographic analysis revealed no significant differences between transition duration and rate and extent of F_2 transition of the two groups. However, the F_2 transitions during the measurable stuttered portion of sound syllable repetitions were typically shorter in duration compared to F_2 transitions during fluent portions for both the groups. They also found missing or atypical formant transitions in children who stutter. They concluded that the apparent lengthening of F_2 transition durations during fluent utterances might be indicative of sound or segmental prolongation.

Prakash, Sarah & Savithri (1999) studied aspects in stuttering children. Four normally nonfluent and four stuttering children were considered for the study. From the steady-state portion of the vowel VI in C1V1C2V2 syllable, frequency of F_2, Formant Frequency Fluctuation (FFF), and FO variation were measured. They reported that stutterers consistently showed higher frequency of F2, greater FFF, and greater FO variation in the vowel steady state portion (VI) of the C1V1C2V2 syllable. In a similar study Prakash & Sarah (1999) also reported higher fluctuations in the steady state portion VI in stutterers.

Prakash (2000) studied acoustic temporal parameters in 20 Kannada speaking children in the age range of 3-8 years (10 stuttering and 10 normal nonfluency children). In experiment I conversational speech samples were audio recorded and the sound/syllable repetitions were acoustically analyzed using CSL 4300. F2 transition duration, extent and speed of F2 transition and pattern of F2 transition were measured. In experiment II C1V1C2V2 Kannada meaningful words formed the material, where Cl was unvoiced or voiced consonants, VI was /a: /, C2 was /r/ and V2 was /u/ or /i/. These utterances were analyzed using "FBAS" (Formant Based Analysis of Speech) of SSL (Voice and Speech Systems, Bangalore). Formant frequency fluctuations, overall F2, F0 variations and vowel duration were analyzed in the steady states of all the vowels. Stuttering children exhibited longer transition duration and significantly shorter extent of F2 transition and faster speed of F2 transition. Stutterers also showed higher percent of absent and discrepant F2 transition pattern. The vowel durations of fluent utterances were significantly shorter in children with stuttering. F0 variations and mean F2 were greater and formant frequency fluctuations were found to be lesser in children with stuttering (though not significantly).

Brosch, Hage & Johannscn (2002) in a longitudinal study analyzed the correlation between acoustic variables, severity and course of stuttering. Fifty-seven preschool children (15 girls and 42 boys) were considered for the study. The children were at a mean age of 5 years and 3 months at the time of their first recording; repeated recordings were done at a 6-month intervals (9 follow-ups). Children were asked to utter single words "tiger" and "tafel", "papapa" and "kakaka" and three sentences. Three held vowels (a, e, o) were considered for various measurements. Voice onset time (VOT), vowel duration, stop gap, variability of the F0 and the signal intensity of sustained vowels and formants (F1, F2 & F3) were measured. Results showed that in children, who did not recover from stuttering, the VOT values and vowel duration were highly variable and stop-gap had a larger scatter. The average F0 was highly stable for all the children. For children who continued to stutter, F2 of/a/ and F1 and F2 of/o/ were significantly lower. Also F1 of/a/ and *Id* was found to be highly variable.

Chang, Ohde, & Conture (2002) assessed anticipatory coarticulation and second formant (F_2) transition rate (FTR) of speech production in young children who stutter (CWS) and who do not stutter (CWNS). Fourteen CWS and 14 age- and gender-matched CWNS in three age groups (3-, 4-, and 5-year-olds) participated in a picture-naming task that elicited single-word utterances. The initial consonant-vowel (CV) syllables of these utterances, comprising either bilabial [b, m] or alveolar [d, n, s, z] consonants and a number of vowels [i ɪ e ɛ æ u o ɔ aɪ aʊ], were used for acoustic analysis. To assess coarticulation and speech movement velocity, the F2 onset frequency and F_2 vowel target frequency (for coarticulation) and FTR (for speech movement velocity) were computed for each CV syllable and for each participant. Based on these measures, locus equation statistics of slope, y-intercept, and standard error of estimate as well as the FTR were analyzed. Findings revealed a significant main effect for place of articulation and a significantly larger difference in FTR between the two places of articulation for CWNS than for CWS. Findings suggest that the organization of the FTR production for place of articulation may not be as contrastive or refined in CWS as in CWNS, a subtle difficulty in the speed of speech-language production, which may contribute to the disruption of their speech fluency.

Subramanian, Yairi & Amir (2003) investigated F_2 transitions in children with stuttering. The initial recordings of 20 children with stuttering (10 persistent stutterers in the age range of 41 to 48 years and 10 recovered stutterers in the age range of 36 to 51 months) and 10 normally fluent children (in the age range of 38-48 months) participated in the study. Subjects repeated five different sentences, out of which 36 perceptually fluent speech segments (CVs embedded in words) were selected. The syllables were divided into three (bilabial, alveolar and velar) phonetic categories based on their initial consonant. The onset and offset of F2 transition, frequency change and the duration of F2 transition were measured using LPC spectrum and spectrograph. Results indicated that children whose stuttering eventually persisted demonstrated significantly smaller frequency change of F_2 transition (extent of F2 transition) compared to recovered group.

In summary, the above mentioned studies report that F_2 transitions characterizing the dysfluent speech of adults and children are either absent or atypical. Studies have varied with regard to the analysis method and speech samples. In spite of these differences, the studies seem to confirm that the lingual coarticulation accompanying a stuttering episode (repetition) as well as fluent utterances of stutterers differ from that of fluent speakers. In spite of all the research findings, it has not been possible to make a distinction between stuttering and normal non-fluency and the exact nature of the relationship between normal dis-fluencies and stuttering dys-fluencies remain unclear. In this context, this project investigated the efficacy of acoustic parameters in differential diagnosis of stuttering and normal non-fluency.

Chapter III

Method

Subjects: Two groups of subjects were involved in the study. Group I consisted of two hundred (200) Kannada speaking children (age range of 3-12 years) diagnosed as having stuttering and group II consisted of two hundred (200) age matched normal Kannada speaking children. Appendix I shows the details of subjects. None of the subjects had any complaint of hearing impairment, mental retardation, neurological problem or language delay. All of them had normal orofacial structure and function.

Material: It consisted of disyllabic words with stop consonants. Ten C1V1C2V2 Kannada meaningful words with the unvoiced consonants [k, c, t, t, p] and their cognates [g, j, d, d, b] in the initial position followed by a long mid vowel /a:/, a trill and vowel /u/ or vowel *I'll* in the final position formed the material. Also, general conversation and picture description were recorded. Table 1 shows the ten words. Pictures developed by Yamini (1990 - 3-4 yrs), Indu (1990 - 4-5 yrs), Nagapoornima (1990 - 5-6 yrs) and Rajendraswamy (1991 - 7-12 yrs) were used. Appendix II shows the pictures.

1)	ka:ru
2)	ga:re
3)	ca:ru
4)	ja:ru
5)	t.a:ru
6)	dabbi
7)	ta:ru
8)	da:ri
9)	pa:ru
10)	ba:ri

Table 1: List of words.

Procedure: Children were tested individually. They were instructed to repeat the words after the experimenter in a microphone kept at a distance of 10 cm from the mouth and these utterances, conversations and picture description were audio recorded on to a high quality audio cassette [MEL TRACK D 90] using a Sony stereo professional cassette deck and stored onto the computer for spectrographic analysis by using Multi Speech software (Kay Elemetrics, New Jersey). Conversation and picture description were transcribed verbatim and sound syllable repetitions (SSRs) were identified and analyzed.

Acoustic analyses: Acoustic analyses were performed using Multi Speech software, which permitted to store the tokens. The tokens was line-fed from the cassette deck on to the computer, digitized at 16 kHz sampling rate using a 16-bit quantization, and stored on to the memory of the computer. Each token was analyzed using 'spectrogram' and 'formant frequency' program (Multi Speech) and the following parameters were extracted.

1. Onset and Offset of F_2 Transition: The onset and offset of F_2 Transition (Hz) was estimated from the visually apparent center of the F_2 energy bands on the spectrogram display at the onset and offset of F_2 transition.
2. F_2 Transition duration (F_2TD): It was measured as the time difference (ms) between the onset of F_2 transition at the beginning of the vowel till the steady state. The beginning of the steady state portion of the following vowel was defined as the time when the formant, paralleled the time axis. This measure of F_2 transition duration is believed to approximate the amount of time the articulators spend moving from one position to other (Yaruss & contour, 1993).
3. Extent of F_2 transition: It was estimated by calculating the difference between the onset and offset frequency of F_2. This is believed to represent the overall movement of the articulators during the transition.
4. Speed of F_2 transition: The speed with which the second formant frequency (F_2) changes during the transition was measured by using the following formula.

   Speed of F_2 transition = Extent of F_2 transition (Hz) / F_2 transition duration (ms)

   This is believed to approximate the speed with which the speech articulation moves from one location to the next.

5. Pattern of F_2 transition: The manner, in which movement of articulators shifted from one phoneme to another phoneme, was visually inspected. This was classified as rising, falling and absent. F_2 transition that demonstrated an upward inflection resulted from negative formant transition (i.e. < 0 Hz) was termed as rising pattern (Stromsta, 1986) [i.e. Onset frequency < Offset

Frequency]. Downward inflections which resulted from positive formant transition (i.e. > 0 Hz) were termed as Falling pattern (Stromsta, 1986) [i.e. Onset frequency > Offset frequency]. When there was no inflection (i.e. extent of formant transition) was 0 Hz it was termed as flat pattern (Stromsta, 1986) or absent F2 transition. The sign of F2 transition was used to determine whether inflection (i.e. upward, downward and bending of a formant on the frequency axis, Stromsta, 1986) of a stuttered transition was similar **to that of** a comparable fluent transition or was atypical. These atypical patterns were noted. Figure 1 illustrates all the measures.

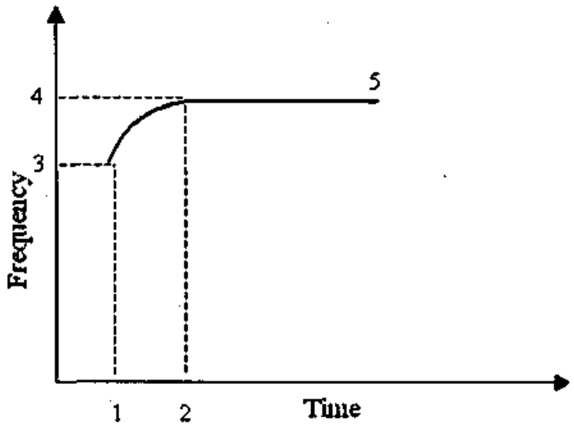


Figure 1: Pictorial illustration of acoustic measures (1- Onset of F2 Transition, 2- Offset of F_2 Transition; 2-1- F_2 Transition duration, 4-3- Extent of F_2 transition, and 3 to 5 - Pattern of F_2 Transition).

Statistical analyses: The Mean and Standard deviation (SD) of these parameters were computed using SPSS software (version 10). Independent t-test was used to find out the significant difference between groups (stuttering and normal nonfluency).

Chapter IV

Results and Discussion

The results indicated significant difference between groups on speed and extent of F_2 transition [{t (398) = 4.99, $p<0.001$}, {t (398) =2.97, $p<0.01$}, respectively]. Offset of F_2 was significantly higher [t (398) = 1.72, $p<0.1$] in group I compared to group II. Also, the onset of F_2 was higher and TD was shorter in group I compared to group II, though not significantly. Group I had higher speed and extent of F_2 transition compared to group II. Percent of absent and discrepant F_2 transition was higher in group I when compared to group II. Table 2 shows the Mean, Standard deviation (SD) and significant differences of all parameters in both groups. Figures 2 to 4 shows the mean values for all the parameters in both the groups. Figures 5 to 8 shows examples of spectrograms illustrating the difference between the groups.

Parameters	Group I (Stuttering)		Group II (Normal Non Fluency)	
	Mean	S.D.	Mean	S.D.
Onset of Fz transition (Hz)	1901	489	1875	457
Offset of F2 transition (Hz)	1925	469	1845	448
F2 Transition duration (ms)	51.08	2332	53	14.46
Extent of F2 transition (Hz)	446	231	383	188
Speed of F2 transition (Hz/ms)	11.10	8.06	7.86	4.30
'Pattern of F2 transition (%)				
Discrepant	34		33	
Non discrepant	32		48	
Absent	34		19	

Table 2: Mean and SD of all acoustic measures in both the groups.

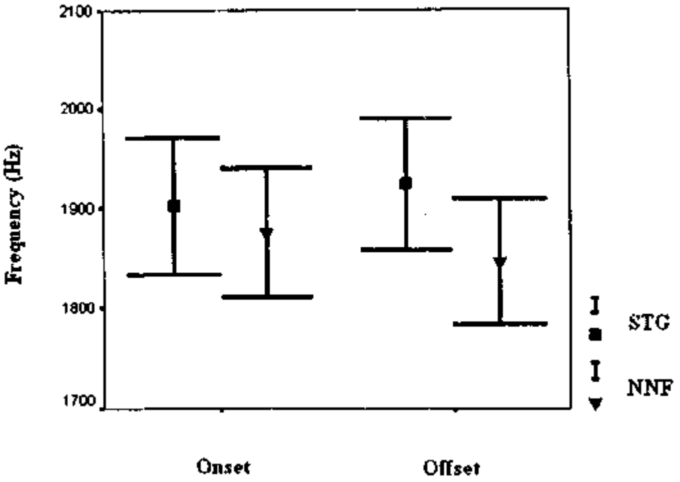


Figure 2: Error bar for onset and offset of F2 transition (Hz) in children with stuttering (STG) and normal nonfluency (NNF).

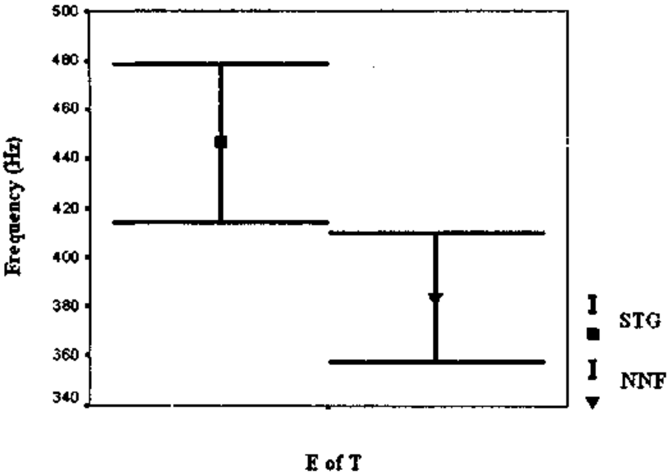


Figure 3: Error bar for extent of transition (E of T) in children with stuttering (STG) and normal nonfluency (NNF).

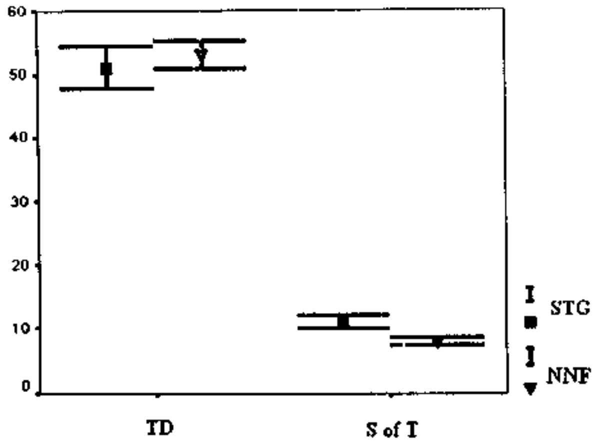
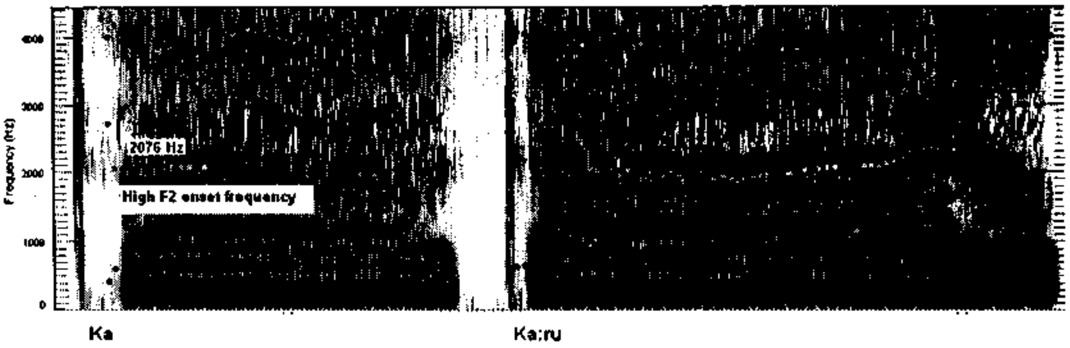


Figure 4: Error bar for F2 transition duration (TD) and speed of transition (S of T) in children with stuttering (STG) and normal nonfluency (NNF).

Repetition of /ka/ by a child with stuttering showing high onset of F2 transition (2076 Hz)



Same utterance by a child with normal nonfluency showing relatively low onset of F2 transition (1967 Hz)

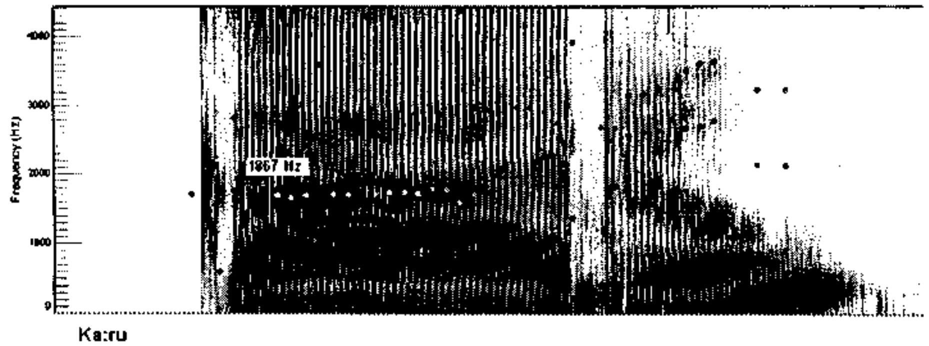
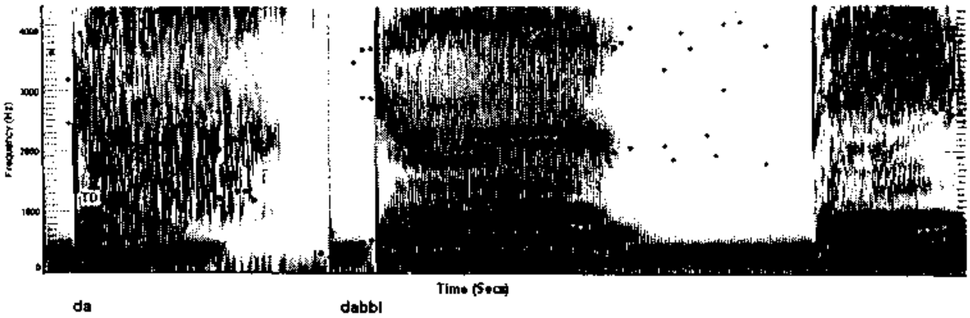


Figure 5: Spectrograms illustrating high onset of F_2 transition in a child with stuttering.

Repetition of /da/ by a child with stuttering showing short transition duration



Same utterance by a child with normal nonfluency showing longer TD

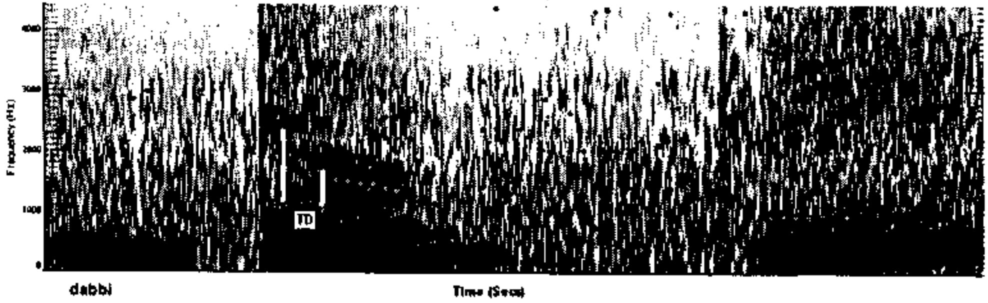
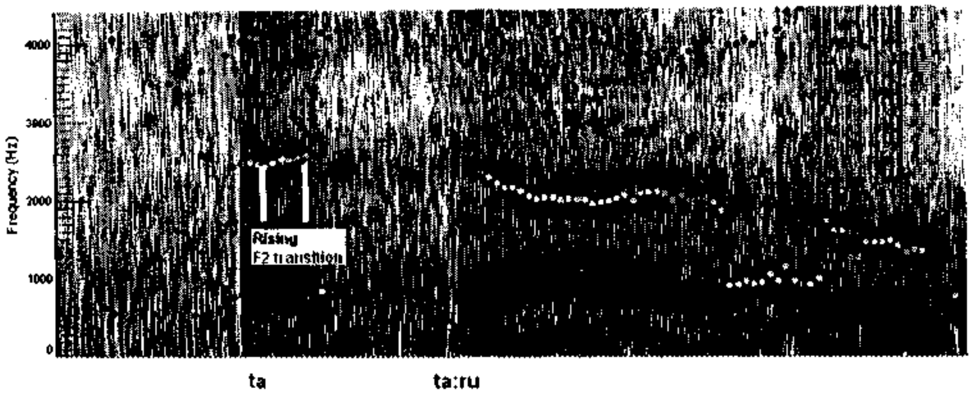
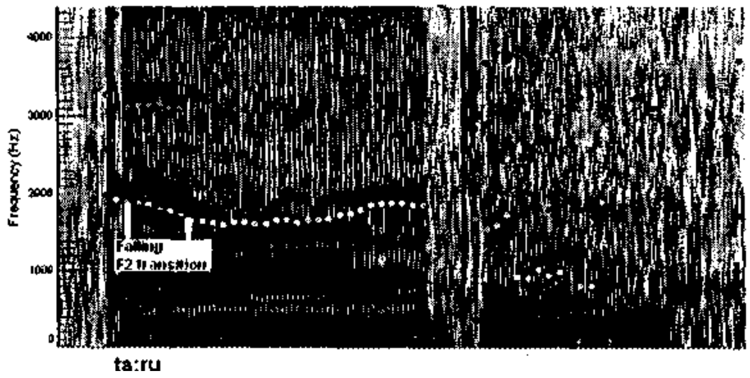


Figure 6: Spectrograms illustrating short transition duration (TD) in a child with stuttering.

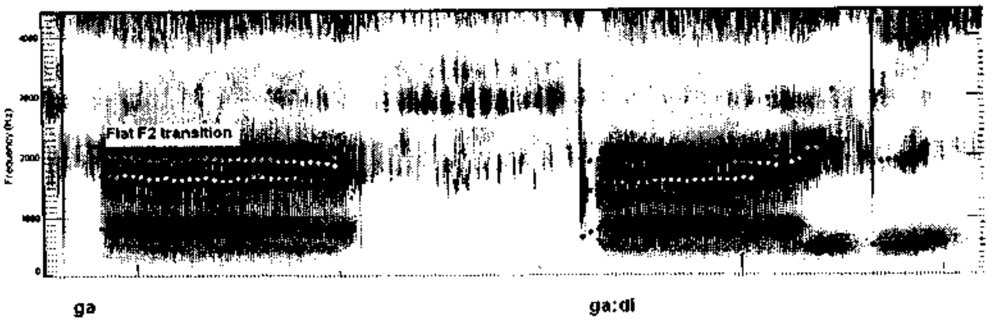


Repetition of /ta/ by a child with stuttering showing rising F2 transition (Discrepant)

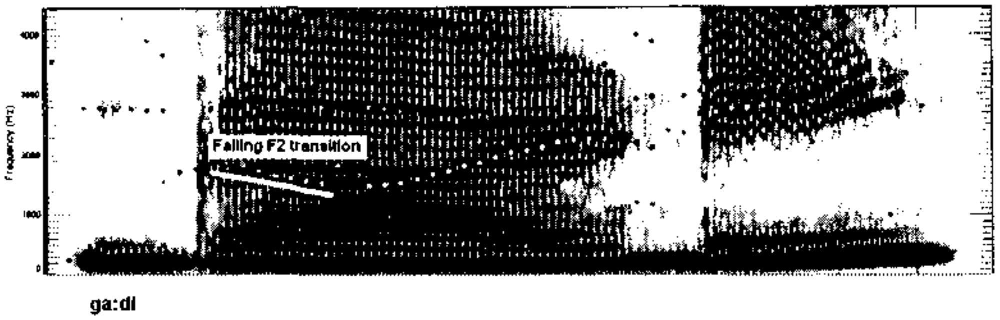


Same utterance by a child with normal nonfluency showing falling F2 transition

Figure 7: Spectrograms illustrating discrepant F2 transition in a child with stuttering.



Repetition of /ga/ by a child with stuttering showing absence of F2 transition



Same utterance by a child with normal nonfluency showing falling F2 transition

Figure 8: Spectrograms illustrating absent F2 transition in a child with stuttering.

The results revealed several points of interest. *First,* extent of F2 transition was found to be significantly higher in children with stuttering (446 Hz) compared to normal children (383 Hz). The higher extent of F_2 transition implies abrupt articulatory movements from one articulatory position to another. These findings are in consonance with findings of Montgomery & Cooke, (1976), and Suchitra (1985). However, all these studies were conducted in adults, whereas the present study is on children. Subramanian et al. (2003), hypothesized that it is possible that children who are destined to become adults with chronic stuttering present formant abnormalities from early on. Hence, considering that the formant abnormalities are similar, the results of the present study (conducted on children) can be compared to some extent with the results of the earlier studies (conducted on adults). Also, these results are in consonance with that of Revathi (1989). Hence extent of F_2 transition can be considered as an important prognostic indicator. *The results indicate* ***that extent ofF2 transition is an important parameter that can*** *be considered* ***for differentiating children with stuttering from normally nonfluent*** *children.*

Second, Speed of F2 transition was found to be significantly faster in children with stuttering (11.10 Hz/sec) compared to normal children (7.86 Hz/sec). This again implies faster articulatory movements in stutterers. While exhibiting sound syllable repetition rates (SSRs), children with stuttering tend to articulate imprecisely and abruptly compared to normally nonfluent children. The results of the study are in consonance with the findings of Kowalczyk & Yairi (1995). This measure can be included in the acoustic tool for differentiating stuttering and normal nonfluency.

Third, the onset and offset frequency of F2 transition was found to be higher in children with stuttering (1901 and 1925 Hz respectively) when compared to normal children (1875 and 1845 Hz respectively). This difference was not statistically significant for onset frequency of F2 transition. Since the offset of F2 transition in the dysfluent utterance of stuttering children was significantly higher, it can be assumed that the positioning of articulators while producing stuttered vowels were different (i.e., more central/schwa vowels were produced) compared to normal disfluent utterance. This supports Van Riper's theory, which states that stuttering is a disorder of timing, i.e., the production of disfluency is phonetically dissimilar to the onset of fluent production of the target syllable. This is in agreement with two other studies supporting Van Ripers's theory, Klich & May (1982) and Hirsh et al (2007), suggesting production of more central vowels in children with stuttering. This finding contradicted Brosch et al's (2002) findings; they found significantly lower F_2 in children with stuttering. In the present study F_2 offset was measured in the dysfluent utterance whereas in Brosch et al's study the formants were measured in the fluent utterances of stutterers, hence the results are not comparable. Hence, F_2 offset frequency/ second formant frequency can be included as one of the parameters in the acoustic measures for differential diagnosis.

Fourth, slightly shorter F_2 transition duration was found in children with stuttering compared to normal children. This supports the findings of Revathi (1989), and Prakash, Saji & Savithri (1998). Shorter transition duration implies faster articulatory movement and shortening the sound or segment i.e. decreased duration, in whole or part, of the iterated unit in stuttering. Absence of significant difference between groups could have resulted from variability seen among children with stuttering. Due to this reason F_2 transition duration cannot be included as an acoustic tool for differential diagnosis of stuttering and normal nonfluency.

I

Fifth, absent and discrepant F_2 transition was found more in children with stuttering (34% and 34%, respectively) compared to normal children (19% and 33%, respectively). These findings are in consonance with Stromsta (1986), Montgomery & Cooke (1976), Suchitra (1985), Howell & Vause (1986), Harrington (1987), Revathi (1989), Yaruss et. al. (1993), and Prakash, Saji & Savithri (1998). Absent F_2 transition may have occurred because stutterers truncate their production of some phonemes during some sound syllable repetitions (SSRs). According to Montgomery & Cooke (1976) discrepant transition may simply reflect the fact that the consonant of the stuttered word was produced with an abnormal posture and the articulatory "path" from this posture to the normally produced vowel was correspondingly disturbed. However, relating these apparent differences in the acoustic signal to articulatory movements is difficult owing to a lack of a direct one-to-one relation between the two. Compared to discrepant transitions the difference in the frequency of occurrence of *absent transitions* was much higher, hence it can be considered as a good indicator in differentiating stuttering and normal nonfluency.

The results indicate that the acoustic parameters speed and extent of F2 transitions and absent/missing F2 transitions can differentially diagnose stuttering from normal non-fluency. However as the offset of F_2 depends upon the following phoneme it may not be a good acoustic indicator of differential diagnosis. In case of plosives followed by vowels, more than 4 Hz/ ms of speed of F_2 transition and 63 Hz of extent of F2 transition indicate that the child has stuttering. This can be measured in further clinical population to confirm or reject stuttering. Based on these three acoustic parameters, children with stuttering can be differentiated from normally nonfluent children. A follow-up of these children (longitudinal study) will further strengthen the result of the present study.

Chapter V

Summary and Conclusions

The present study investigated the efficacy of acoustic parameters in differential diagnosis of stuttering and normal non-fluency. Two groups of subjects were involved in the study. Group I consisted of two hundred (200) Kannada speaking children (age range of 3-12 years) diagnosed as having stuttering and group II consisted of two hundred (200) age matched normal Kannada speaking children. Ten C1V1C2V2 Kannada meaningful words with the unvoiced consonants [k, c, t, t, p] and their cognates [g, j, d, d, b] in the initial position followed by a long mid vowel /a:/, a trill and vowel /u/ or vowel /i/ in the final position formed the material. Also, general conversation and picture description were recorded. Conversation and picture description were transcribed verbatim and sound syllable repetitions (SSRs) were identified and analyzed. Each token was analyzed acoustically using 'spectrogram' and 'formant frequency' program (using Multi Speech software). Onset and offset of F2 transition, F2 transition duration, extent and speed of F2 transition, and pattern of F2 transition were measured. These parameters were compared between groups. Results indicated higher onset and offset of F2, shorter F2 TD, higher extent and speed of F2 transition in children with stuttering when compared to normal children. Absent and discrepant F2 transition patterns were found to be more in children with stuttering compared to normal children. Thus, the results of the present study support the fact that the acoustic parameters can also be used for differential diagnosis of children with stuttering and normal children.

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Appendix I

Subject details

List of subjects - Normal nonFluency (M = Male, F = Female)

Serial No	Case Name	Age in years **/gender**
1.	Ismail	4M
2.	Darshan	5.7 M
3.	Puttu	4 M
4.	Banuprakash	7M
5.	Dishita	3F
6.	Rohan	5M
7.	Prathikprabhu	3M
8.	CM Khushi	3.6 F
9.	Abhishek	4 M
10.	Rajeshwari	4F
11.	Majunath	4M
12.	Vignesh	5.6 M
13.	Akshey	3M
14.	Sayed kaliq	4.7 M
15.	Sushma	6F
16.	Yadunanda	2M
17.	Neelakantha	4.M
18.	monisha	3F
19.	Anupurna	5F
20.	Meghashree	6F
21.	Parvathi	7M
22.	Ramya	5.6 F
23.	Abhi	8 M
24.	Abhishek	8M
25.	Anushree	7F
26.	Bhuvaneshwari	9 F
27.	Chandini	9F
28.	Chiranth	10 F
29.	Dikshika	10F
30.	Ganga	9F
31.	Jevanthi	8F
32.	Kusuma	6F
33.	Monica	7F
34.	Navin	9M
35.	Pavana	7M
36.	Prithviraj	8M
37.	Shamnath	8M
38.	Shradha	9F
39.	Chirag	7M
40.	Ullas	6M

41.	Yogisha	7M
42.	Vaishnavi	7F
43.	Suditrashri	8F
44.	Sinchana	6F
45.	Sharan	6M
46.	Rakshit	6M
47.	Pintu	6M
48.	Neema	6F
49.	Monica	6F
50.	Mhalakshmi	6F
51.	Janavi	6F
52.	Inchara	6F
53.	Dhanush	6M
54.	Chitra	6F
55.	Chandra	6F
56.	Bhumika	6F
57.	Abhishek	6M
58.	Chaya	6F
59.	Chaitra	6F
60.	Dilip	6M
61.	Sanya	6F
62.	Janavi	6F
63.	Minakshi	6F
64.	Nagaraj	6M
65.	Nitin	6M
66.	Pooja	6F
67.	Sandeep	7 M
68.	Shobha	7 F
69.	Shruti	7 F
70.	Suhas	7 M
71.	Varun	7 M
72.	Vashavi	7 F
73.	Ullas	7 M
74.	Chaitra	7 F
75.	Shobitha	5F
76.	Sandya	6F
77.	Pornachandra	4M
78.	Patil	8M
79.	Naveen	8M
80.	Michu	8M
81.	Kavya	8F
82.	Jeetha	8M
83.	Gagana Shankar	8M
84.	Chittara	8F
85.	Chetana	8F
86.	Chandan	8M
87.	Anu	8M
88.	Akshay	8M

89.	Khirtha	8F
90.	Chirag	8M
91.	Sajana	8F
92.	Pavan	8M
93.	Preetam	8M
94.	Sneha	8F
95.	Nikhil	8M
96.	Akshata	8F
97.	Kumuda	8F
98.	Nandini	8F
99.	Shreyas	8M
100.	Spoothy	8F
101.	Kadambari	8F
102.	Lohita	8F
103.	Rashmi	8F
104.	Sinchana	8F
105.	Vibhav	8M
106.	Monika	7F
107.	Spoorthy	7F
108.	Sukanya	7F
109.	Prarthana	7F
110.	Pintu	7M
111.	Jeevitha	7F
112.	Abhiram	7M
113.	Vibha	7F
114.	Unnati	7F
115.	Sharda	7F
116.	Sharan	7M
117.	Darshan	7M
118.	Pradeep	7M
119.	Pavan	7M
120.	Bharath	7M
121.	Pooja	7F
122.	Priya	7F
123.	Sheetal	7F
124.	Siri	7F
125.	Vidyasagar	7M
126.	Gagan shankar	8M
127.	Prajwal	8M
128.	Sharath	8M
129.	Sindhu	8F
130.	Surabhi	8F
131.	Vijay	6M
132.	Sindhu	6F
133.	Riyamol	6M
134.	Shankar	6M
135.	Suri	6M
136.	Sheetal	6F

137.	Abhishek	6M
138.	Bharath	6M
139.	Raghu	6M
140.	Sharath	6M
141.	Sirisha	6F
142.	Vidya	6F
143.	Shailaja	6F
144.	Shruti	6F
145.	Janaja	6F
146.	Rajeshwari	6F
147.	Yukti	7F
148.	Sanjana	7F
149.	Dhriti	7F
150.	Nischal	7M
151.	Sagar	7M
152.	Manindra	7M
153.	Pallav	7M
154.	Impana	7F
155.	Janavi	7F
156.	Mahalakshmi	7F
157.	Disha	7F
158.	Meghana	7F
159.	Sahana	7F
160.	Skandan	7F
161.	Varsha	7F
162.	Spoorti	7F
163.	Yashwanth	7M
164.	Shreya	7F
165.	Shraddha	7F
166.	Sneha	7F
167.	Sindhu	7F
168.	Vandana	6F
169.	Chandan	6M
170.	Shruti	6F
171.	Dhatri	6F
172.	Gagan	6M
173.	Mahesh	6M
174.	Indu	6F
175.	Manish	6M
176.	Deepti	6F
177.	Mohan	6M
178.	Manasa	6F
179.	Jyoti	6F
180.	Richa	6F
181.	Sonu	6M
182.	Priya	6F
183.	Dhanya	6F
184.	Kumara	11M

185.	Sandhya	10F
186.	Nikhil	11M
187.	Manu	10M
188.	Santosh	11 M
189.	Bhagya	10F
190.	Prashanth	11 M
191.	Karthik	10M
192.	Raju	11 M
193.	Mahadeva	11 M
194.	Kavya	11 F
195.	Prakash	11 **M**
196.	Prasad	11 M
197.	Girisha	10M
198.	Manoj	11 M
199.	Keerthi	10F
200.	Banuprakash	11 M

Gender	**2-3**	**3-4**	**4-5**	**5-6**	**6-12**	**Total**
Boys	1	**2**	**7**	**3**	80	**93**
Girls		**3**	**1**	**3**	100	107
Total	**1**	**5**	**8**	**6**	**180**	**200**

List of subjects - Stuttering

Serial No	Case Name	Age **in** years/ gender
1.	Kamalesh	6M
2.	Avinarh	5M
3.	Praveen	5M
4.	Natyachuli	8F
5.	Praveen	10M
6.	Nineeth	11 M
7.	Nagesha	8M
8.	Keerthi	12M
9.	Manasa	4F
10.	Poonacha	8M
11.	Neha	3.8 F
12.	Thejashri	2.6 F
13.	Prabhu	7M
14.	Kalyan	12M
15.	Kaciappa	13M
16.	Naveen	12M
17.	Naveen	13M
18.	Arunprakaash	10M
19.	Divakar	4M
20.	Shruthi	10F
21.	Chitra	8F
22.	Parmeshkar	10M
23.	Sandeep	12M
24.	Rihan	7M
25.	Venkatesh	11 M
26.	M Raju	8M
27.	Shashank	5M
28.	Aniruth	7M
29.	K.C. Sunil	7M
30.	Nithin	5.8 M
31.	Preetham	10M
32.	Vikas	7.10M
33.	Anil	8M
34.	Mohan	4M
35.	Manoj	7M
36.	Suhas	8M
37.	Nandan	5M
38.	Devaraju	8M
39.	Ajay	3.5 M
40.	Manu	9M
41.	Kruthika	7.10 F
42.	Pratibha	10F
43.	Kartik	8M

91.	Parikshith	10M
92.	Dishanth	6M
93.	yashaswant	7M
94.	Amrin	12F
95.	Raghavendra	11 M
96.	Dikshit	12.6 M
97.	Sriraj	2.5 M
98.	Rohan	4.5 M
99.	Lisha shankhar	1.9 F
100.	Darshan	6M
101.	Nagaveni	9F
102.	Sharadh	11 M
103.	Lithin	4M
104.	Yogitha	4M
105.	Naveen	12 M
106.	Chethan	9M
107.	Amogh	5M
108.	Chinmaya	3.10M
109.	M. Khizar	11 M
110.	Suhas	2.5 M
111.	Yeshwant	7M
112.	Ritish	4M
113.	Manu	7M
114.	Prashant	9M
115.	Mohan	3M
116.	Kushal	3.2 M
117.	Mudhasir	7M
118.	Mod shezaz	5.6 M
119.	Shayesha	9F
120.	Sourab	3.6 M
121.	Pratap	8M
122.	Raghu	10M
123.	Mallikarjuna	10 M
124.	Akhil nath	7.5 M
125.	Prajwal	11 M
126.	Darshan yadav	11 M
127.	Yogesh	8M
128.	Sanjay	10M
129.	Ankit	9M
130.	Dharani	11 M
131.	Harish	12M
132.	Rangaswamy	10M
133.	m.aFnan	9M
134.	Kavana	5F
135.	Ajay	6M
136.	Sharath	11 M
137.	Sumitha	13M

44.	Mhd.Riyaz	7.6 M
45.	Kiran	10M
46.	Nishanth	5.6 M
47.	Shobha	8F
48.	Sumuksha	3.1 M
49.	Deepti	2.9 F
50.	Rohit	10.6 M
51.	Madhusudhan	11 M
52.	Nagini	10 F
53.	Sampalh	8M
54.	Santhosh	6M
55.	YousiF Ahmed	10M
56.	Sunil Kumar	11M
57.	Chandan	9M
58.	Bhayashri	10F
59.	Harshith	3M
60.	Sridhar	12M
61.	Pavan	3.6 M
62.	Dilipchandra	11 M
63.	Avinash	9M
64.	Naveen	7M
65.	Arjun	10M
66.	Vaishaari	7F
67.	Mkilsta	10M
68.	Sunil	7M
69.	Lavanya	4.6 M
70.	Asheain	7.3 M
71.	Karthik	11M
72.	Manoj	4M .
73.	Fathima	9F
74.	Abishek	4.4 M
75.	Balachandra	6M
76.	Maitri	10F
77.	Darshan	10M
78.	Rohan	5M
79.	Manish	6 M
80.	Deepak	5 M
81.	Shashank	4.5 M
82.	Abhishek	6M
83.	Chiranjan	3M
84.	Pradeep	9M
85.	abhishek	12M
86.	Moh.ZaMeer	12M
87.	Syed aFtab	11 M
88.	Prajwal	3.3 M
89.	Abhishek	10.5 M
90.	Manoj	6M

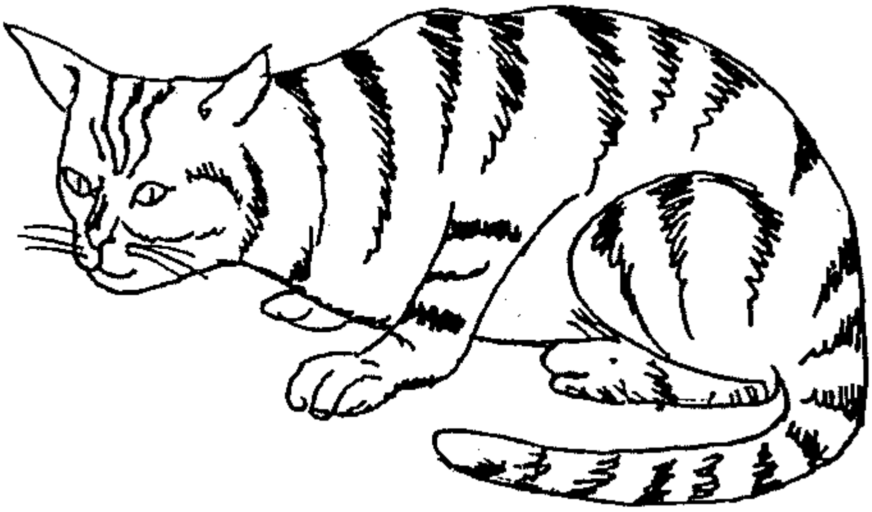
138.	Adarsh	12M
139.	Hemanth kumar	4.5 M
140.	Praveen kumar	12M
141.	Gowrisha	9M
142.	Shashank	5M
143.	Manikanta	7M
144.	Shreyas	4.9 M
145.	Madhusudhan	9M
146.	Ravichandra	6M
147.	Shashank kumar	7M
148.	Akshay	12M
149.	Prajwal	4M
150.	Sumanth	4M
151.	Anirudh	12M
152.	Sanath vinod	10M
153.	Kiran	10M
154.	Harish kumar	11 M
155.	Darshan	9M
156.	Netra	4.5 F
157.	Kavyashree	11 F
158.	Lakshita	5F
159.	Palguni	8M
160.	Guruprasad	12M
161.	Harshit	12M
162.	Manjunath	4M
163.	Mahesh kumar	8M
164.	Vaibhav	9M
165.	Sahana	4F
166.	Harshit	6M
167.	Karthik	3M
168.	Pracheeth	3M
169.	Pradhan	8M
170.	Mallappa	10M
171.	Chandhan	6M
172.	Goutham	11 M
173.	Hemanth	7M
174.	Praveen	11 M
175.	Revanth	5M
176.	Nikhil	8M
177.	Rohit	3M
178.	Sanjay	6M
179.	Pawan	12M
180.	Divyashree	7F
181.	Impana	9F
182.	Nisarga	6F
183.	Abhinav	5M
184.	Akheel	4M

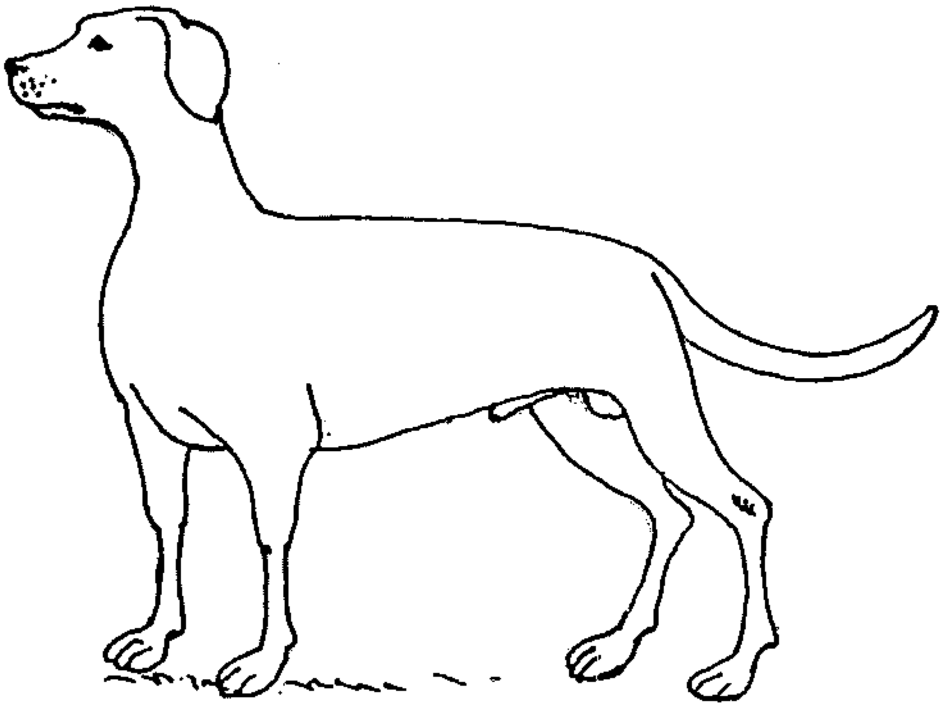
185.	Likitha	3.3 F
186.	Kruthik	8M
187.	Vaishnavi	5F
188.	Brinda	8F
189.	Sanjana	10 F
190.	Jayanth	9M
191.	I.isha	8 I'
192.	Suhas	7M
193.	Suchindra	6F
194.	Sujan	7M
195.	Arnogha	5F
196.	Samarth	8M
197.	Sharath.	12M
198.	Girisha	6 F
199.	Mohith	11 M
200.	Sumanth	10M

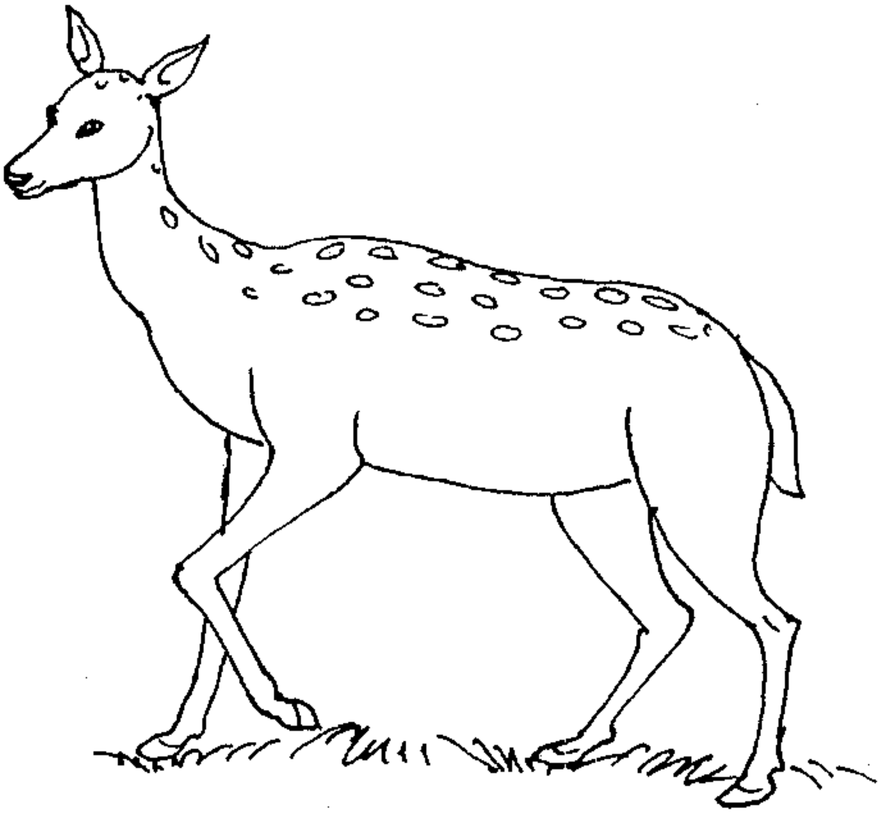
Gender	**2-3**	**3-4**	**4-5**	**5-6**	**6-12**	**Total**
Boys	8	**17**	**16**	**16**	105	**162**
Girls	3	4	5	3	23	38
Total	**11**	**21**	**21**	19	**128**	**200**

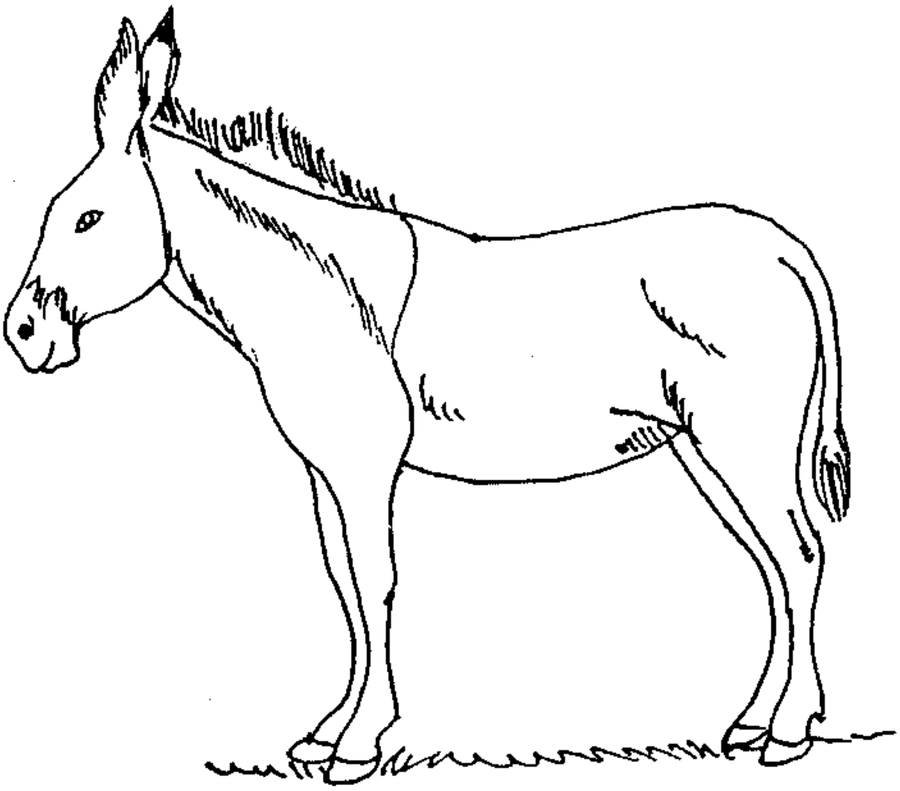
Appendix II - Material

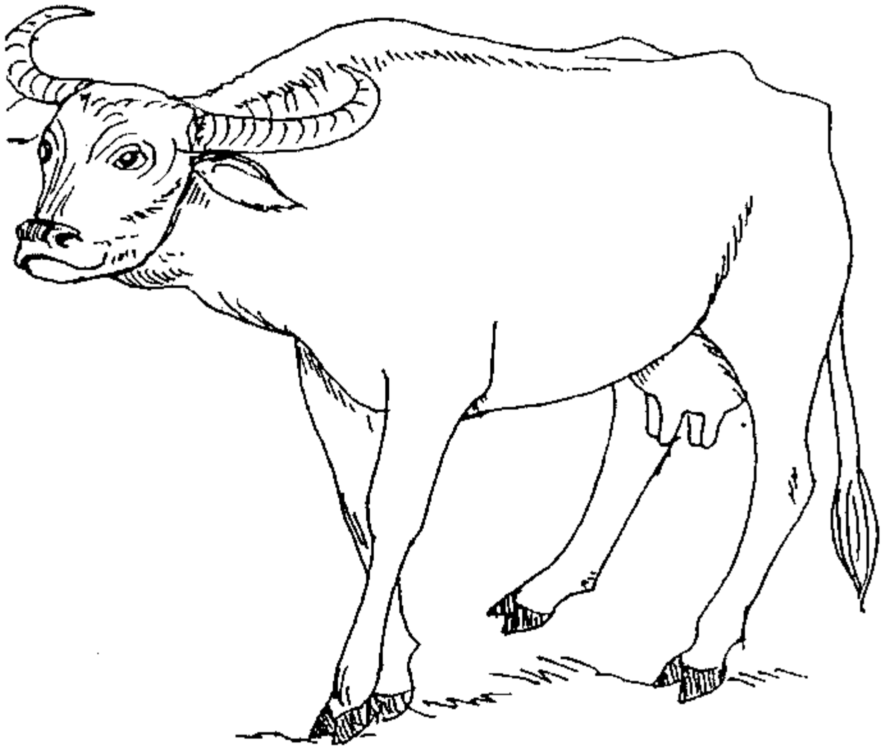
$-4 years - Simple pictures

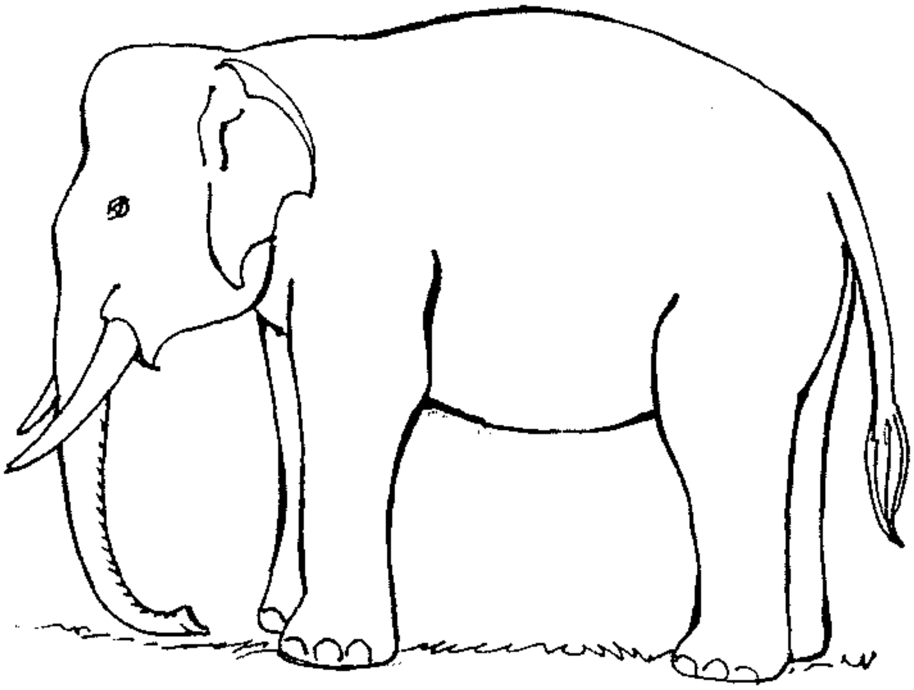


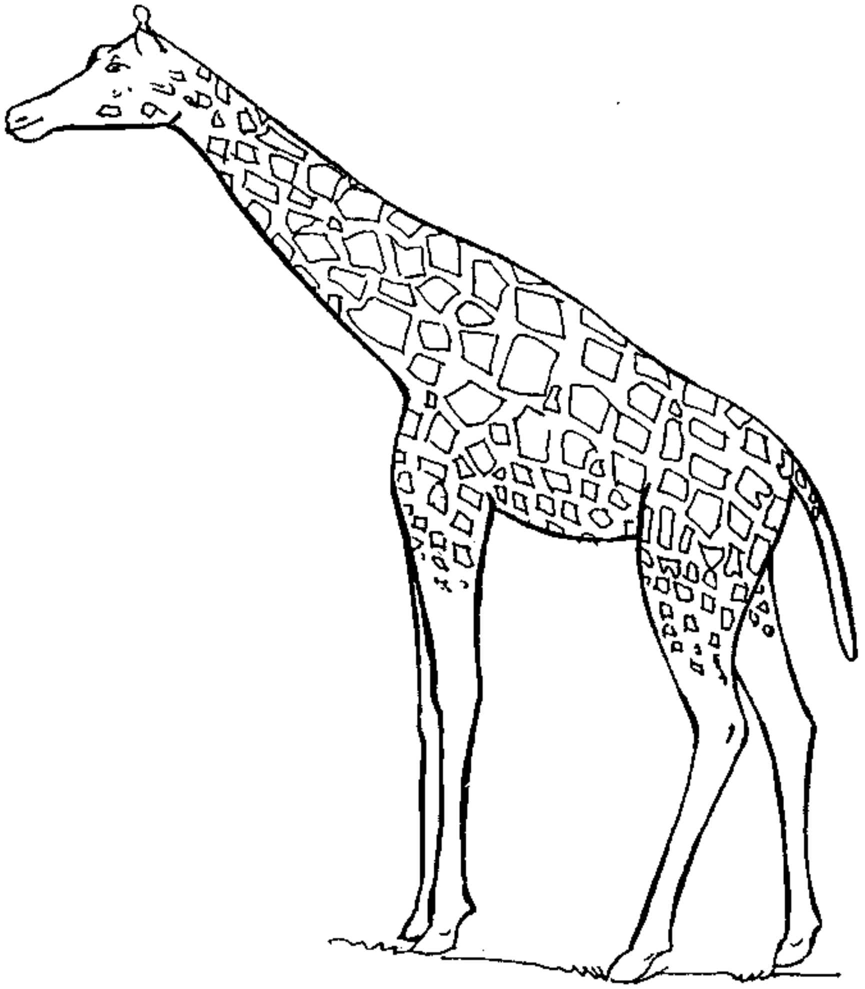


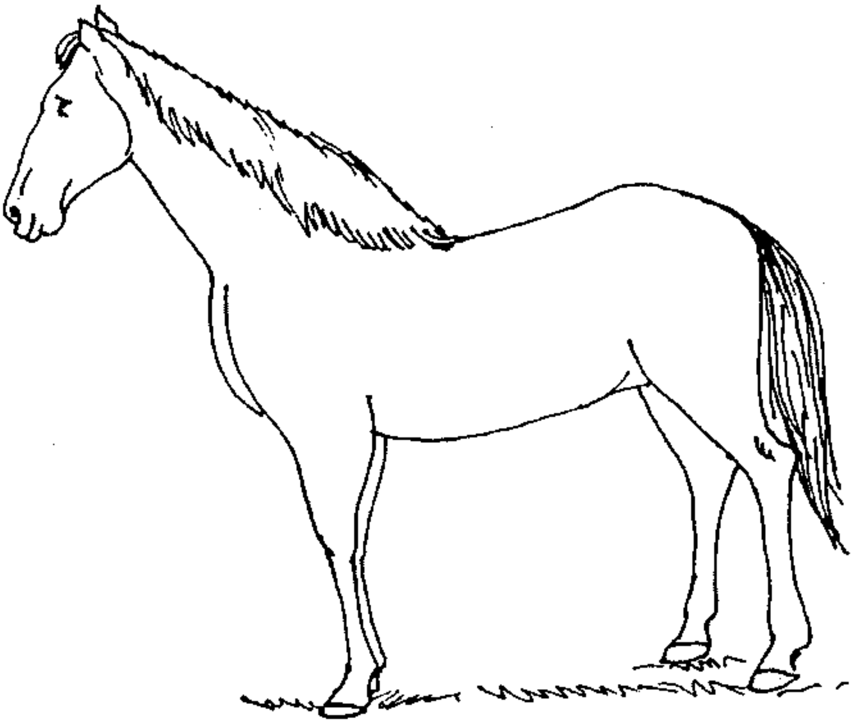


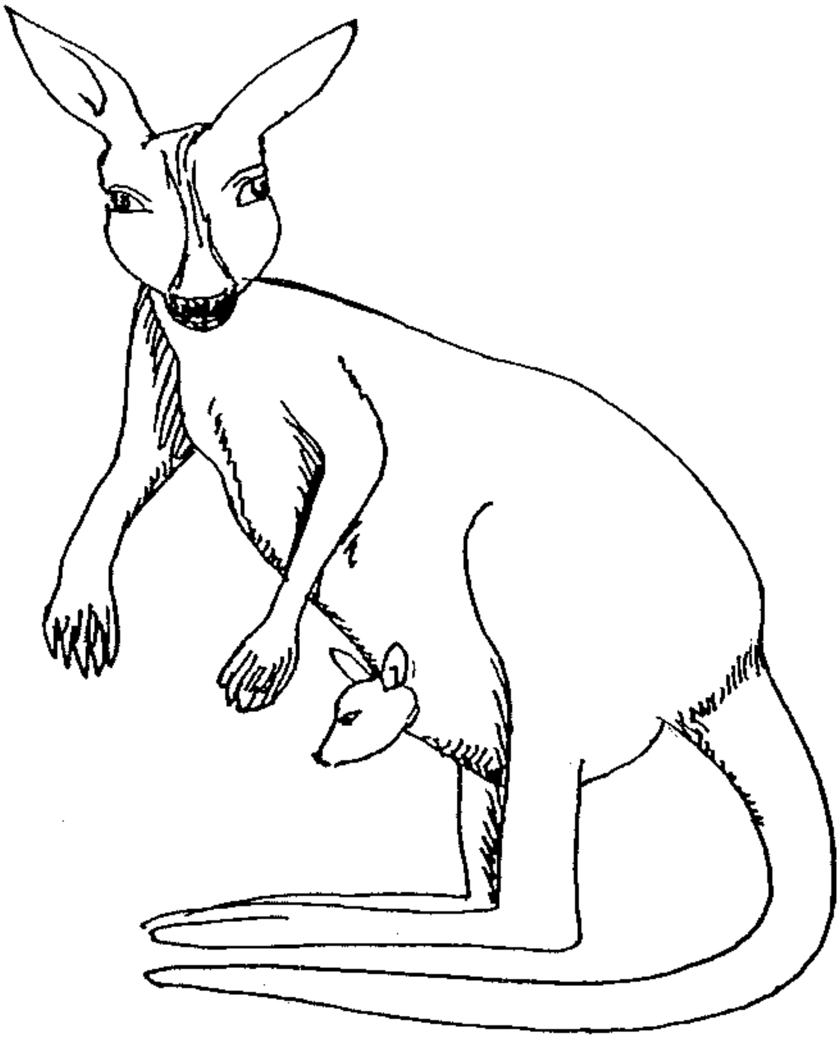


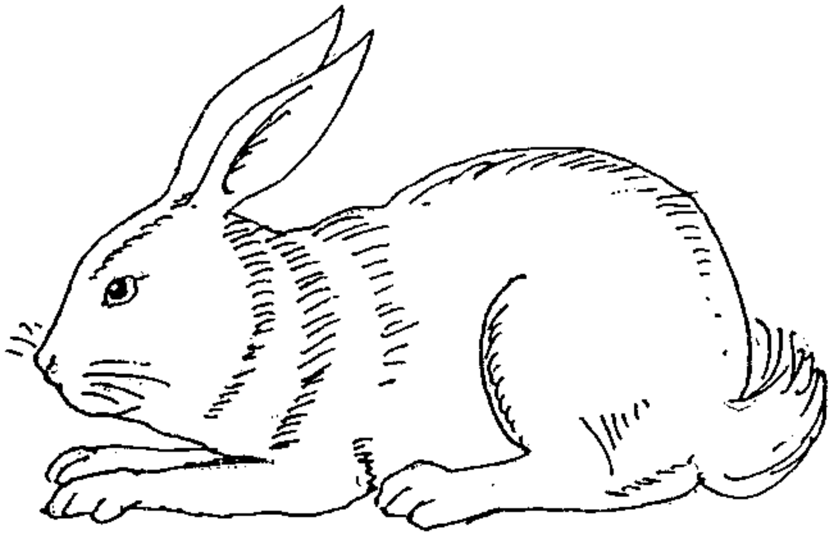




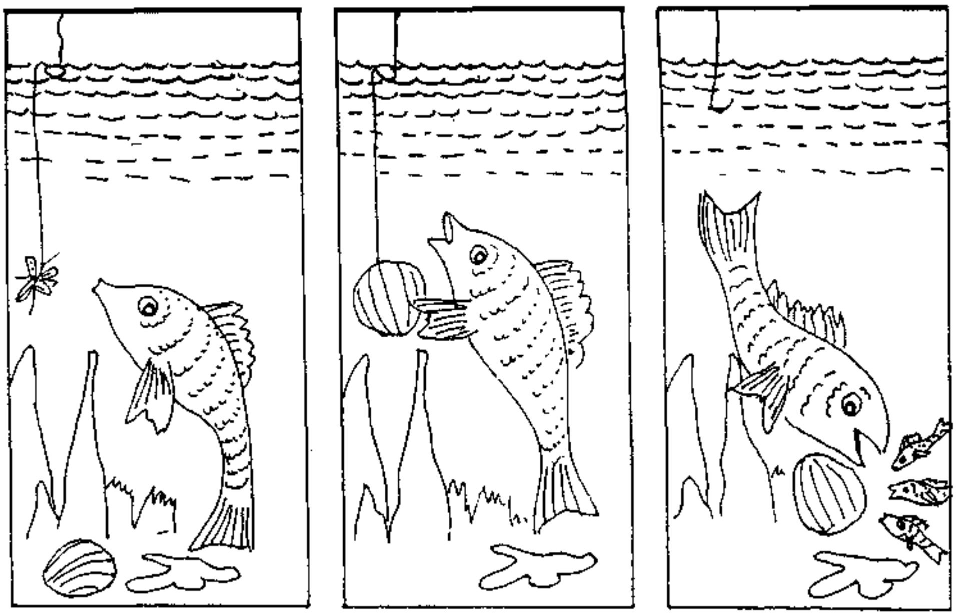


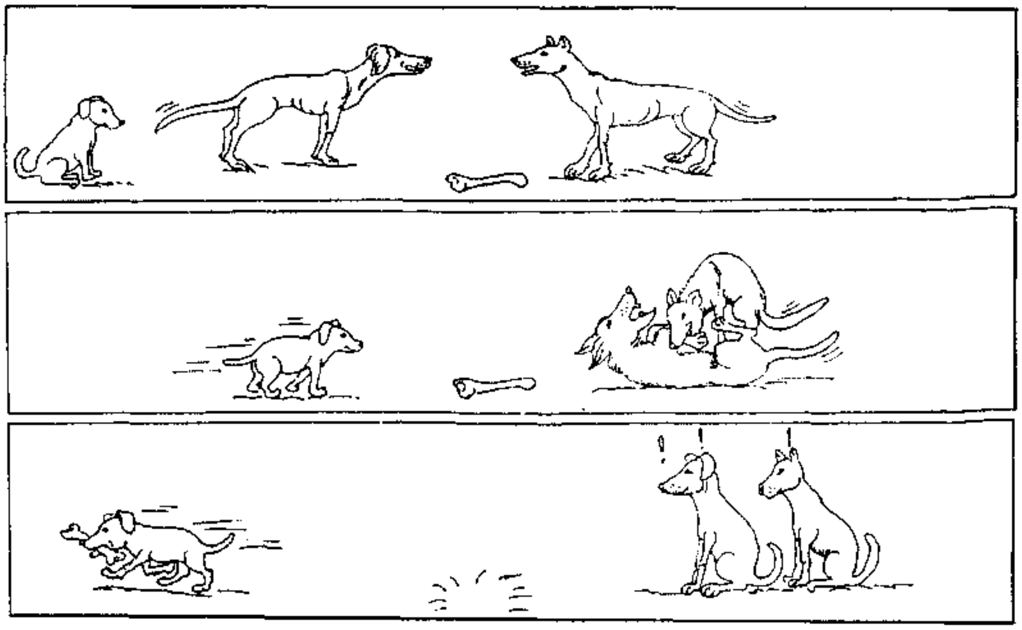


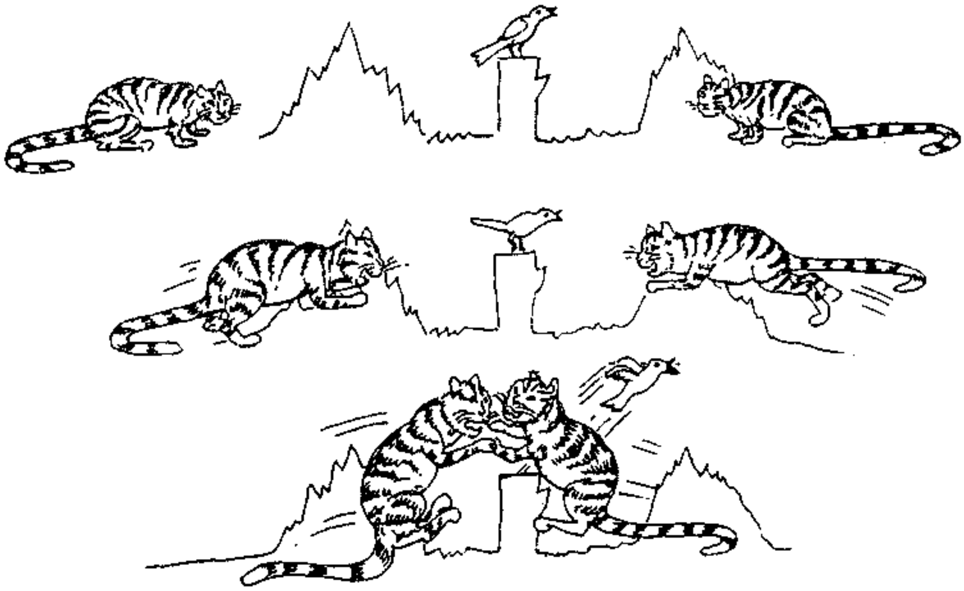


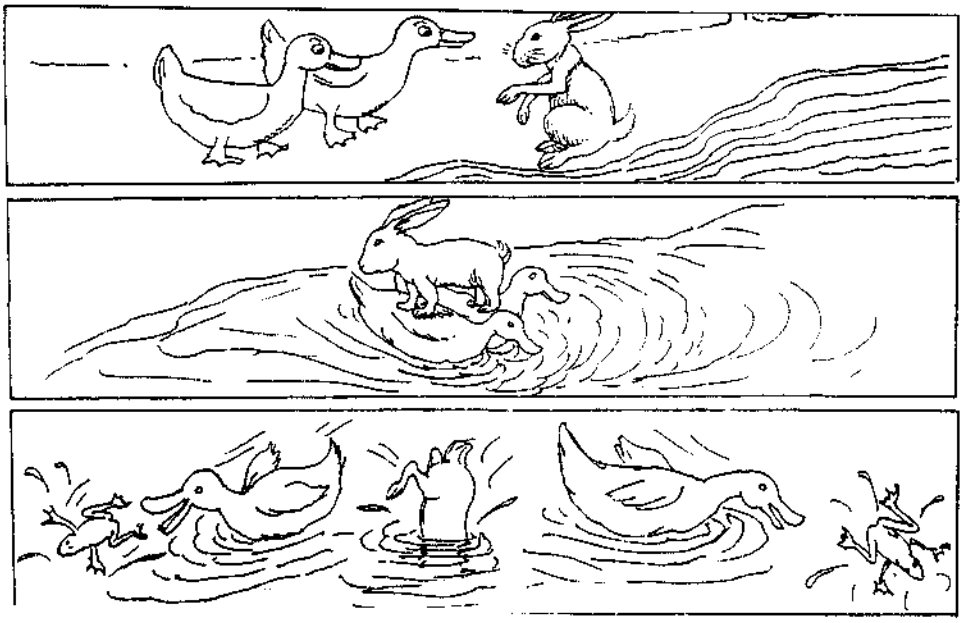


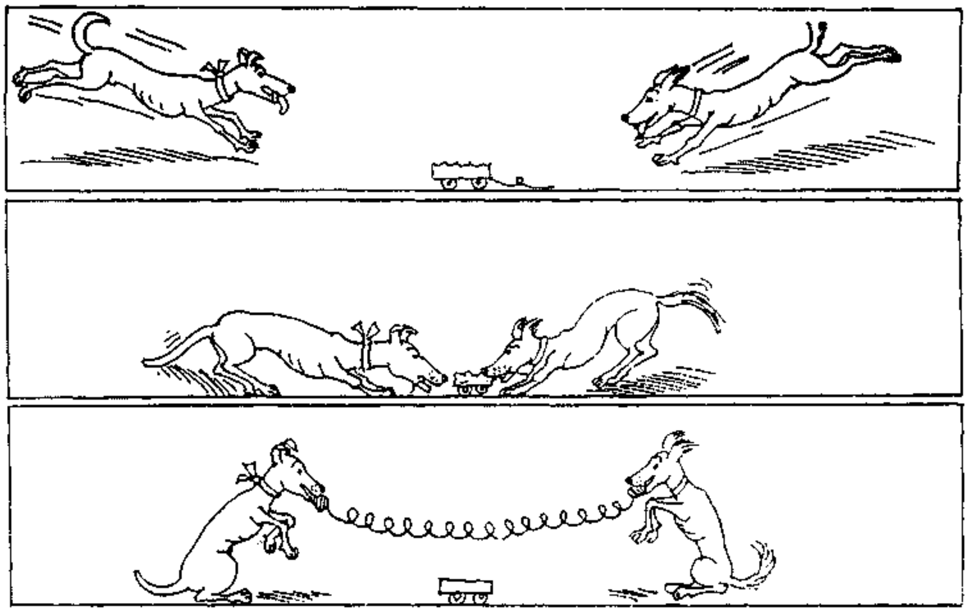
4-5 years - Connected pictures

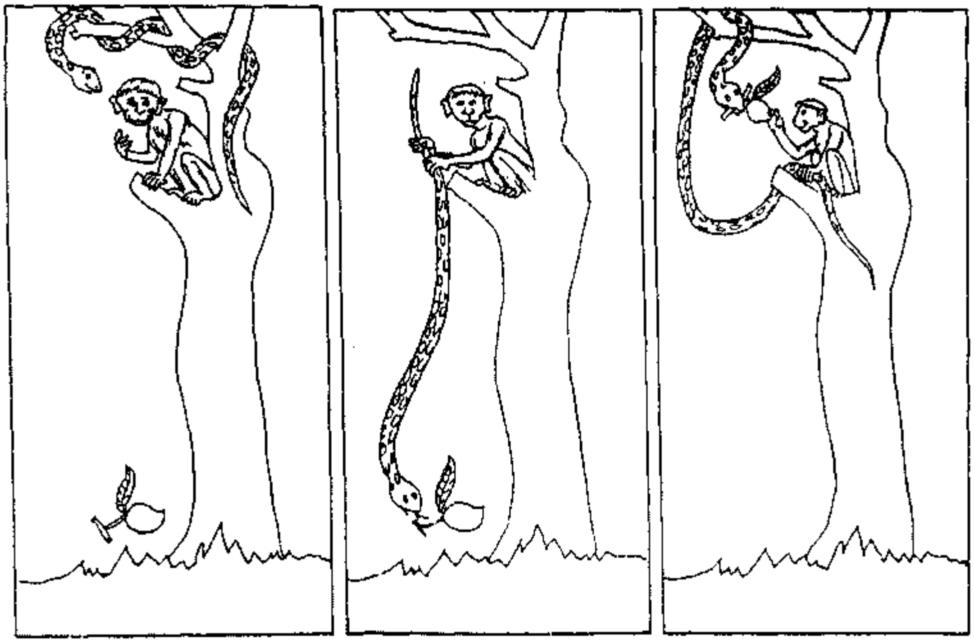




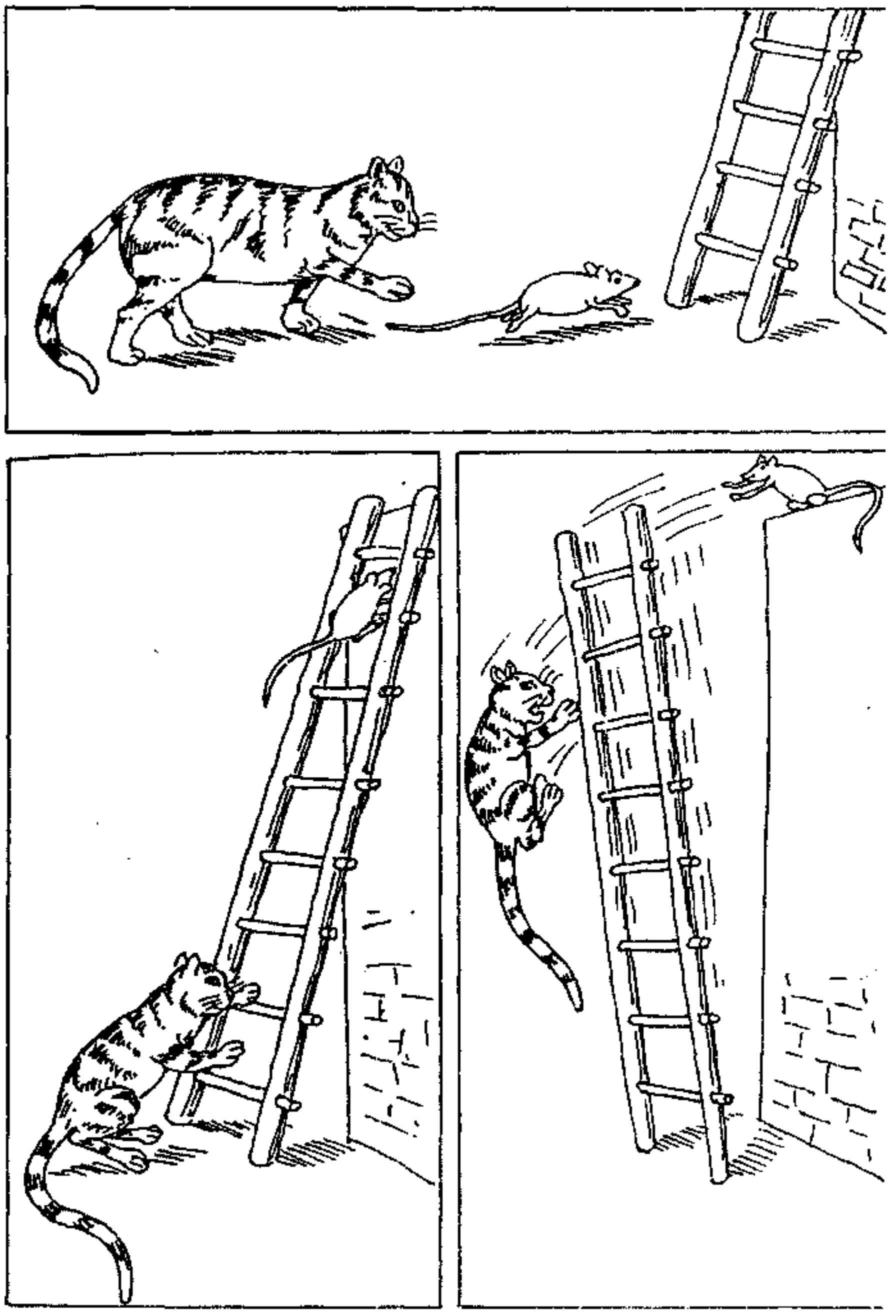


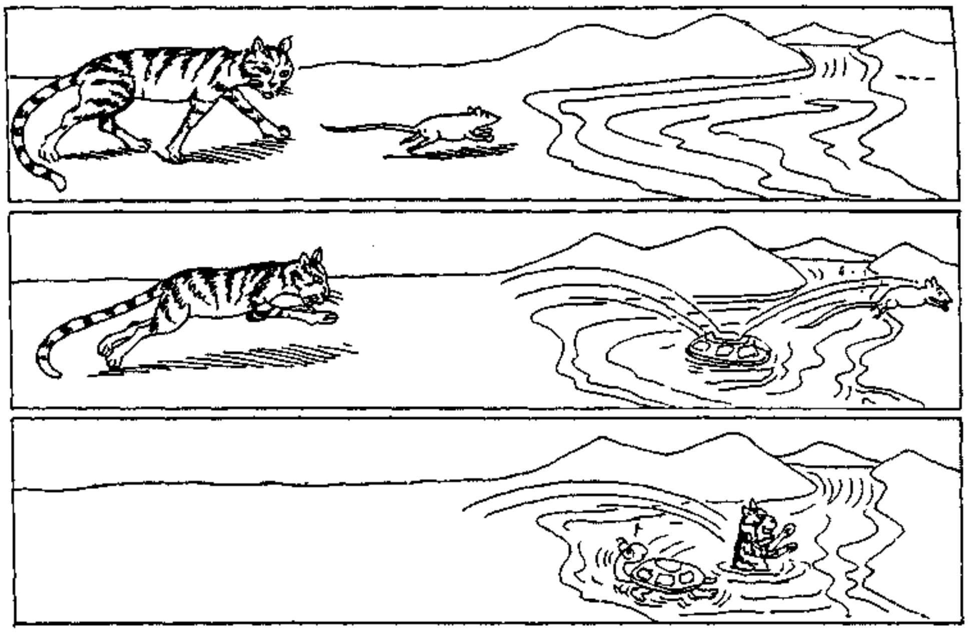


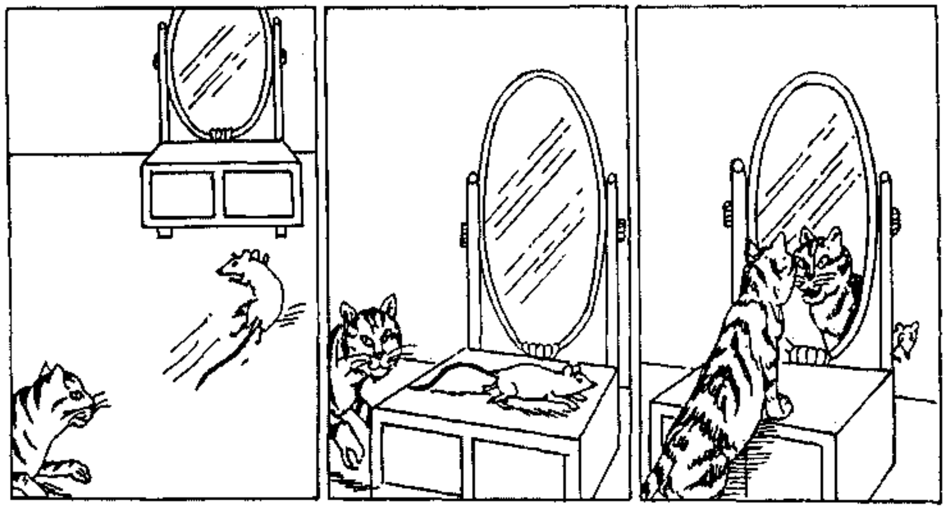


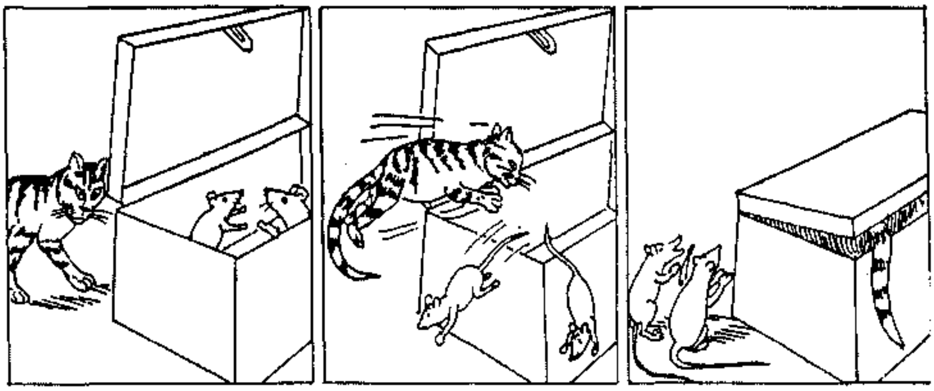


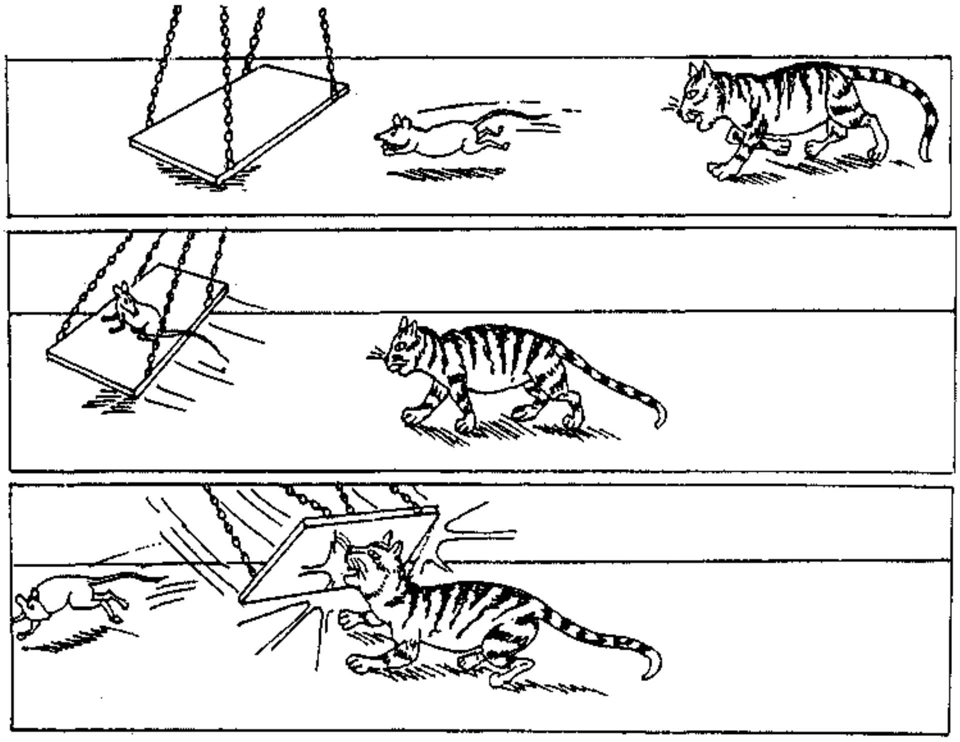
5-6 years - Mooshik cartoons

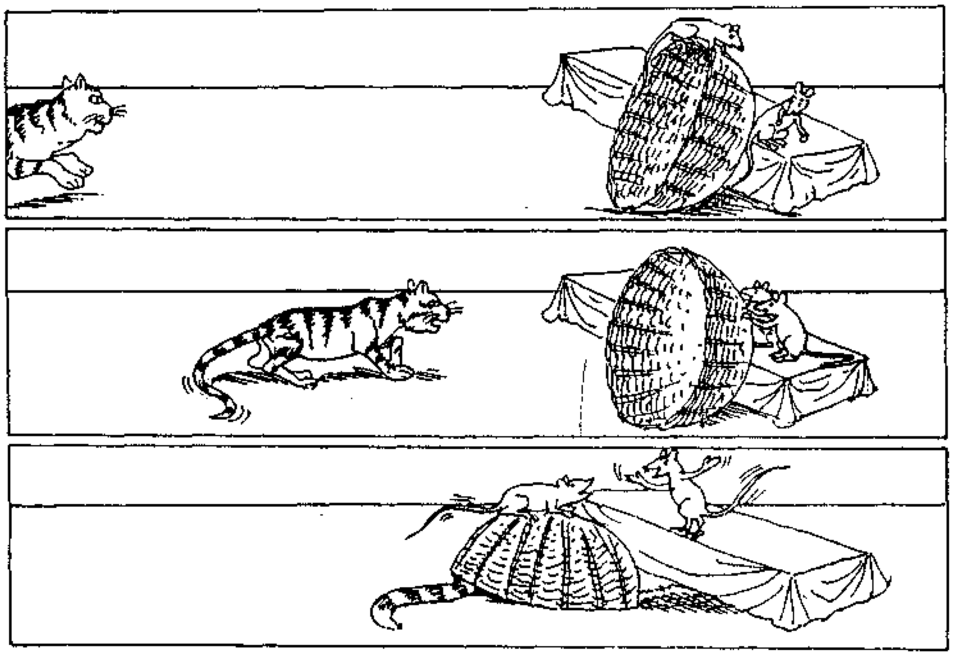




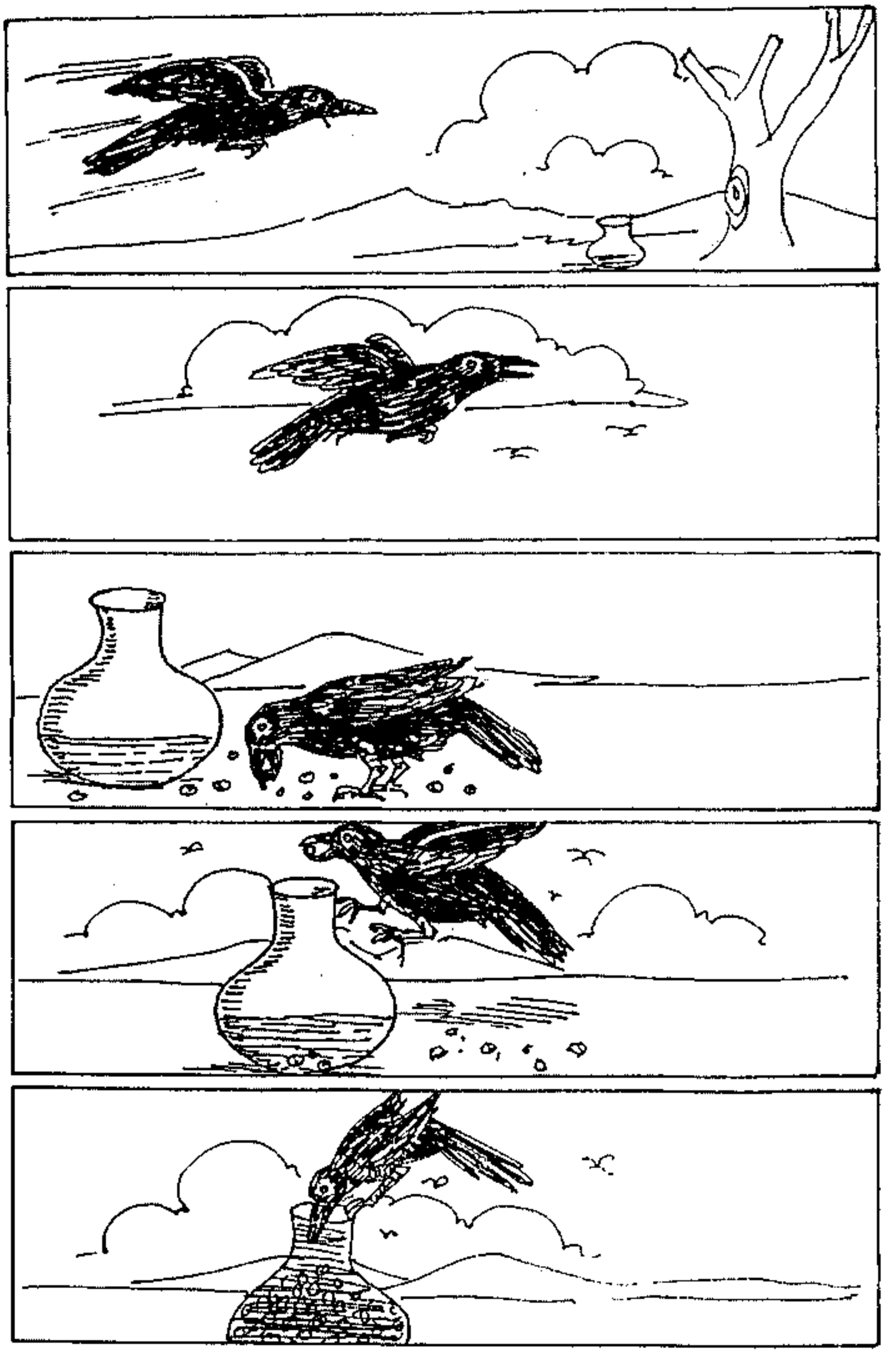


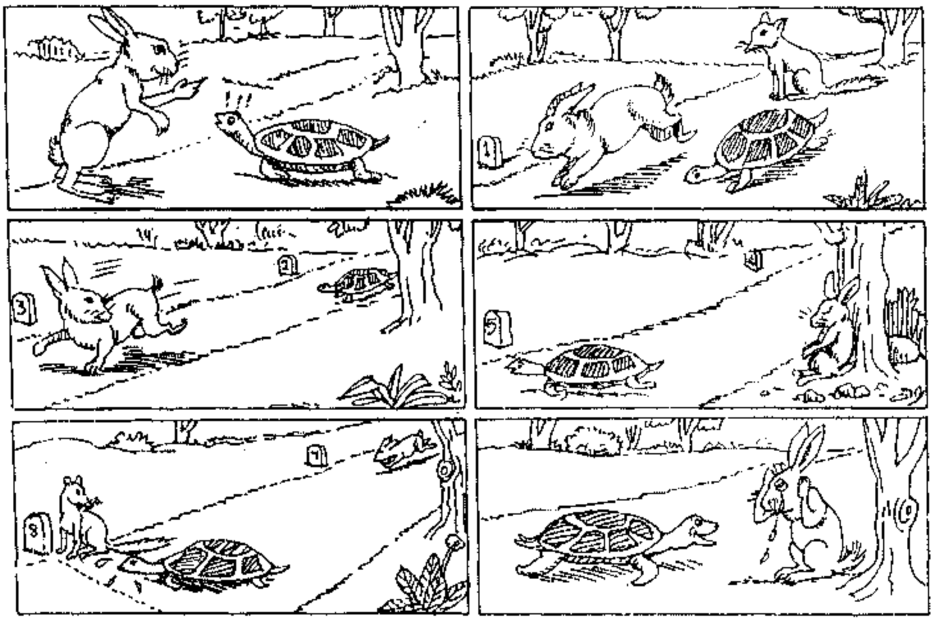






6-7 years - Pictures depicting Panchatantra stories

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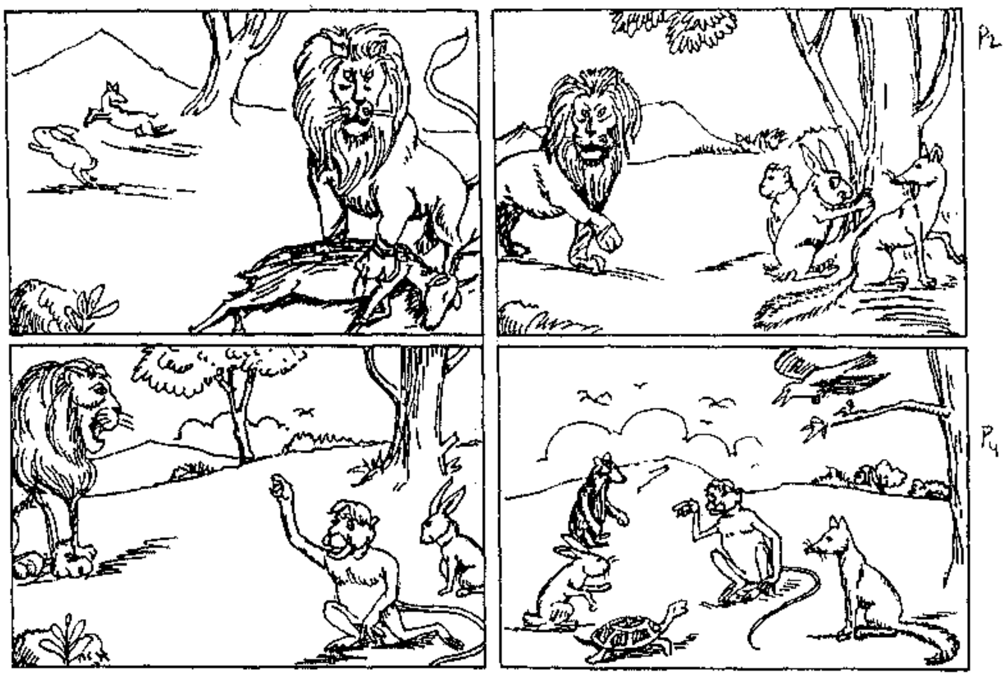
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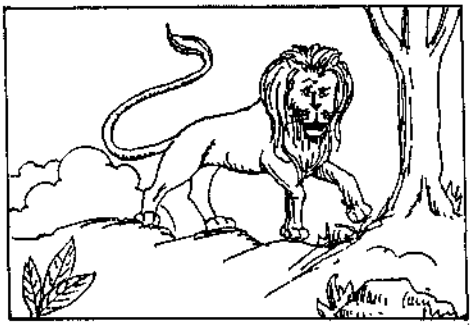

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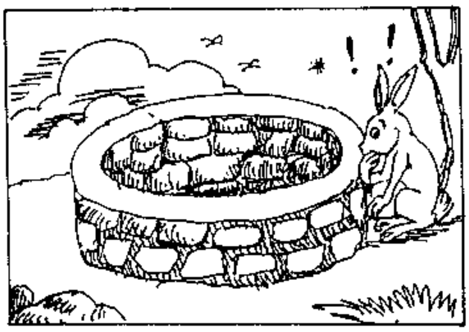

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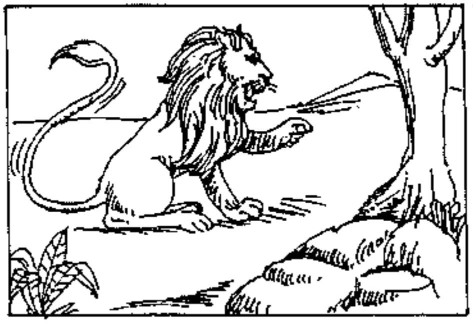

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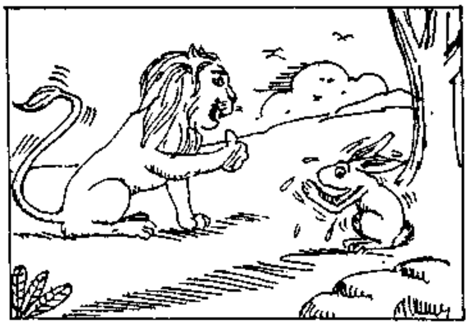

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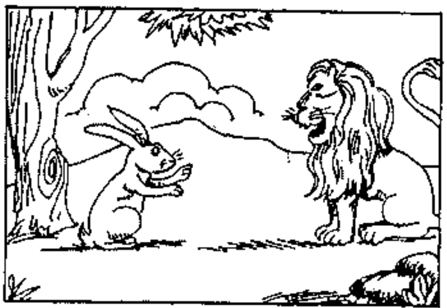

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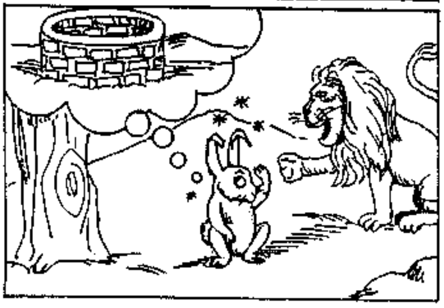

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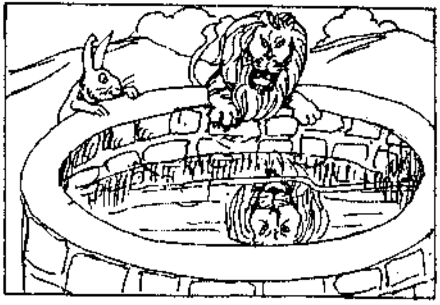

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