A CINEPHOTOGRAPHIC STUDY OF COARTICULATION OF LIP ROUNDING IN ENGLISH AND FRENCH

by

Margaret E. L. Roberts

B.A., University of Victoria, 1967.

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in the Department

of

Paediatrics

Division of Audiology and Speech Sciences

We accept this thesis as conforming to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

June, 1972

In presenting this thesis in partial fulfilment of the requirements for an advanced degree at the University of British Columbia, I agree that the Library shall make it freely available for reference and study. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by the Head of my Department or by his representatives. It is understood that copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Department of Paediatrics, Division of Audiology and Speech Sciences

The University of British Columbia
Vancouver 8, Canada

Date June 2, 1972

ABSTRACT

In this study the dynamics of lip rounding are investigated. Lower lip protrusion was measured in a frame-by-frame analysis of six high-speed (66 frames/sec) cinephotographic films: three for English (with one speaker) and three for French (with three different speakers).

A corpus of utterances was constructed for each film separately using results and hypotheses derived from previous film(s). With the techniques applied in this study, no reliable method of determining onset of rounding could be established for English and thus the effect of syllable and word boundary position on coarticulation patterns could not be determined. Consonant context appeared to have a greater effect on timing of extremum protrusion with respect to acoustic onset of the vowel, than did degree of stress.

For French, there was evidence to suggest that coarticulation of rounding may be phonemic. Although the data were limited, it was observed (for one pair of "minimal" sequences said by one subject) that the onset of rounding occurred later than reported by Daniloff and Moll (1968) for English or by Kozhevnikov and Chistovich (1965) for Russian. As in the case of the English data, no obvious difference in timing of extremum protrusion was found for variations in stress for the French data.

It was concluded that for both English and French some of the basic assumptions of the experiment were untenable. In particular,

it is questionable that a point of onset of rounding before, during, or after a consonant cluster can be specified without first systematically determining the amount of protrusion which is associated with each consonant in isolation and then in various contexts. It is apparent from the data that coarticulation of rounding is likely to be influenced by other parameters such as intonation, stress and phonetic (in particular consonantal) context. Future research should attempt to control as many of these parameters as possible before significant patterns (if they exist) can be observed.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGMENT

I wish to acknowledge my debt and express my gratitude to all those who may find a little bit of themselves--their interest, their ideas or their labours--in this finished work. Without you this thesis would have been impossible.

Especially I'd like to thank:

André-Pierre Benguerel - my thesis advisor and friend,for his endless patience, advice and understanding.

John Gilbert - not only for being on my thesis committee, but particularly for the ideals he has set for the Division of Audiology and Speech Sciences.

Dr. R. Gregg - for serving on my thesis committee and for commenting on the drafts of the thesis.

Joyce Edwards - my clinical supervisor, for her boundless enthusiasm in all things.

My subjects - for their time and cooperation.

Gord McConnell - for keeping the experimental equipment in running order.

Madeleine Holbrook - for typing the manuscript.

My family and friends - for their interest and encouragement throughout my Master's program.

and finally:

Colleen and Barbara - for the laughter and loyalty we shared these past two years.

CHAPTER 1

INTRODUCTION

The study of language and its structure includes investigations of how finite units of speech are combined and organized. Two approaches, one intuitive, the other experimental, have been used to examine the relationship between speech and the units of which it is composed. Although the two approaches are discussed independently here, it is recognized that the results of both methods must eventually be brought together and lead to the same conclusions if significant information about speech is to be revealed. The two approaches cannot be considered independent from each other for initially all experimental hypotheses are based on introspection and direct observation and ultimately all theories must be experimentally verified before they can be accepted as truths.

In the intuitive approach, linguists postulate "rules" based on direct observations of language. They abstract information from what they know about language and expand this information to form a set of rules accounting for the hierarchy of commands which appear to be involved in speech production. In terms of the levels of adequacy of a theory proposed by Chomsky (1965) in his discussion of generative grammars, this intuitive approach may be considered to have reached the first, or descriptive, level of adequacy. According to Chomsky's definition, it can be said to be justified on external grounds to the extent that it correctly describes the phenomenon. The aim, then, of

an intuitive approach to the study of language organization is to progress from this descriptive level to a deeper explanatory level which includes justification of the rules on internal, rather than external, grounds.

The second way of investigating the structure of speech is an experimental one. In this approach an attempt is made to determine what occurs during speech production by observing specific aspects of the speech process through appropriate experiments. By incorporating the results and conclusions of such research into a single theory, an overall picture of the composition of speech should emerge.

Coarticulation studies represent one area of experimental research investigating the dynamic aspects of speech production. The study of non-static parameters of speech has increased in importance in the last decade as it has become obvious that the investigation of invariant characteristics reveals little about relationships which unite these characteristics in running speech. Speech synthesis studies, in particular, have shown that it is not enough to simply specify static parameters of speech sounds, rather it is necessary to understand and delimit how the parameters change and influence each other as a function of time, speaking rate and stress, etc. Coarticulation research attempts, among other things, to specify these dynamic relationships. By observing a particular aspect of a speech sound, variations of that feature can be determined in the overall progression of a speech sample. In this way, larger phonological units can be delineated and information about the possible hierarchy of commands which serve to coordinate speech production can be established.

The dynamics of articulation are most profitably investigated at

the physiological level. Such studies involve the direct observation and measurement of the behaviour of the main articulators, tongue, velum, teeth and jaw, and lips. Activity of internal articulators may best be observed by means of X-ray cinematography, a procedure which has two major disadvantages which limit its effectiveness as a research tool. The main drawback to this technique is that only small amounts of data can be obtained per subject because each person can be exposed to only a limited amount of radiation. The second drawback is that this technique usually requires a slow and tedious frame-by-frame analysis of the data. In spite of these limitations, cineradiography still remains the most effective way of observing movement of internal articulators. On the other hand, the external articulators, i.e., the jaw and lips, may be observed more directly by cinematographic and photo-oscillographic techniques. Fujimura (1961), for example, used the former method in his study of lip movement, while Kozhevnikov, Chistovich et al. (1965) used the latter in their examination of the dynamic behaviour of the lips.

The inaccessibility of cineradiographic equipment and consideration of the limitations of the X-ray procedure mentioned above, led to the selection of the filming of the lips as the research method for the present coarticulation study. The purpose of the project is to investigate the phonetic feature "rounding" as it is evidenced in certain English and French utterances containing rounded vowels. Changes in height, width and area of mouth opening, plus lower lip protrusion as possible representations of "lip rounding" can all be observed and measured by a frame-by-frame analysis of high-speed movies.

Similar experiments examining lip rounding have been carried out by Kozhevnikov and his colleagues (1965) and by Daniloff and Moll (1968).

In their study of Russian, Kozhevnikov, et al., reportedly established a coarticulatory unit over which the vowel /u/ appeared to have an influence. They postulated that this unit is not constrained by so-called "syllable" or "word" boundaries. Daniloff and Moll, using a cinefluorographic method*, extended the earlier study in order to determine how many phones are coarticulated with the vowel /u/ in English. The objective of the experiment reported in this paper is to investigate further the influence of lip rounding on adjacent phones. The study includes an analysis of both English and French data and attempts to specify limits for the extent of this influence. The observed boundaries of lip rounding may or may not correspond to those of established phonological units but they must, nevertheless, be investigated in relation to them. Such units as the syllable, the word and the breath group, will therefore be considered,and discussed in terms of the experimental results.

---

* (a cineradiographic technique which decreases the amount of radiations a subject is submitted to).

CHAPTER 2

SURVEY OF RELEVANT LITERATURE

2.0 Introduction

The survey of the literature relevant to this research experiment is presented in five sections. Section 2.1 is an overview of some definitions of the syllable unit. Section 2.2 discusses the idea of the syllable as a unit experimentally investigated and defined by examination of specific linguistic features. Included is a summary of the application of such research to this experiment. Section 2.3 discusses and defines phonological units larger than the syllable which may be applicable to the interpretation of the present research results. Section 2.4 discusses the parameters used to define "rounding" and Section 2.5 is a review of the techniques available for observing lip rounding.

2.1 The Concept of the Syllable

The purpose of the following discussion is to survey some of the definitions which have been applied to the term "syllable" in order to illustrate the complexity and ambiguity which arises when one attempts to delimit speech production units. The present research is aimed at establishing the domain of influence, if any, of one phonetic feature of a vowel (lip rounding), on other sounds in a sequence. The unit possibly delineated by this "domain of influence" may be directly

related to phonological units such as syllables. The syllable has, however, been variously defined and it is necessary to look at some of these definitions in order to explain the application of the term in this co-articulation experiment.

Intuitively most speakers of a language have a notion of what a syllable is. Given a possible sequence of phones in his language, a speaker can usually state how many syllables there are in that string. Although the person realizes that such units exist, it is difficult for him to specify what criteria he uses to come to his conclusions. To the naïve speaker the syllable is merely a unit larger than a single speech sound but smaller than a word. The number of vowel sounds is likely to indicate the number of syllables. He may reason that his "feeling" for the speech syllable correlates with his ability to define the meter or pattern of poetry: in poetry each vowel carries a major or minor stress, in speech each vocalic element represents a part of one syllable.

The speaker of English relies solely on his intuitive ability to locate syllables for there are no explicit rules which specify how such a decision is to be made. This intuition has been used in such speech research as the investigation of prosodic features, including syllable timing and stress. Allen (1970), for example, reviewed some of the literature in this area and examined the validity of using subject intuition to establish stress timing in a given language. He concluded that there was a correlation between the subject's intuitive notion of the role of the syllable in the rhythm of the utterance and the subject's ability to tap at the occurrence of each syllable. That is, particularly for maximally stressed units in the utterance, the subject's tapping marks fell consistently within the stressed syllable.

A prescriptive definition of the syllable in some languages supplements the intuitive notion described above. Speakers of French, for example, are taught "rules" for dividing words into syllables. Given a string, CVCVCV, the French speaker would divide it into the series of open syllables, CV-CV-CV. Similarly, there are rules for determining which consonants of a cluster belong to which syllable. In the sequence CVCCV, for example, if the consonant cluster is a possible initial word cluster then it is not split and the syllable division yields CV-CCV. If, however, a cluster cannot be found initially in a word, then it is split to give CVC-CV.

The linguistic approach to defining the syllable has been to specify features at either the centre of such units or at the boundary between consecutive ones. DeSaussure (1915), for example, defines the syllable in terms of the point marked by passing from implosion to explosion in a chain of sounds. Here his use of the word 'implosion' is not the same as that in normal phonetic use where it usually refers to consonants formed on an ingressive air stream. DeSaussure applies the terms implosion and explosion to the closure and release of sounds. In the sequence a$\overset{\rangle\langle}{\text{pp}}$a, for example, the first /$\overset{\rangle}{\text{p}}$/ results from closure, the second /$\overset{\langle}{\text{p}}$/ from release. According to deSaussure, the syllable boundary, therefore, lies between these movements. Stetson (1945) interprets and summarizes deSaussure's point of view thus:

> Saussure taught that the syllable is a basic unit in which the phoneme has a function. The explosive phase of the syllable consisted of the progressive opening of the vocal canal by one or more phonemes. The implosive phase then begins the progressive closure of the vocal canal by one or more phonemes. Saussure describes the phoneme in auditory terms but in his phonological theory they are articulatory functions. (p. 17).

Rosetti (1959), Stetson (1945), and Pike (1943) described central aspects of the syllable in defining this unit of speech production. To Rosetti the syllable was determined by the air stream--the centre of the syllable being that part in which there was movement of air. A series of stop consonants could not, therefore, form a syllable, while a series of consonants, in which at least one was a continuant, could. Similarly, the vowel portion of a sequence would constitute the central distinguishing syllabic feature of that sequence.

Stetson (1945) studied the respiratory muscles involved in speech and used his data to define a syllable. He said that:

> The syllable is a fusion, a concurrence of movements and not a mere series of sounds. (p. 47).

Stetson stated further that:

> The basic elementary movement of speech is the chest pulse of the syllable; and the series of these pulses grouped into feet, into breath groups and into phrases make up the train of syllables. (p. 50).

According to Stetson, the syllable so formed is made audible by a vowel and is started (released) and stopped (arrested) by the intercostal muscles of the chest or by complete or leaky closure of a consonant articulation. (p. 52).

Pike's (1943) articulatory definition of the syllable was based on Stetson's chest pulse theory but emphasized strictural functions. Strictures were defined as partial or complete closures of an air passage. He stated that:

> A <u>syllable</u> is a single unit of movement of the lung initiator which includes but one crest of speed. Every occurrence of an initiator time bulge followed by renewed speed of the initiator movement is a trough or border between two syllables. Physiologically, syllables may also be called <u>chest pulses</u>. (p. 116).

He elaborated on this theory in order to define the centre of the syllable:

> The segment during which the speed of the initiating movement is greatest in the syllable is the syllabic.....all other segments in the syllable are nonsyllabics. The syllabic may be considered the functional centre, nucleus or crest of the syllable. (p. 117).

The linguistic specifications of the syllable discussed above have been divided into two groups depending on whether the theorist emphasized central or terminal aspects of the unit under consideration. From another point of view, however, the definitions belong in a single group since they are similar in that all define the syllable in terms of specific linguistic features. The features differ in each case (intensity, airflow, etc.), and thus the unit which is established differs depending on which feature is specified, but the principle remains the same. That is, although, deSaussure, Pike, Stetson and Rosetti define the syllable in terms of points within the unit (beginning, middle, or end), they can also be seen to define the syllable in terms of the extent of influence of a single parameter. The resulting units ("syllables") are unlikely to be the same for all criteria used. Investigations using this principle of defining units with reference to dynamic parameters is presently an important area of linguistic research. There are many studies which have attempted to experimentally delimit units of speech production by observing one feature and establishing its boundaries, its onset and offset, within larger phonological units. Some of this research and its application to the present experiment is discussed in the following paragraph.

2.2 Experimental Studies Attempting to Delimit Speech Production Units

Many approaches have been used in attempts to delimit "units of speech production". Temporal relationship studies, studies of speech errors and coarticulation research represent some of the areas of linguistic endeavour relevant to this investigation and will thus be surveyed below. First, however, it is necessary to note the distinction between a phonetic and a phonemic unit. A phonetic syllable (if such a unit exists) is a syllable in which the unit of organization is defined by the same criteria for all languages investigated. If, however, there is evidence that the "syllable" limits or defining parameters are not independent of the language under study, then one must assume that "syllabicity" is phonemic. It may be seen from the results of the literature reviewed below that syllable units are language specific rather than language universal.

The temporal relationships in monosyllabic and disyllabic English words were investigated by Lehiste (1971) who established that temporal compensation exists between pairs of segments as well as within the segments that constitute the word. This internal cohesiveness of component parts of words leads Lehiste to support a theory that words may be characterized by other factors than those established by reference to word boundaries. The observed internal cohesiveness is an important point for departure when studying the component features which make up phonological units as a whole. Thus it is relevant to monitor one parameter, such as "rounding", and determine if it has any predictable boundaries or extent of influence within continuous speech.

Fromkin (1971) collected numerous speech errors and, rather than classify them, explained them in terms of units of linguistic performance. In particular, she found that when errors occur by substitution there is a consistency of replacement--initial segments replace initial, final replace final, etc. According to Fromkin, her data support a concept of the integrity of the syllable structure. She states that:

> In a string CVC#VC...CV#CVC, one never finds in errors a substitution of the final consonant of the first word for the initial consonant of the final word .....(this) seems to contradict the position taken by Kozhevnikov and Chistovich, 1965, where the suggestion is made that in the production of Russian utterances a CVC#VC sequence is reorganized into articulatory programs for each CV sequence. (p. 39).

The work by Kozhevnikov, et al., (1965) (referred to by Fromkin) contains coarticulation studies relevant to the present research project. Kozhevnikov and his colleagues used various techniques, including electromyography, photography and dynamic palatography, in an effort to determine the composition of an "articulatory program" and to gain insight into the organization of a syllable. Their investigations covered such phenomena as the movements of the lips in protrusion, the time relations within a complex of consonants and the disturbances of articulation which occur under conditions of delayed auditory feedback. Of particular relevance to the present study is an experiment in which they observed movements of the lips in strings of consonants preceding rounded vowels. From the data analyzed in this, and other experiments, they concluded that an articulatory program is constructed according to a type of open syllable of the CV type.

In an early investigation of articulatory phenomena Fromkin (1965) studied the action of the orbicularis oris muscle during production of specific CVC monosyllables. She stated that the aim of her project was:

> to test the possibility of correlating linguistic units such as phonemes or distinctive features with neuromuscular activity. (p. 118).

Her finding that certain phonetic features (i.e., rounding; tense/lax) can be described with reference to neuromuscular activity is of interest here in a discussion of units of speech production. In particular, Fromkin concluded that:

> This study of just one muscle, leads one to imagine the possibility that further investigation of all the muscles involved in the production of any one speech sound may provide a means of segmentation of an utterance into phonemes. (p. 169).

This concept of segmentation of units by means of physiological parameters has been used in other coarticulation studies to group individual phonemes into larger production units.

Öhman (1966) reported a spectrographic study of Swedish, American and Russian VCV clusters. He concluded that such utterances are not simply linear sequences of successive gestures. The vowel context influenced each utterance, the production of the VC part depending on the final vowel of the VCV sequence while the CV portion was dependent upon the preceding vowel. The author stated:

> We have clear evidence that the stop consonant gestures are actually superimposed on a context-dependent vowel substrate that is present during all of the consonant gesture. (p. 165).

Carney and Moll (1972) reported the same conclusion when they extended the study to include fricative consonant-vowel coarticulations.

MacNeilage (1969) evaluated a model of speech production based on discrete phoneme commands by investigating electromyographic and cinefluorographic data of 36 CVC syllables. His results did not show any effects of initial and final consonants on each other but his data indicated contextual effects between adjacent phonemes. He concluded:

> There was a difference in some aspects of the motor control of every vowel and final consonant in the study depending on which of the possible phonemes preceded it. (p. 1222).

Although less frequent, there were similar right to left effects, those observed in the initial consonant being greater than those in the vowel. He postulated a "compatibility" and gamma loop mechanism to explain the left to right effects and an anticipatory mechanism for the right to left effect. In this latter discussion he considers that because the effect of the vowel on the preceding consonant is greater than that of the final consonant on the vowel, a tentative conclusion can be made that in English:

> in this type of syllable, the CV component is a somewhat more cohesive or interdependent portion of the total command structure than is the VC component. (p. 1233).

In this belief he is in agreement with similar statements by Kozhevnikov, et al., (1965) about Russian syllables. He stated, however, that he does not agree with:

> the conception of the consonant and the vowel as independent commands coarticulated by means of mechanisms of reciprocal innervation. (p. 1233).

He postulated that:

> the relatively greater freedom and perhaps greater necessity to begin articulation of the vowel during the consonant may be causal factors in the development of the relatively cohesive command structure of the CV sequence. (p. 1233).

Although MacNeilage's data, like the Russian research, shows that CV is a cohesive unit, it must be noted that his data is not in agreement with other research findings concerning the same language (English) that he was investigating. Lehiste (1971), for example, found a closer relationship between VC than between CV sequences in her temporal relationship studies.

Daniloff and Moll (1965) have reported an investigation of lip rounding similar to that presented here. They took as their basis the reference to "articulatory syllables" made by Kozhevnikov, et al. (1965). They stated that the purpose of their cinefluorographic study of lip protrusion was:

> to determine over how many phones in a string coarticulatory lip-rounding gestures could be observed and to study the effects of rate of utterance, word and syllable boundaries, and phonetic structure on such coarticulation. (p. 709).

Their results agree with those of Kozhevnikov, et al., i.e., that coarticulation of lip protrusion was evident in up to as many as four consonants preceding the vowel. It must be noted, however, that in all of the speech samples in which four consonants preceded the vowel, a "rounded" consonant, /r/, immediately precedes the vowel and possibly affected the data.

Daniloff and Moll discuss their data in relation to the "articulatory syllable" postulated by the Russian authors. They suggest that although their work on English is consistent with the model

proposed by Kozhevnikov, et al., further research is necessary with other "adequately defined features" in order to determine the boundaries of such features. They are not convinced that their data establishes a boundary of the rounding effect of the vowel. They state that:

> The fact that lip rounding has been found to extend back only to the beginning of a prevocalic consonant sequence does not imply necessarily that this time point marks the boundary of some unit. (p. 720).

Daniloff was led to his contradiction of Kozhevnikov's "articulatory syllable" because his record of onset of the lip protrusion gesture with reference to the initial consonant was not exactly the same as that of the Russians. He says that:

> Kozhevnikov and Chistovich described this gesture as beginning simultaneously with the closure phase of the first consonant in the sequence. In the present study, most of the protrusion gestures observed began before the first consonant contact, near the point in time at which articulatory movement toward the contact was initiated. (p. 717).

The present research is an attempt to investigate further the coarticulatory effect of lip rounding studied by Daniloff and Moll. Both English and French are used in this effort to provide additional evidence to support or reject Kozhevnikov's "unit of articulation".

2.3 Phonological Units Other Than The Syllable

The purpose of the detailed discussion of the "syllable" in the previous Section was to define this term and illustrate its applicability to the present research. It was hypothesized that, if the feature "rounding" has an influence on preceding phones, then the extent of the influence is likely to be of syllable size. As noted earlier,

Kozhevnikov, et al., (1965) have in fact postulated a unit called an "articulatory syllable". However, the possible coarticulatory influence over larger phonological units cannot be ignored. Some units which may be relevant to the interpretation of the immediate experimental results include the word, the stress group and the breath group. Only a brief definition of each of these terms is given below as their meaning is not as obscure as that of the syllable.

Words are minimal free forms which have semantic meaning. They are units specified by semantic rather than articulatory or acoustic criteria. The form of a word may vary with respect to the number of phones of which it is composed, with respect to its pattern of syllabification and with respect to the position and amount of stress. Because words vary so much in form it is unlikely that they are the unit over which coarticulation takes place. They are, however, of interest to a coarticulation study if there is evidence that coarticulatory patterns are influenced by the presence or absence of word boundaries within a sequence of phones under investigation.

Pike (1969) has listed the "stress group" as one of the three "natural units of sound". The other two were the segment (phone) and the syllable. According to him:

> a stress group is a sequence of several syllables one of which, the stressed syllable, has a much stronger initiator pressure than do the others. (p. 119).

Heffner (1949) referred earlier to these stress units as "speech measures, phrase groups or sense groups". He contended that these units are necessary to the phrasing of even larger "breath groups"--that is, units between which a breath is, or may be, taken in

(p. 173). Similar definitions were presented more recently by Moses (1964). He stated that:

> A speech measure (or rhythmic group) consists of one or two (seldom more) stressed syllables, usually accompanied by several semi-or unstressed syllables, and 'delimited by facultative pauses'. A breath group is made up of one or more speech measures between pauses, at which breath is taken. (p. 129).

2.4 Parameters for Defining "Rounding"

In order to use the term "rounding" to describe an entity whose variation through time can be both observed and measured, it is first necessary to establish an operational definition of the term and the parameters used to specify it. This section attempts to define the term as it is applied to the present experiment and surveys some of the recent research directed at determining parameters of "rounding".

Two kinds of "rounding" have been referred to in the literature and each has been variously defined. Terms such as inner rounding versus outer rounding (Sweet, 1908), horizontal lip rounding versus vertical lip rounding (Heffner, 1950) and lip rounding versus lip compression (Ladefoged, 1970) have all been used to describe labial activity. It is not the purpose of the present experiment to attempt to examine or verify the existence of the two types of rounding which have been discussed in the literature. Rather the aim of this investigation, like other coarticulation studies, is to experimentally examine one aspect of speech in an effort to determine some information about how it changes as a function of time. The speech aspect of interest to the present experiment is here termed "rounding". In particular "rounding" will refer to that activity of the lips which is observed as "lip protrusion".

A number of studies report attempts to delimit parameters which adequately specify labial activity. Fujimura (1961) used measurements of mouth opening to quantitatively describe the articulatory movements under study in his investigation of bilabial stop and nasal consonants. Midsagittal lip separation and horizontal extent of lip separation were measured as a function of time. These measurements were then used to provide data for estimating area of lip opening.

Lindblom (1965 a, b, c) has proposed a "difference curve" to represent lip activity. He computed jaw-dependent neutral positions associated with labial parameters and from these positions established the amount of labial activity by determining the amount of deviation from the neutral position. These mathematical representations of lip activity could then be used to show the variation, as a function of time, of parameters such as "spreading". In the case of the sequence / adɔd /, for example, the position of the lips changes from a spread (+ "spread") to a rounded (- "spread") condition as the vowel changes from /a/ to /ɔ/.

Fromkin (1964) reported on photographic, X-ray and plaster cast data used to determine some characteristic parameters of lip positions in American English vowels. She concluded that the set of rounded vowels can be distinguished from non-rounded vowels by a description of lip height, lip width, and lower lip protrusion. She also noted that within the set of "rounded" vowels so established, /u/ always has the minimum value on both height and width dimensions.

In a later study (1965), Fromkin investigated certain phonetic features through the observation of muscular activity. Specifically, she recorded the onset of electromyographic activity of the orbicularis oris muscle, in order to determine its function in the production of 12

vocalic and three consonantal phonemes of American English. She found that degrees of muscular tension distinctly separated rounded and unrounded vowels. In choosing the rounded/unrounded distinction she noted that:

> The term "rounded" in reference to American English vowels is misleading, since for the most part only protrusion of (the) lower lip is involved. (p. 121).

Perkell (1969) refers to Fromkin's findings in his report of a cineradiographic study of certain physiological aspects of speech production. Three of the measurements he made were upper lip protrusion, lower lip protrusion and height of lip aperture. His data show that there is a difference in timing between lip protrusion and aperture constriction for /u/ and /ɔ/. He concludes, therefore (in agreement with Fromkin), that the two activities have independent functions.

Lip protrusion was also the parameter used by Kozhevnikov, et al., (1965) in their studies of "articulatory syllables". They also used electromyographic techniques to record the activity of the orbicularis oris muscle of the lower lip and so obtain measurements for the amount and time of lip protrusion.

Similarly, Daniloff and Moll (1968) in their coarticulation studies of lip rounding measured only lip protrusion. To them, this parameter provided an adequate indication of the phonetic feature being studied and was therefore used synonomously with the term "lip rounding".

2.5 Techniques for Observing Rounding of the Lips

Several instrumental techniques reported in the literature have been used to investigate the phonetic feature "rounding". The one most

practical for the proposed experiment from the point of view of availability of equipment is that of direct cinematography. In a study of the articulatory movements involved in the production of bilabial stops and nasal consonants, Fujimura (1961) took motion pictures of the lips at 240 frames per second. A stroboscopic light provided a synchronized flash for each frame. Utterances were simultaneously recorded on one track of a magnetic tape while a pulse train, synchronized with the flashes, was recorded on the second track. The cinematographic procedure has several drawbacks, the most important being that it is often necessary to sacrifice accuracy of observation of fast varying phenomena because of the limited frame rate of the camera. In addition, photographic data must be processed by hand, a factor which must be considered when deciding upon the filming speed to be used and when determining the amount of human error affecting the results.

Taking into account the drawbacks of Fujimura's photographic method, Kozhevnikov, et al., (1965) devised a photo-oscillographic device for observing lip movement. In this method the moving object, the lips, were photographed through a narrow slit on a film which moved continuously at a constant rate. Adhesive tape or theatrical paint was placed on subject's lips for recording the vertical and horizontal dimensions of lip movement and, depending upon which dimension was being investigated, the photorecording device was placed so that the film moved in a horizontal or vertical direction. Displacements of threads attached to the lips by adhesive tape were similarly photographed and used to record movement in the sagittal plane. The oscillograms, which were simultaneously made, were magnified or copied onto grid paper and analyzed to give information on lip movement in

the three planes.

Daniloff (1968) used cinefluorography in his investigation of lip rounding. Lateral X-rays were made at a camera speed of 150 frames-per-second. A strip of thin aluminum foil was affixed to the midline of the tongue tip, and the midline of the tongue and hard palate were coated with a barium sylphate solution in order to aid in identifying these structures. Lip protrusion measurements were obtained by superimposing film tracings on a template containing the lower jaw outline and perpendicular reference lines.

Electromyography is the method most frequently reported in the recent coarticulation studies of lip movement, (Kozhevnikov, et al., 1965; Fromkin, 1965; Tatham, 1968; MacNeilage, 1969). Bipolar electrodes are used in this method to register electrical activity of muscle units. The surface electrodes used by Fromkin (1965), for example, in her study of the orbicularis oris muscle, consisted of half a hollow silver bead connected to a suction pump which maintained a negative pressure to enable the bead to adhere to the lips. The electromyographic signals recorded by the electrodes used by Fromkin were first amplified and then displayed on an oscilloscope. The audio and electromyographic signals were recorded on a multichannel tape recorder. These recordings were then played back and displayed by means of a graphic recorder for measurement and interpretation of the data.

The measurement of electrical impedance changes between electrodes placed on the lips is another recent method of observing their action. Various pickup devices were experimented with by Kozhevnikov, et al., (1965) and used to record the movements of lip closure rather than lip rounding. The most successful method they described was made of a round

plexiglass clamp attached to the lower lip. A needle-like gold contact was fastened to the clamp and a fine steel ring mounted above. The small contact clearance and the flexibility of the spring assured that the contacts touched when a slight pressure was exerted on the lip pickup. The contact closed the circuit and a sinusoidal signal was fed to the recording system. (p. 25).

Some preliminary experiments have been made by Ludvigsen (1968) using high frequency electrical impedance measurements to register lip pressure and rounding. He placed four electrodes on the lips--one at the midline of each lip and one in each corner of the mouth--and simultaneously recorded the horizontal and vertical impedances by means of two electroglottographs. Neither labiogram gave reliable information about the desired parameters. He concluded, however, that:

> The labiograms give a great deal of information concerning the position and movements of the lips. This information might be used to throw light on other features than lip pressure and rounding of the lips. (p. 6).

CHAPTER 3

AIMS OF THE INVESTIGATION

The research experiment reported here was designed to delimit parameters of lip movement which are representative of the phonetic feature "rounding" and to observe the variation of these parameters as a function of time in specific English and French utterances. In particular the aims of the investigation can be summarized as follows:

1. To determine if the feature rounding can be quantified in terms of some measurable parameter(s) and if so which one(s).
2. To develop a reliable experimental technique to investigate coarticulation of lip rounding.
3. To attempt to establish a unit over which the phonetic feature "rounding" has an influence. Such a postulated unit is investigated in terms of the boundaries of other phonological units such as syllables, words and breath groups.
4. To compare the effect of rounding between selected French and English speech samples.

CHAPTER 4

EXPERIMENTAL APPARATUS AND PROCEDURES

4.1 Subjects

There were four subjects involved in the experiment--one for English, three for French. All were considered to have normal speech. The English speaking subject was a native of Vancouver, Canada. French Speaker #1 was a native of Grenoble, France, who had been a resident of B.C. for the past two years. Her dialect was considered to be closest to "standard French". French Speaker #2 was a native of Lausanne, Switzerland, who had been in North America for 12 years. French Speaker #3 was a native of South central France who had resided in North America for seven years. All four subjects had had at least an introductory course in linguistics and phonetics and it was therefore difficult to conceal the nature of the experiment in which they were participating. This knowledge was not considered to invalidate the data collected.

4.2 Filming, Sound Recording and Time Alignment

Figure 4.1 shows a schematic diagram of the apparatus used for filming and recording the speech samples. Subjects were placed in a "holding" frame designed to minimize head movement (Figure 4.2). The head was positioned by reference points at the tip of the nose and on each temple, and by a flat board at the back. Major movements were impeded by the apparatus but small rotational movements were not impossible and

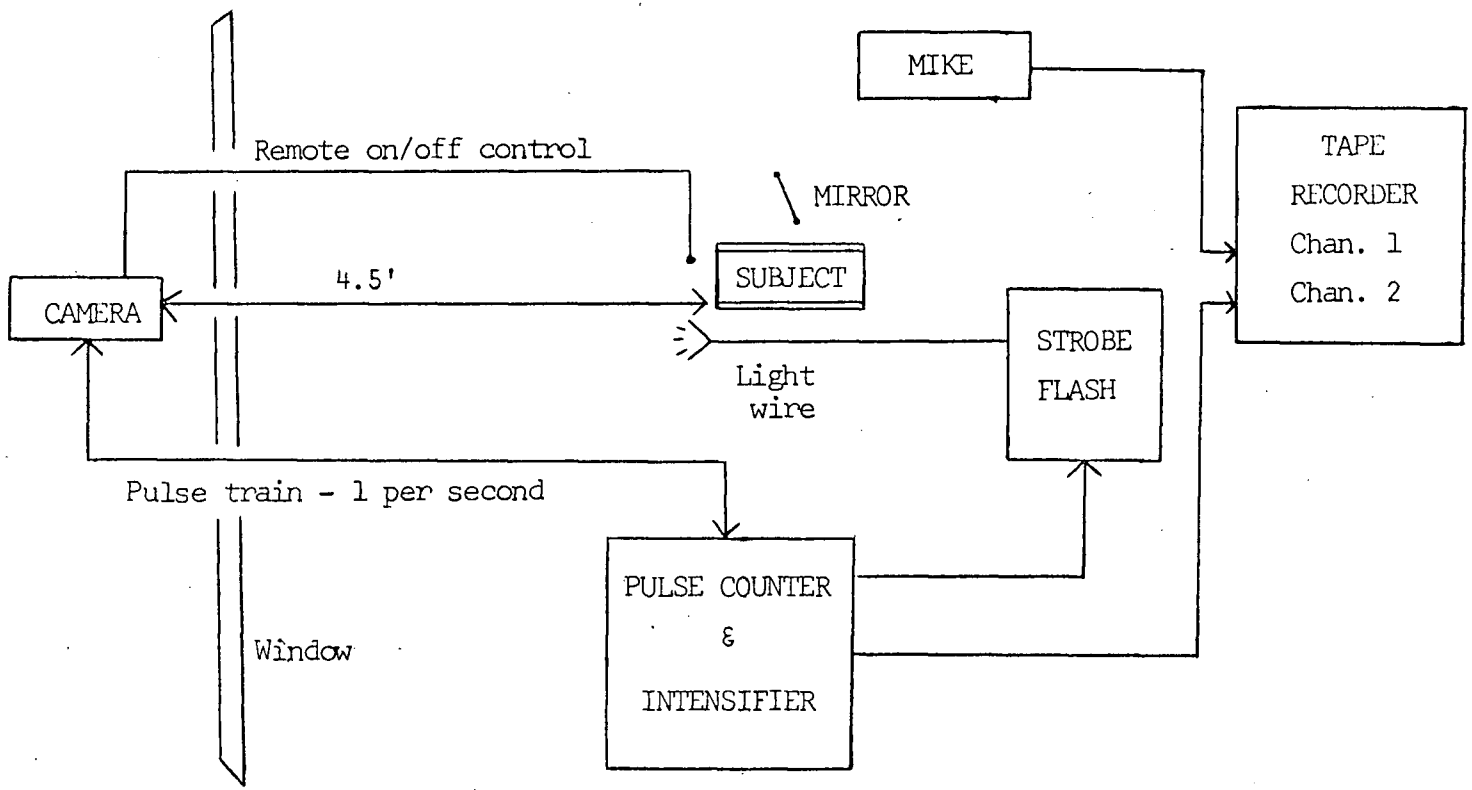

Figure 4.1. Block diagram of instrumentation for filming and recording.

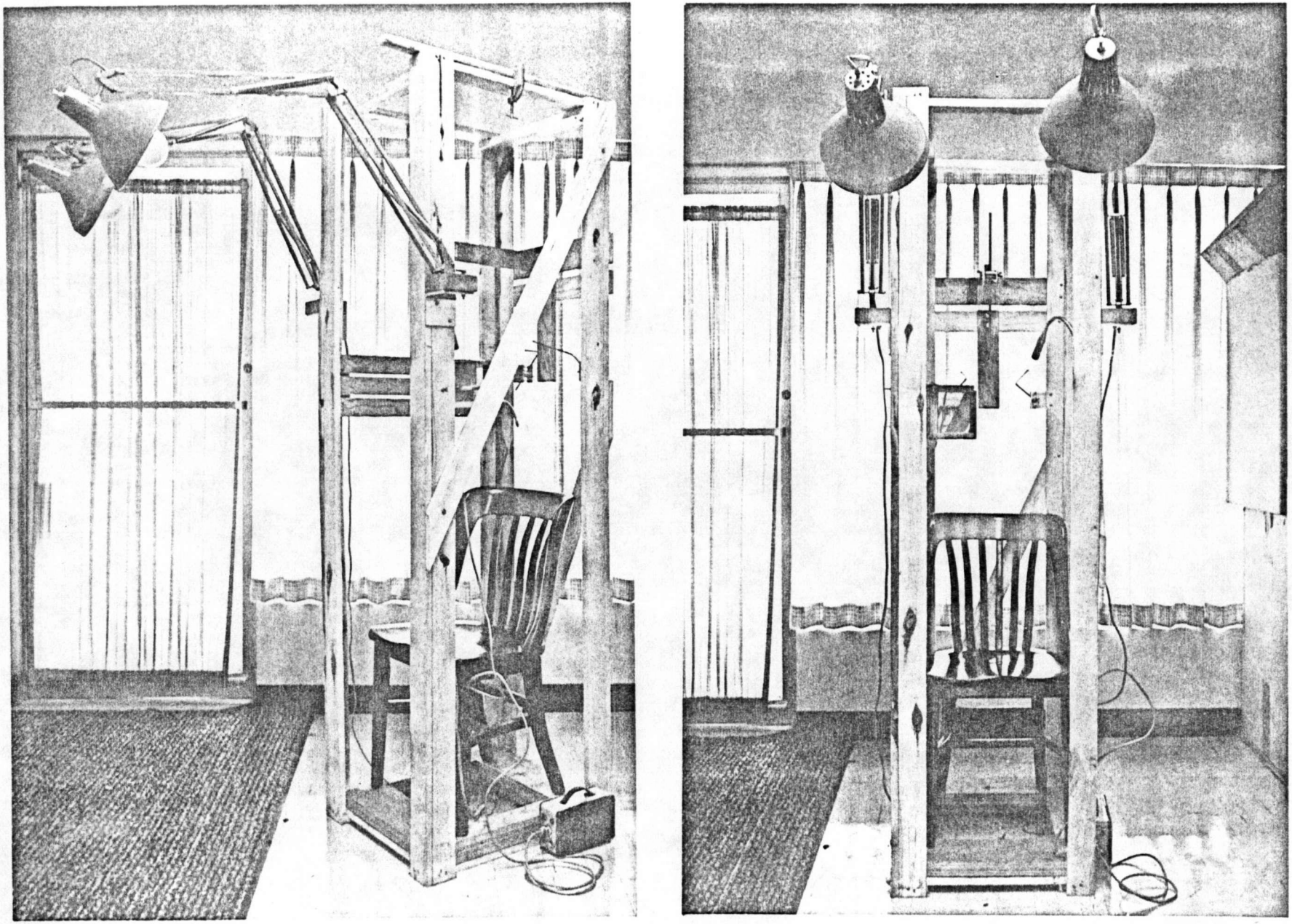

Figure 4.2. Photographs of 'holding' frame used to position subject.

subjects had to be asked to refrain from such activity. A 5" x 5" mirror hinged vertically to the wooden frame could be adjusted to provide a lateral view of the subject's face. Also secured to this "holding" apparatus were a microphone, two swivel lamps with 500 watt bulbs and white reflectors.

The focal plane of the camera (Beaulieu R16) was 4.5' from the subject's lips. Films were made at a speed of 66 frames per second (maximum available) with a lens having a focal length of 68 mm. The subject controlled the camera's motor via a remote control on/off switch. This procedure minimized film wastage by reducing the time between the start of the film and the onset of speech.

Speech samples were recorded with a 1" Brüel and Kjaer condenser microphone associated with one track of a half-track two-channel Revox tape recorder. A pulse train, generated by the camera at a rate of one per frame, provided a means of alignment between film and recording. The train of pulses from the camera was sent to a counter having two outputs. From one of these outputs every 50th pulse was intensified, and triggered a strobe light which produced an identifying flash on every 50th frame. The second output (with every 50th pulse intensified) was sent to the second track of the tape recorder. In this way, every 50th pulse could be recognized and subsequently aligned with the corresponding frame on the film.

4.3 Analysis of the Data

4.31 Sound

The signals recorded on the tape were displayed graphically on a six channel Siemens Oscillomink liquid jet recorder. The following

output signals were displayed:

Channel 1 - speech wave - from track 1 of tape
Channel 2 - duplex oscillogram - from track 1 of tape
Channel 3 - pulse train - from track 2 of tape
Channel 4 - fundamental frequency of speech wave
Channel 5 - log intensity of speech wave
Channel 6 - time pulse - 1 per second

A Frøkjaer-Jensen transpitchmeter provided the inputs to Channels 2 and 4. The intensity or speech power detector (Channel 5) was similar to the one developed by Peterson and McKinney (1961).

Mingograms displaying the above six signals were used to segment the speech utterances and to determine the number of the corresponding film frames. Spectrograms were needed in some cases to verify the mingogram segmentations but for the most part it was possible to reliably identify the speech sounds under consideration by studying the mingographic displays of Channels 1 and 2. Once a speech sample was segmented (see Figure 4.3) the frames featuring each particular sound were determined from the numbers of the corresponding pulses. Only those frames representing information important to the present study were then measured.

4.32 Film

Projection Set-Up

A schematic diagram of the viewing table used for the frame-by-frame analysis of the film is shown in Figure 4.4. The film is projected by an L & W modified Kodak Analyst Projector, via a mirror, onto a horizontal ground glass plate. The horizontal position of this table makes it possible to easily measure each frame directly. All parameters, including area obtained by a planimeter, can be made without first tracing the image, a procedure which would introduce an added source of

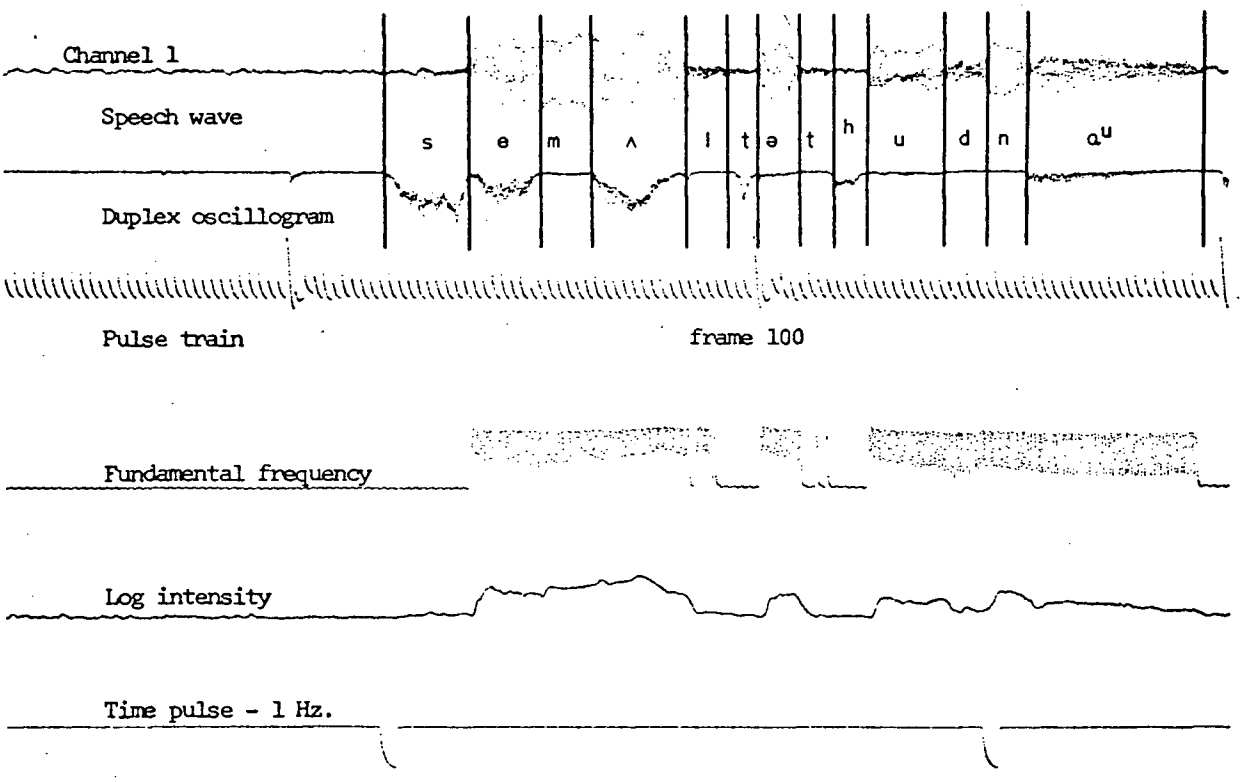

Figure 4.3. Mingogram illustrating segmentation and film alignment procedure.

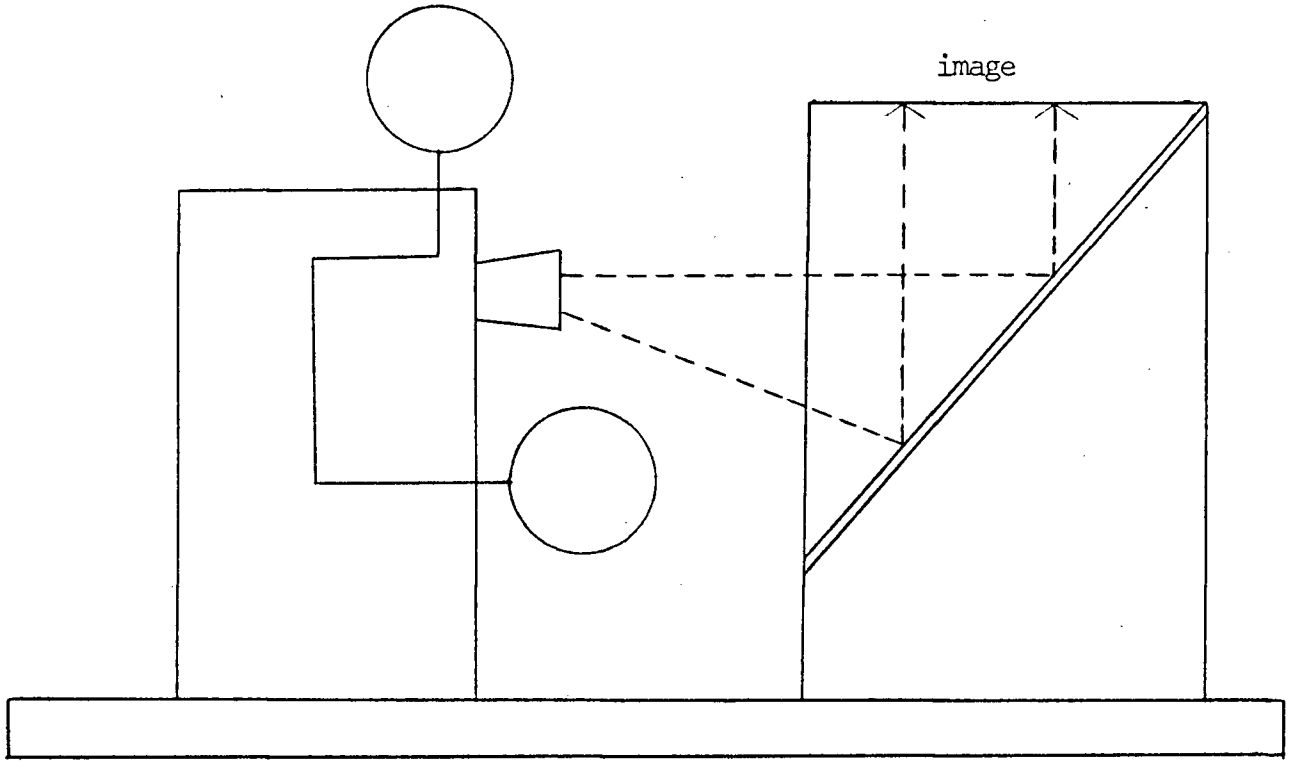

Figure 4.4. Schematic of projector and measurement table.

error in the data.

Parameters Measured

Height, width and area of mouth opening, plus lower lip protrusion can all be measured on the projected image. During the initial stages of the experiment all four parameters were measured for each frame under study. As will be seen below, only lower lip protrusion was used for most of the coarticulation study.

The four parameters are diagrammed in Figure 4.5. Also illustrated is the pattern of reference points which was drawn on each subject and used to aid in measurement procedures, particularly for height and width parameters. The techniques used for obtaining the data can be summarized as follows:

(1) Calibration.

Several frames of a calibration card were taken at the beginning of each film. The card, on which a square grid was drawn, was photographed in a position corresponding to the filming position of the subject's lips. Prior to every measuring session the calibration frames were measured in order to maintain a constant degree of magnification from sitting to sitting. The optimum picture quality was found to be at a magnification of one and one half times the original. All parameters have been measured at this magnification; all numbers cited hereafter contain this 1.5 factor. It is important to note here that magnification of the image reduces the measurement error discussed later in Section 4.4. While magnification

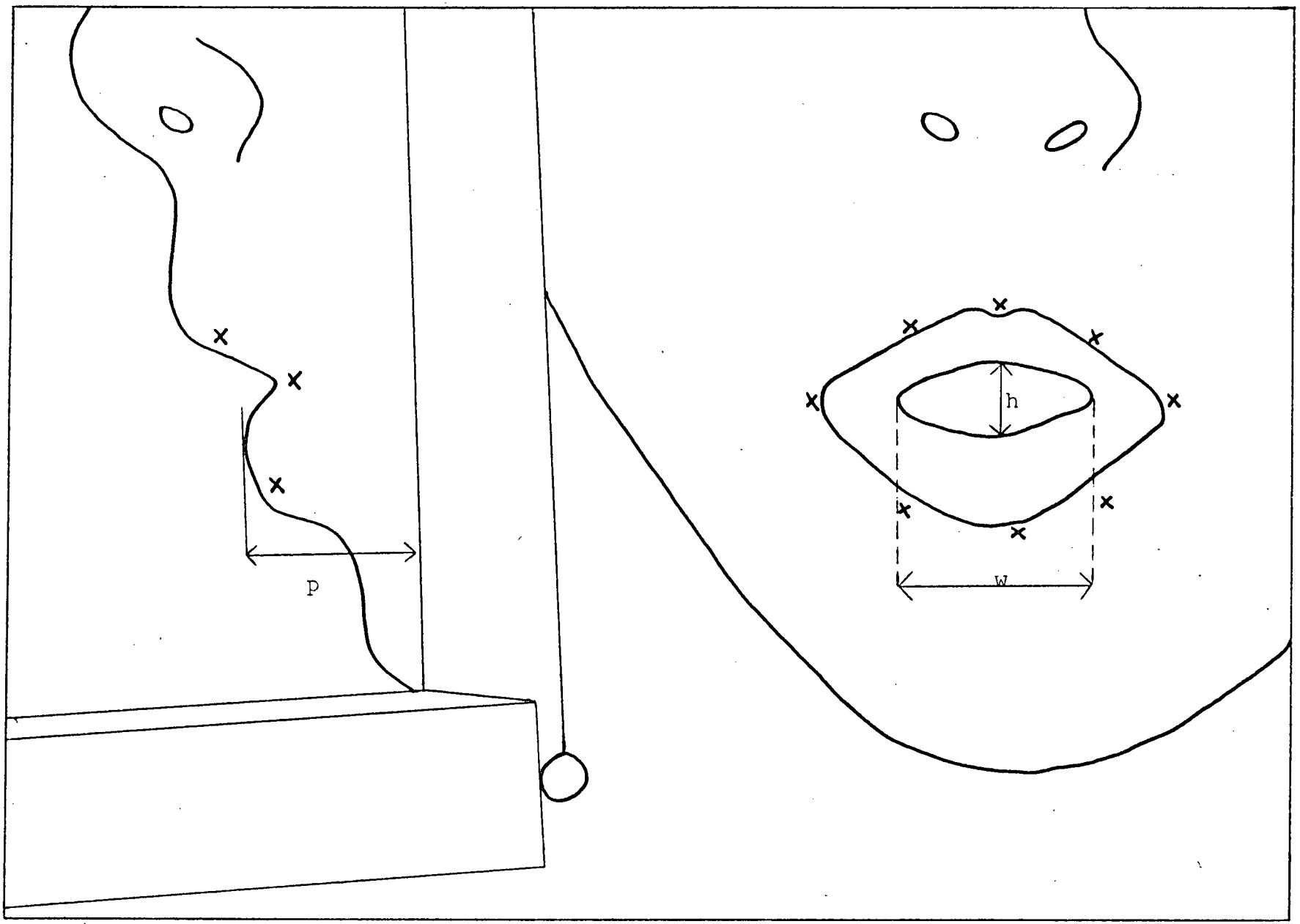

Figure 4.5. Lip dimensions measured on projected image.

p = lower lip protrusion
h = height of mouth opening
w = width of mouth opening

may decrease the sharpness of the actual image, the process of reading the ruler is not affected. Each measurement is made to the nearest 0.5 mm whether the image is life size or 1.5 times life size. The larger the image is, therefore, the smaller is the effect of the error ($\pm$ 0.5 mm) on the total measurement procedure.

(2) Lateral Photographs.

Lower lip protrusion (p) was taken as the maximum distance between the edge of the mirror and the outermost (in a forward direction) point of the lower lip.

(3) Frontal Photographs.

1. Height of lip opening (h) was measured as the distance between two horizontal lines drawn through the midpoint of the inner edge of the upper lip and through the lowest point of the lower lip.
2. Width of mouth opening (w) was defined as the distance between two vertical lines drawn through the corners of the lips.
3. Area of lip opening (A) was determined in two ways. In the first, a planimeter was used to measure the area directly. In the second, on the assumption that the shape of the mouth opening is near enough that of an ellipse, the area was

calculated from the formula $A = \pi ab$

where $a = h/2$

$b = w/2$

Repeated measurements using both methods were made on a series of frames. It was found that variability was larger when using the planimeter. Since the ellipse approximation method was not only less variable than the direct area measurement but was also much faster, this procedure was chosen when measurements of (A) were required in the study.

Once reliable procedures had been established, all frame measurements were plotted directly onto special graph paper designed such that the time scale was identical to that on the mingogram display.

An example of area (A) and protrusion (p) measurements for one sequence are given in Figure 4.6. A comparison of the two graphs indicates that protrusion provides more information relevant to this coarticulation experiment. In particular it is apparent that, because area of lip opening for bilabial consonants is invariant (i.e., is always zero), the coarticulatory effect of rounding cannot be observed in sequences in which such consonants are included. Lower lip protrusion is a better means of displaying the "rounding" feature, therefore, and was thus used as the primary parameter in this study. Hereafter protrusion is synonomous with rounding.

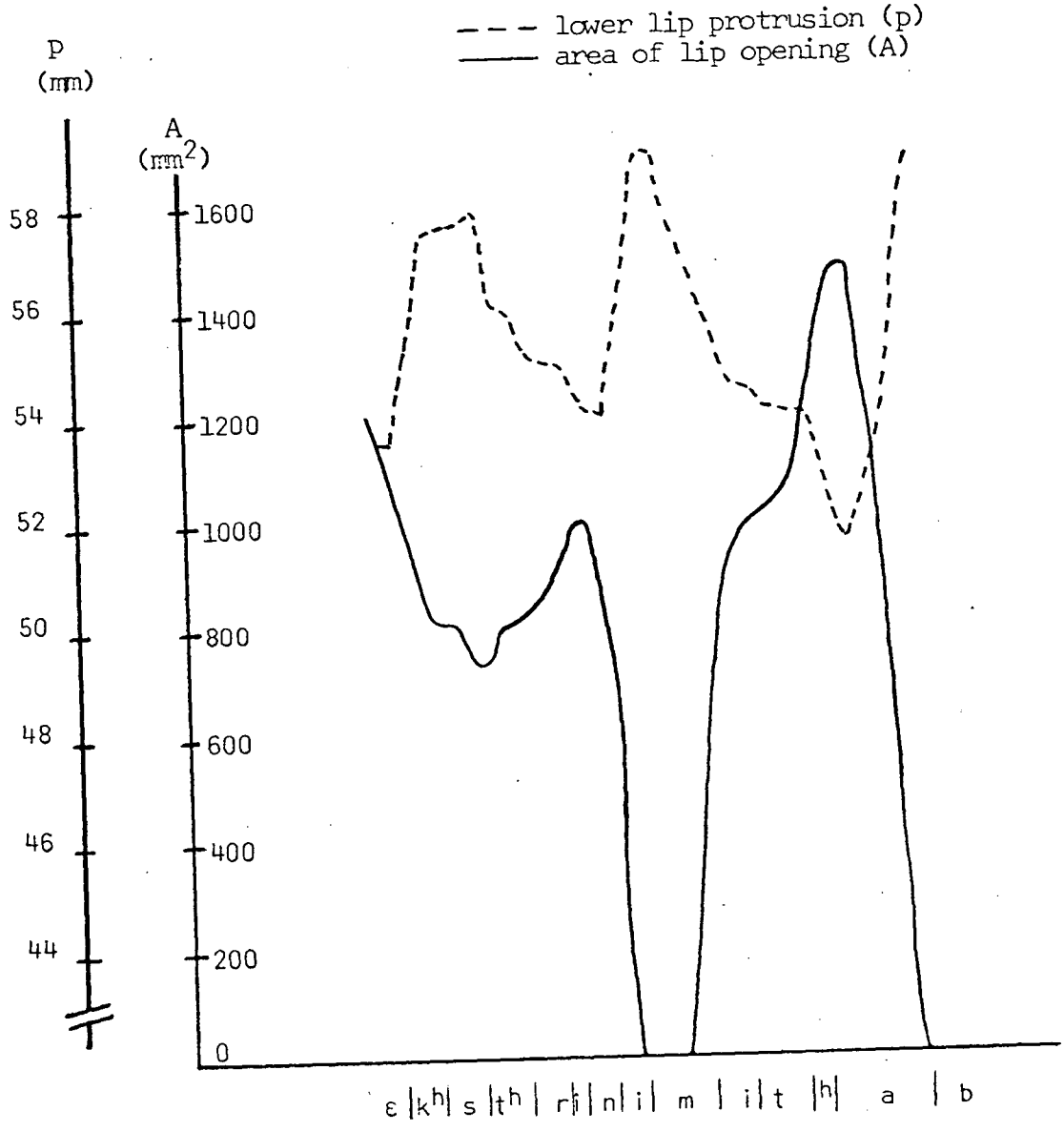

Figure 4.6. Lower lip protrusion (p) and area of lip opening (A) made for the French sequence "la dextre inimitable".

4.4 Accuracy and Repeatability of Measurements

An estimate of the sources of error made in the collection and recording of any body of data must be determined before one can discuss the information the data may reveal. The error in the present study occurs as a result of projection technique, measuring technique and the curve interpretation process used when repetitions of the same utterance were averaged.

The optical technique necessarily introduces distortion of the image to be measured. This distortion is constant, however, and is not considered a significant source of error in this study where the relative value of a parameter rather than its absolute value are investigated.

A parallax error is made when determining the point to be measured. An attempt was made to minimize this error by reading each measurement with the eye vertically above the point in question.

The major source of error is in the actual frame-by-frame measurement of each parameter. All measurements were made to the nearest 0.5 mm. Protrusion varied over a range of 15 mm and relative error was therefore equal to 0.5 or 3.33%.

An estimate of the reliability of the measurement procedure was determined by computing the difference between repeated measurements of the same frames. In order to eliminate the bias introduced by analyzing consecutive frames, a total of 60 frames, each 15 frames apart, were remeasured and the results compared with the original measurements made. This procedure was carried out on one black-and-white film and one colour film. The standard deviation was found to be 0.356 mm and 0.440 mm for the colour and black-and-white films respectively.

The difference between the two types of film was thus minimal. For economic reasons alone black-and-white films were used for the bulk of the experiment.

In summary, the total average error for the entire measuring process is approximately 0.5 mm. This error is of the same order reported by Houde (1968) for a similar procedure and is considered to provide useable results.

Initially two repetitions of each utterance were filmed and recorded in order to determine the amount of intra-subject variability. A curve representing the average of the two measured curves was determined and used for the coarticulation comparisons. The standard deviation calculated for these estimated average curves was found to be 0.458 mm for the initial French film and 0.488 mm for the English film. Since the deviations were small, only one repetition was made of each utterance on subsequent films, thus allowing the analysis of a greater number of different utterances.

CHAPTER 5

RESULTS AND DISCUSSION

5.0 Introduction

Results of the present coarticulation experiment are presented and discussed in this chapter. This mode of presentation was chosen because it follows the process used to study the data during the experiment. That is, throughout the project each film was taken, analyzed and the results interpreted before a succeeding film was made. By proceeding in this way, the corpus of utterances for every film could be designed to modify the hypotheses under investigation on the basis of observations made on previous films. In the presentation of the results below, the films for each language are discussed in the sequence in which they were made. The data obtained for English and French are given in Sections 5.1 and 5.2, respectively.

5.1 The English Films

Several pilot films using spoken English were taken and analyzed to provide technical information about filming and measurement procedures. These films produced few results relevant to the hypothesis under investigation, but did yield important and useful information about the feasibility of the experimental outline. These results have been summarized in Chapter 4 and will not be repeated here. Subsequently, three English films were made. At the first sitting, two

films, one black-and-white (film #1), and one colour (film #2), were taken, the same corpus being used for both (See Appendix). The sequence of utterances for film #3 (See Appendix) was intended to test hypotheses made from results of films #1 and #2.

5.11 Steady State Vowels

All films started with a sequence of steady state vowels which was analyzed to ensure that rounded vowels could in fact be distinguished from unrounded vowels by some articulatory parameter such as lower lip protrusion. Results were similar for all such sequences. Figure 5.1 illustrates the separation of vowels when area of lip opening is plotted against lower lip protrusion.

The Pearson correlation r between the two parameters p and A was 0.6577. This relatively low correlation corresponds with the results of Fromkin's (1964) study of lip positions in American English vowels. She concluded that height and width measurements (which were used in the present study to calculate area of lip opening A) are not necessarily correlated with the movement of the same muscles which produce lower lip protrusion. Two independent systems are in action. On the one hand, for /u/, the orbicularis oris muscle pushes the lips forward at the same time as pulling them together to decrease width and height. In that case the one parameter, A, can be used to approximate the other, p. For / / and / o /, on the other hand, the lower lip is pulled down and forward by the depressor labii inferioris muscle, thus producing a difference in degree of lower lip protrusion but little change in width and height dimensions (p. 223).

It is evident from Figure 5.1 that /u/ (the vowel used in the

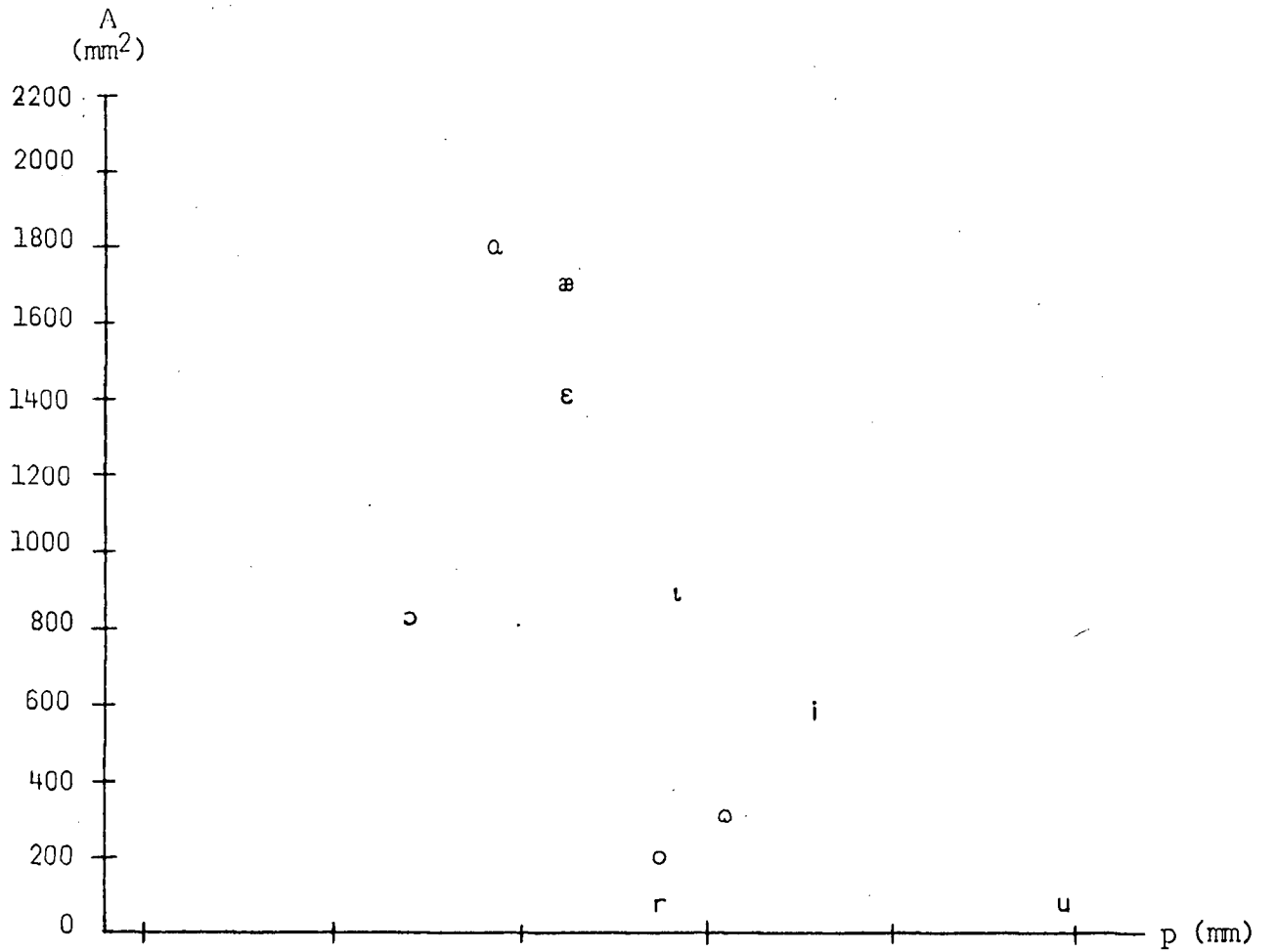

Figure 5.1. Area of lip opening (A) versus lower lip protrusion (p) for steady-state English vowels. (r=-0.6577)

present English study as representative of a "rounded" vowel) can be distinguished from all other vowels by having the maximum protrusion and the minimum area.

5.12 Films #1 and #2

The corpus of utterances used in the first two English films was composed of sequences in which the consonant cluster preceding the vowel under consideration was getting progressively longer. Although an attempt was made to use real words, it was not always possible to achieve this requirement and still maintain a "minimal pairing" between rounded and unrounded sequences.* Words used for comparison are shown in the Appendix. All of these words were said in the context "and the..." (/ ænðʌ /). The frame sentence / ænðʌ /, was used because, in the preliminary films, it was apparent that the utterances under study were influenced by the phones in their immediate environment. The constant frame not only provided an unchanging environment from which the sequence of interest could be extracted, but also provided a means of testing the variability of a large set of identical phrases spoken by the same subject. Thirty-two repetitions of the frame were analyzed for this purpose and are discussed later in this section.

In addition to these words, a group of utterances were included to test the effect of the presence of syllable and word boundaries on the coarticulation patterns under study. These utterances are given in the Appendix.

---

* By (un)rounded sequence we will henceforth refer to a sequence in which the vowel relevant to our study is (un)rounded.

Interpretation of the graphs made of the protrusion measurements was difficult and no reliable method of determining the onset of rounding could be established from the procedures used in this study. Similarly no conclusion could be drawn concerning the effect of the presence of syllable and word boundaries within a preceding consonant sequence. With these negative results in mind, it is relevant to question some of the hypotheses and conclusions made by Daniloff and Moll (1968) which formed the basis for some of the assumptions in the present experiment. They plotted, as in the present study, lower lip protrusion as a function of time. Segmentation of the utterance was achieved by determining, on the cinefluorographic film, the frame number at which identifying articulatory contacts were made. In addition to measuring protrusion, the authors also recorded:

> (1) the points at which articulators began movement toward or away from a consonantal closure or steady state,
>
> (2) the points at which consonantal closures or steady states were achieved,
>
> (3) the points at which the velum began to rise or lower, and
>
> (4) the points at which a steady-state position for /u/ was achieved, reflected in the minimum tongue-palate distance.
>
> (Daniloff and Moll, 1968, p. 711).

These points were then marked on the plots of lip protrusion versus time. In Daniloff and Moll's study the point of onset of

rounding was determined as that point on the graph of lower lip protrusion versus time where the protrusion gesture became positive. Although it is apparent that this point represents the onset of rounding, it is not obvious that it represents rounding due to the vowel rather than rounding associated with adjacent consonants. In order to determine if adjacent consonants did contribute to the rounding gesture, Daniloff and Moll made measurements of protrusion in utterances containing /r/, /l/, /m/, /s/, and /p/ preceding unrounded vowels. They concluded that there was essentially no changes in the measurement of lip protrusion for /m/, /s/, and /p/, and protrusions associated with /r/ and /l/ were small and inconsistent. From these results the authors were unable to explain the separate protrusion gestures observed for /l/ and /r/ in some of their experimental sequences. They stated that:

> it is possible, of course, that lip protrusion is characteristic of these consonants and is increased in magnitude in rounded vowel contexts. (p. 717).

It appears from the results of the present study that the above statement is most likely correct, for it was not possible to determine a specific point on the graph which represented the onset of rounding due to the vowel rather than the combined influence of consonants and vowel. As seen in Figure 5.2, different patterns are evident depending on whether a rounded or an unrounded vowel is present in the sequence, but the actual beginning of this influence cannot be determined. From the graphs it also appears that the "rounded" consonant /r/ has a compounding influence when combined with a rounded vowel but no conclusive statement can be made from these data.

As noted earlier in this section, thirty-two repetitions of the

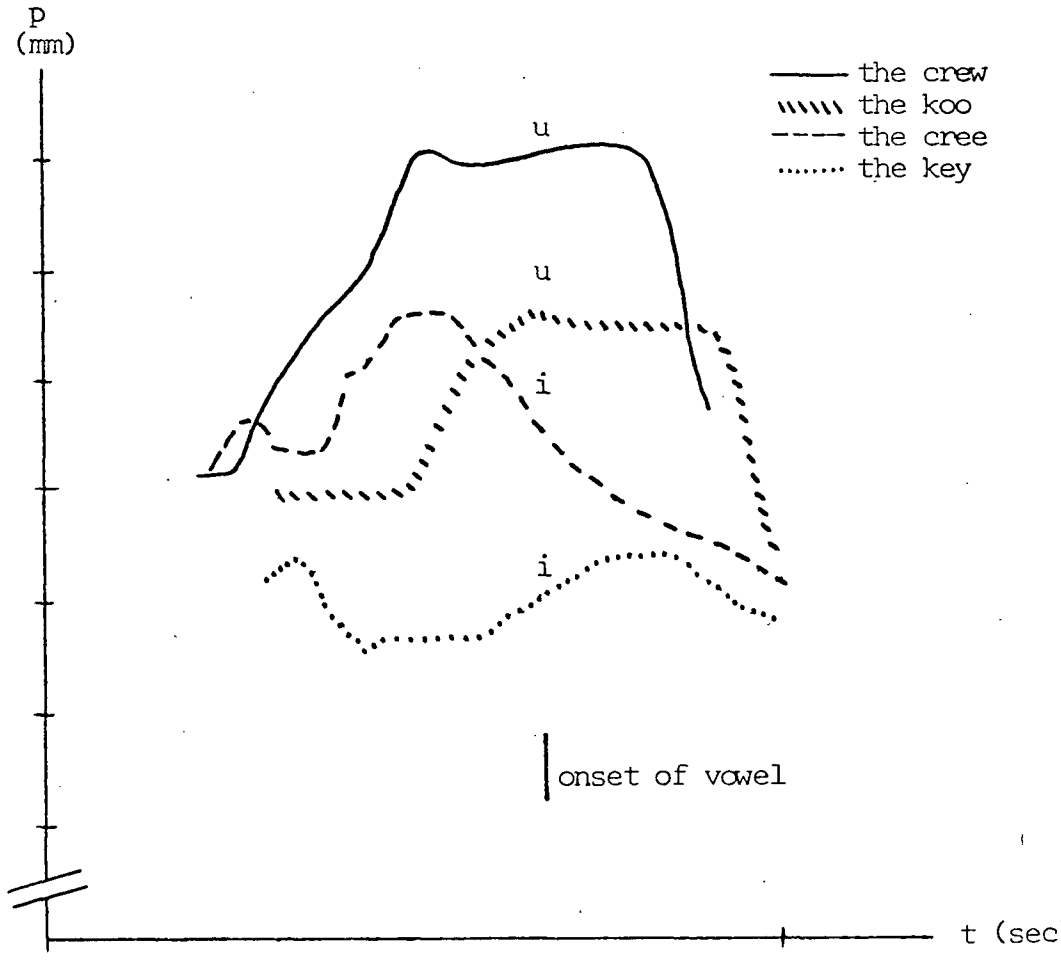

Figure 5.2. Lower lip protrusion (p) for sequences comparing rounded and spread vowels. (English film #1)

utterance / ænðʌ / were analyzed in order to determine the variability in the sequence when it was followed by different words. For comparative purposes the utterances were divided into four sets according to the following criteria:

(A) all items considered (n = 32).

(B) items preceded by a rounded vowel syllable (n = 19)

(C) items followed by a rounded vowel syllable (n = 18)

(D) items followed by a syllable containing the spread vowel /i/. (n = 14).

Three measurements of protrusion were made on each repetition:

$p(t_1)$ at the onset of voicing of / æ /.

$p(t_2)$ at the point of change in intensity between / æ / and / n / as seen on trace 1 of the mingogram display. (This point was not used in the statistical tests but was needed to determine the shapes of the curves shown in Figure 5.3).

$p(t_3)$ at the midpoint of frication of / ð /.

Some of the resulting graphs are shown in Figure 5.3

The mean and standard deviation of $p(t_1)$, $p(t_3)$, $p(t_3) - p(t_1)$, duration and velocity were calculated for each of the four subsets. A summary of these results is given in Table 5.1. As seen in the table there is little difference between the four subsets in the average amount of protrusion at time one. The wide variability in protrusion at time one (49.19 mm to 57.25 mm for subset A) suggests an absence of a "target" position for the vowel / æ /. It is, therefore, not informative to compare the value of $p(t_1)$ with other measurements made later in the utterance. It does appear, however, that the relative change

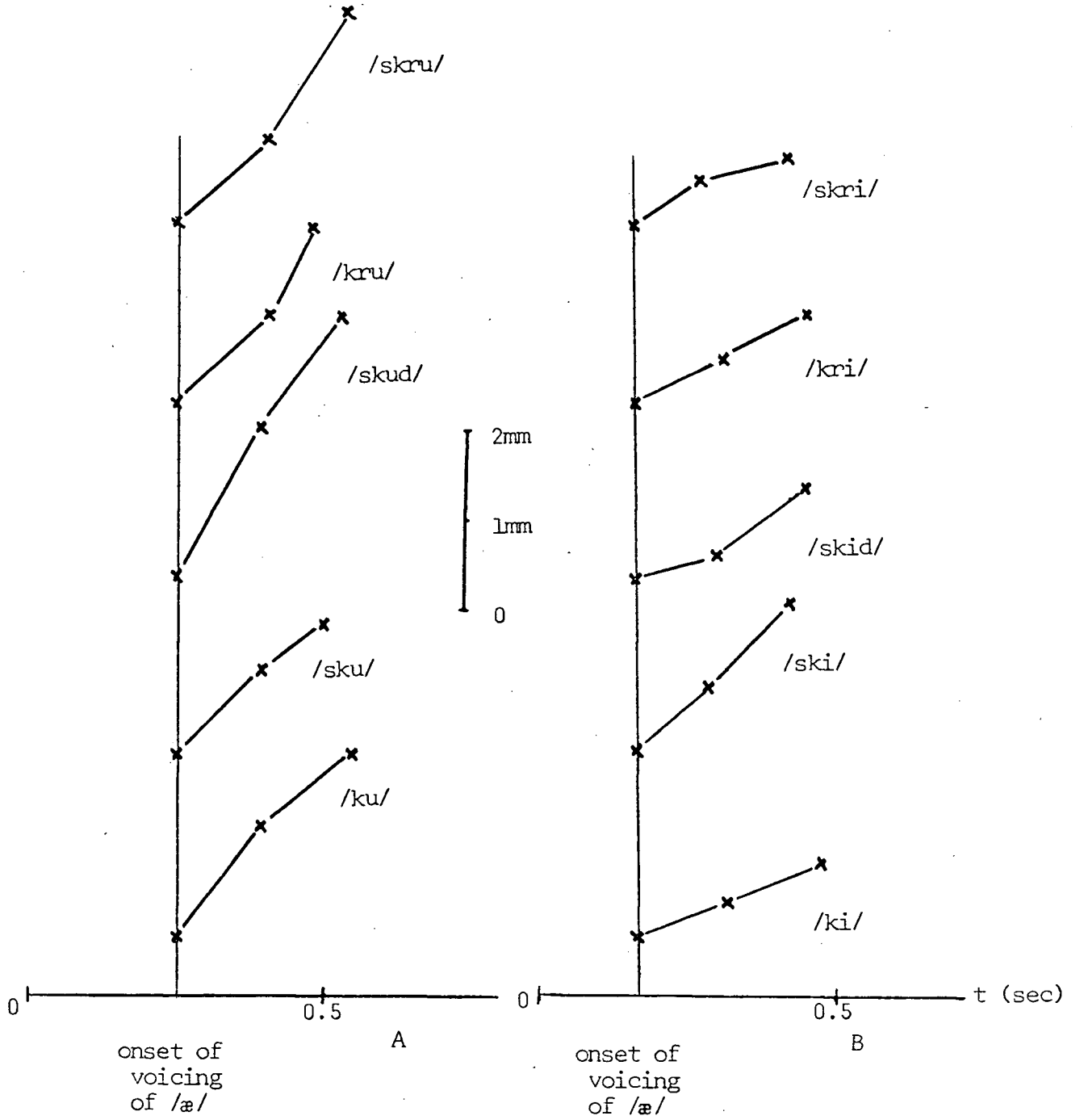

Figure 5.3. Protrusion measurements of the sequence /ænðʌ/ aligned with respect to the protrusion at the onset of voicing of /æ/.

A) items followed by rounded vowel /u/
B) items followed by spread vowel /i/

TABLE 5.1

SUMMARY OF MEANS AND STANDARD DEVIATIONS
CALCULATED ON SUBSETS OF THE FRAME
SEQUENCE "AND THE..." (/ ænðʌ /)

S		$p(t_1)$ (mm)	$p(t_3)$ (mm)	$p(t_3)-p(t_1)$ (mm)	Duration (sec)	Velocity (mm/sec)
A	M	53.22	56.66	3.38	0.27	12.85
	SD	1.34	1.21	1.29	0.02	5.13
B	M	53.47	56.68	3.21	0.27	11.92
	SD	1.27	1.22	1.26	0.03	4.70
C	M	53.14	56.90	3.80	0.27	14.26
	SD	1.52	1.26	1.37	0.02	5.38
D	M	53.32	56.29	2.82	0.27	11.06
	SD	1.12	1.09	0.95	0.03	4.33

S = subset of items considered

(A) all items considered (n = 32).

(B) items preceded by a rounded vowel syllable (n = 19).

(C) items followed by a rounded vowel syllable (n = 18).

(D) items followed by a spread vowel syllable (n = 14).

in protrusion, $(p(t_3) - p(t_1))$, provides more information about the gesture under consideration. In particular it appears from Table 5.1 that the average change in protrusion is 1 mm greater when "and the..." is followed by a rounded vowel sequence than when it is followed by a spread vowel sequence. The t-value ($t = 0.7385$, $df = 30$) calculated between the means indicates that this difference is not significant. Similarly the average velocity of the gesture appears to be greater for the subset followed by a rounded vowel sequence, as opposed to a spread vowel sequence. The t-value between the mean velocities ($t = 0.6292$, $df = 30$) is not significant.

In order to determine the relationship between velocity, duration and change in amount of protrusion, Pearson correlations were calculated between these measurements for each of the subsets. Results are presented in Table 5.2. No significant relationships were evident between change in amount of protrusion and duration, or between duration and velocity. In all four sets there is a high positive correlation between the change in amount of protrusion $(p(t_3) - p(t_1))$ and the velocity of the protrusion gesture. That is, velocity of lip protrusion (or movement towards an extreme position) is directly proportional to the difference in protrusion between the beginning and end of the utterance. A similar relationship was noted by MacNeilage (1972) in a discussion of jaw movement during the production of vowels. He reported that:

> ....maximum velocity of jaw opening and closing movements is directly proportional to the amount of jaw opening required for the vowel in the set (i), (ɛ), (æ). (p. 30).

TABLE 5.2

CORRELATIONS BETWEEN CHANGE IN PROTRUSION FROM t_1 TO t_3; DURATION OF UTTERANCE; AND VELOCITY OF PROTRUSION GESTURE, MEASURED ON REPETITIONS OF THE FRAME SEQUENCE "AND THE..." (/ ænðʌ /)

	S	Duration	Velocity
$p(t_3) - p(t_1)$	A	0.186	0.950***
	B	0.073	0.982***
	C	-0.095	0.982***
	D	-0.050	0.871***
Duration	A		-0.352
	B		-0.235
	C		-0.254
	D		-0.474

S = subset of items considered

(A) all items considered (n = 32).

(B) items preceded by a rounded vowel syllable (n = 19).

(C) items followed by a rounded vowel syllable (n = 18).

(D) items followed by a rounded vowel syllable (n = 14).

*** significant beyond the 0.001% level

There was some evidence that stress influenced the protrusion gesture. This particular hypothesis was tested when the concurrent study of French films revealed that stress affected the patterns under study in that language. When the onset and offset of /u/ was plotted with reference to the point of extremum protrusion,* it appeared that, if the syllable containing the rounded vowel was stressed, then extremum protrusion occurred before the onset of the vowel and was maintained to a point within the vowel. When, however, the rounded-vowel-syllable was unstressed, the extremum point was reached and the lips retracted before the vowel began. The vowel duration plots are given in Figure 5.4. It is evident that in all cases in which the sequence under consideration was said as a stressed word in the frame "and the...", the extremum was reached during /u/. In the case of /ʌnskru /, /nʌnskru /, and / hænskru /, when the stress occurred on the first syllable, the extremum occurred before /u/. The first repetition of the sequence /ʌnskru / had emphasis on the second syllable and the graph for this sequence lends support to the tentative hypothesis that stress influences the form and function of the vowel.

5.13 Film #3

The corpus of utterances for film #3 (See Appendix) was designed to further investigate the effect of stress observed in films #1 and #2. Several complications occur when attempts are made to study the effects of changes in stress on English words, particularly

---

* Hereafter extremum protrusion will mean maximum protrusion for rounded vowel sequences, minimum protrusion for unrounded vowel sequences.

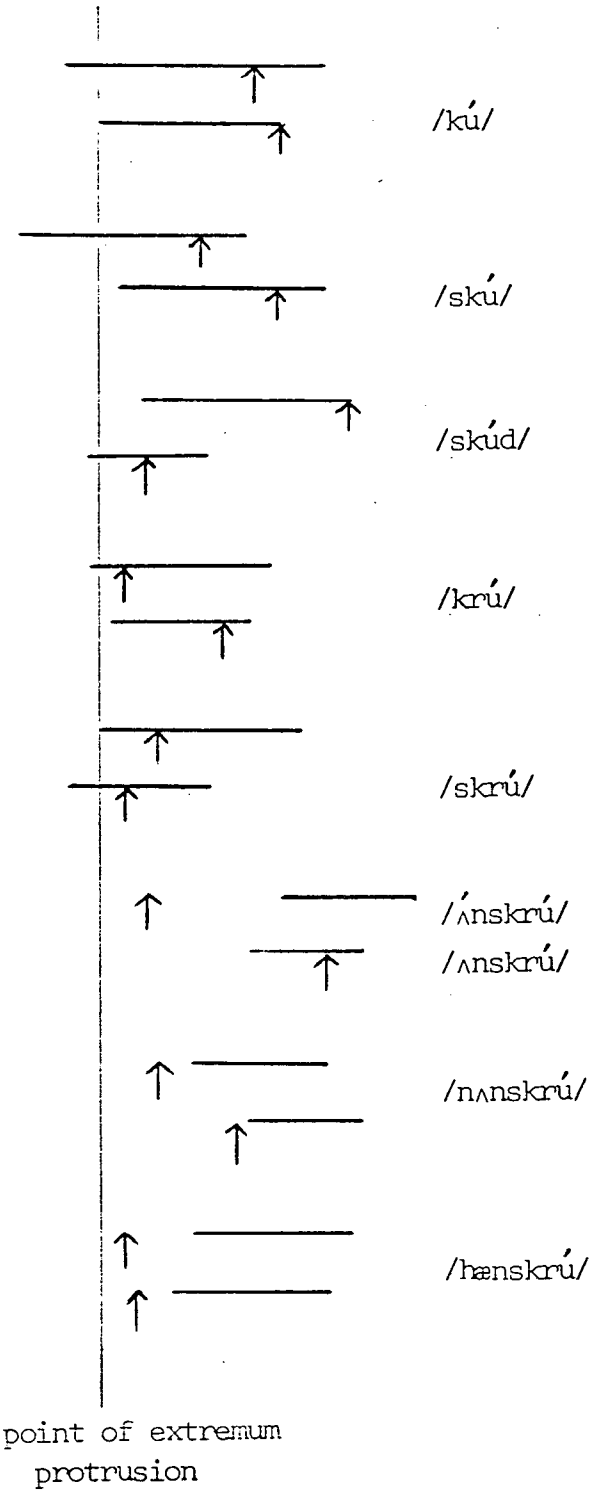

Figure 5.4. Vowel onset and offset plotted with reference to extremum protrusion. Arrows indicate points of retraction from extremum protrusion.

in syllables containing /u/. It is practically impossible to find minimal pairs of utterances differing only by stress (not to speak of the difficulty of finding consonant clusters which do not have an associated protrusion gesture which obscures the gesture under investigation). In addition, /u/ is nearly always stressed and when unstressed is reduced to /ʊ/. A similar reduction to /ɪ/ occurs with /i/, the vowel one would use to compare the difference in effect of stress between the maximally rounded vowel and the maximally spread vowel. In order to eliminate this problem, two types of stress patterns were chosen. The list given in the Appendix includes words in which stress on the vowel under consideration (/i/, /ɪ/, /u/, /ʊ/) shifts from secondary to primary (/mʌ́ltɪtud/ to /mʌltɪtúdɪnəs/). The sentences in the Appendix were designed to test for differences in vowel effect when emphatic stress is present.

In films #1 and #2 it appeared that extremum protrusion occurred within the vowel under consideration when the vowel was stressed, but when the vowel was in an unstressed position, as in / nʌ́nskru /, extremum protrusion occurred before the onset of the vowel. Results of film #3 conflicted with this observation (See Figures 5.5 and 5.6). In all cases extremum protrusion was retained to a point within the vowel. There was no evidence that when /u/ was minimally stressed, protrusion retracted from the target position before the onset of the vowel. An explanation for the results observed in the previous film may be that the consonant context of the stressed syllable had a greater influence than the stress pattern itself. It was first hypothesized that primary stress on an initial syllable produced the difference in the position of extremum protrusion with reference to vowel

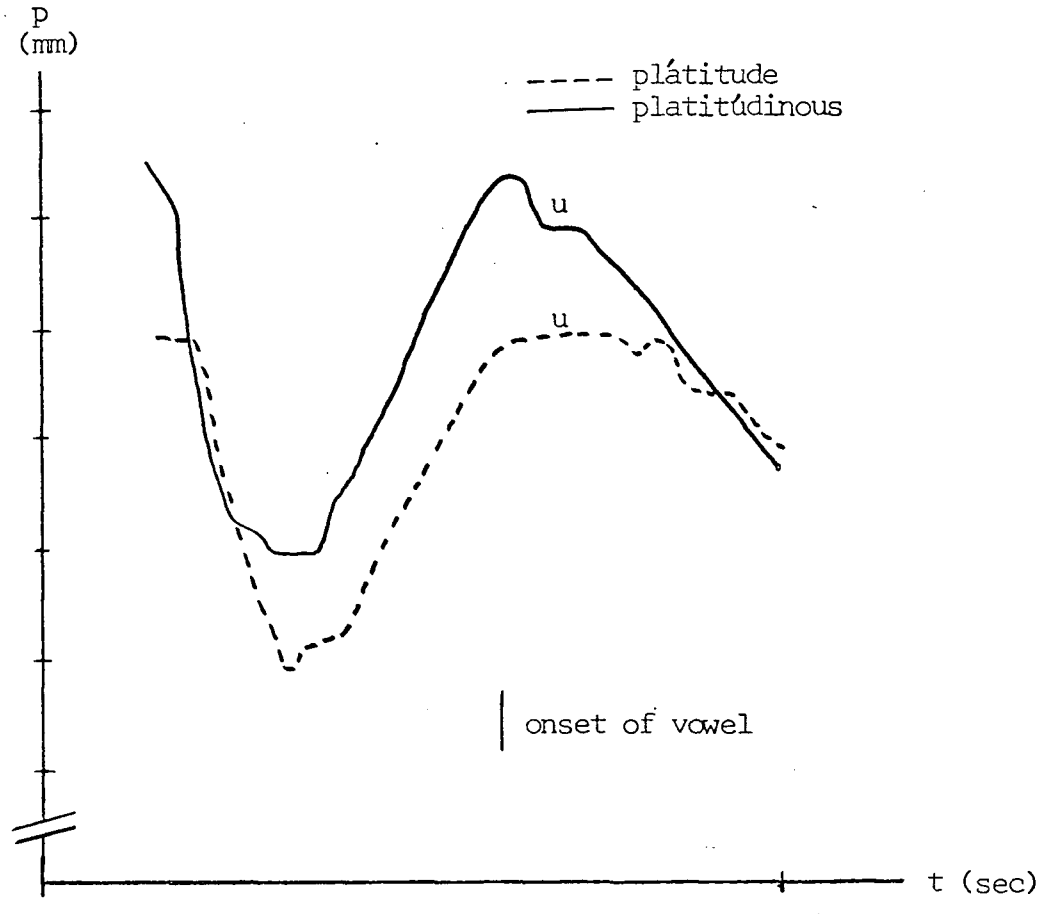

Figure 5.5. Lower lip protrusion (p) for sequences comparing primary and secondary stress. (English film #3)

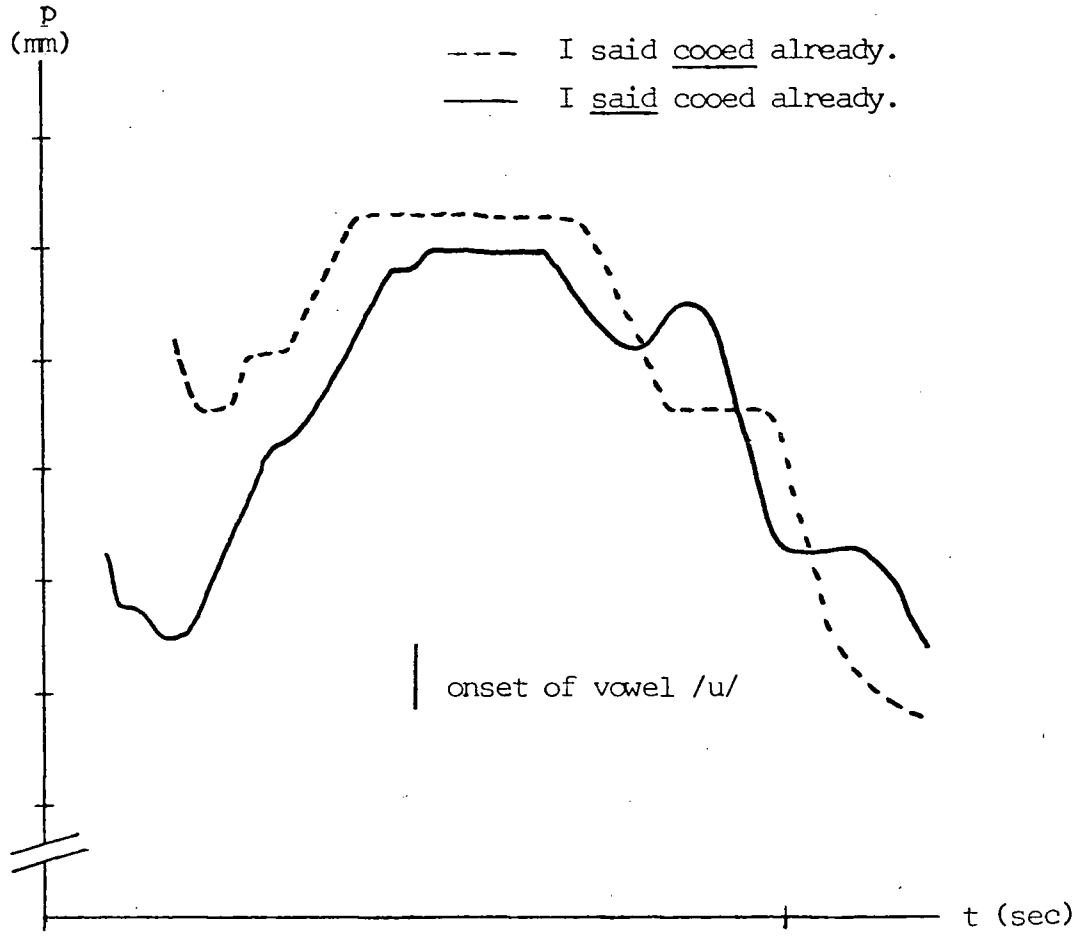

Figure 5.6. Protrusion measurements made on sentences comparing the effect of emphatic stress. (English film #3)

onset. This was not substantiated, however, when stress was purposefully investigated in film #3. The only other aspect which made the three utterances / ʌnskru/, / nʌnskru/ and / hænskru/ different from the comparable / ænčʌskru / sequence was the presence of the consonant /n/ preceding the /skr/ cluster. As mentioned above, Daniloff and Moll (1968) alluded to the possibility that lip protrusion associated with consonants /l/ and /r/ may be increased in rounded vowel contexts. Observations made in the present study indicate that /n/ interferes with the protrusion of /u/, and is additional evidence for rejecting the assumption that consonants do not affect the coarticulation of protrusion.

It was noted above that spread vowel sequences (/i/, /ɪ/) were included in the corpus. The interference of adjacent consonants with spread vowels make conclusive statements about the onset of protrusion impossible at this time. Thus comparisons with the rounded set of utterances could be made only in the emphatic-stress shift condition. In that case, for both rounded and spread vowels, emphatic stress conditions produced a more extreme protrusion by an average of 2 mm.

5.14 Conclusion

Few conclusions can be drawn from the English data collected in this study. It is apparent that more research needs to be conducted before coarticulation of lip rounding can be adequately discussed. Assumptions were made at the outset of the present research, some of which, based on previous research, proved untenable. As indicated above, the assumption (made here and in previous studies) that a point of onset of protrusion can be easily determined is now particularly

questionable. In addition, sufficient consideration has not been given to the nature of consonant grouping in English. Future research must deal with the latter problem before an answer to the question of timing of lower lip protrusion can be considered. In the coarticulation experiment reported by Daniloff and Moll (1968), the authors used English consonant clusters which a supplementary experiment showed, in their opinion, to have no direct influence on the onset of the protrusion gesture. Results of the present investigation did not substantiate their conclusion. Certain phones, including /r/, /s/ and /l/, did appear to influence the effect of the adjacent vowel, especially when the vowel was rounded. The two component parts of the rounding gesture, attributable to the vowel and consonant contexts, could not be separated. In English, it is impossible to find rounded vowel utterances containing clusters of two or more consonants which do not include at least one of the consonants which possess a protrusion gesture. It is therefore apparent that specific experiments will need to be performed in order to establish when, and to what degree lower lip protrusion is present when these sounds are produced. A systematic study of these consonants before, after and between both rounded and unrounded vowels may reveal information which can be applied to a study of a particular consonant's function within a consonant cluster in comparable rounded/unrounded contexts.

Future research should also include an investigation of larger sequences than the actual CC...V portions. Daniloff and Moll plotted measurements for only those frames which included the immediate consonants and vowels of interest to their study. A greater awareness of the consonantal influence might have been achieved if the analyses had

included more of the utterance. In the present study, when larger segments were examined, it was apparent that many factors, including stress, affected the timing and amount of lower lip protrusion. Although these judgments were not completely quantifiable, they were sufficiently so to reveal the complexity involved in solving the problem of determining specific boundaries for the hypothesized "articulatory syllable".

5.2 The French Films

Three films, one for each of three subjects, were made using French. As will be seen from the discussion, few consistent or predictable conclusions could be made from the data of film #1. In order to determine if the initial results were subject specific or whether they actually reflected coarticulation of lip rounding in French, two additional subjects were filmed. Intersubject variability was tested on French rather than English because it was easier to design a French corpus to test the hypothesis under investigation. That is, for French, a corpus can be constructed to compare rounded and unrounded sequences preceded by constant consonant contexts, whereas in English it is not possible to find rounded vowel utterances containing clusters of two or more consonants which do not include at least one of the consonants which possess a protrusion gesture.

The corpus of utterances for each of the three French films is given in the Appendix.

5.21 Steady State Vowels

Steady state vowels were filmed for each subject. Vowel separation for Speaker 3, on a graph showing area of lip opening versus lower lip protrusion, is illustrated in Figure 5.7. A similar pattern was obtained for the other two speakers. The Pearson r calculated for the vowels in Figure 5.7 was -0.8168. The average r for the three subjects was 0.8630. This value is higher than that calculated for the English vowels discussed in Section 5.11 ($\underline{r} = -0.6577$). The discrepancy between English and French r values may be due to a difference in sample size - 15 French vowels as compared to seven English vowels. When nasal vowels were excluded from the French sample, the correlation was -0.6156, -0.9322, and -0.5174, for Speakers 1, 2, and 3 respectively.

5.22 Film #1

The corpus of utterances used in film #1 (See Appendix) was constructed to: 1) compare the effect of vowels /i/, /u/, and /ɣ/ on the preceding constant consonant sequence /kstr/, and 2) determine if word boundary position within the above consonant cluster influences the onset of lower lip protrusion.

As in the case of the English data, no reliable method of determining a point of onset of lower lip protrusion due to the rounded vowel could be established for the data of film #1. In film #1 there was evidence that extremum protrusion occurred in the same place (within /s/) for all the consonant sequences examined, but there was no indication that a unit of coarticulation could be determined or, if so, then the word boundary did not appear to have a definite influence (See Figure 5.8). Many repetitions of the same sequence may provide more information about

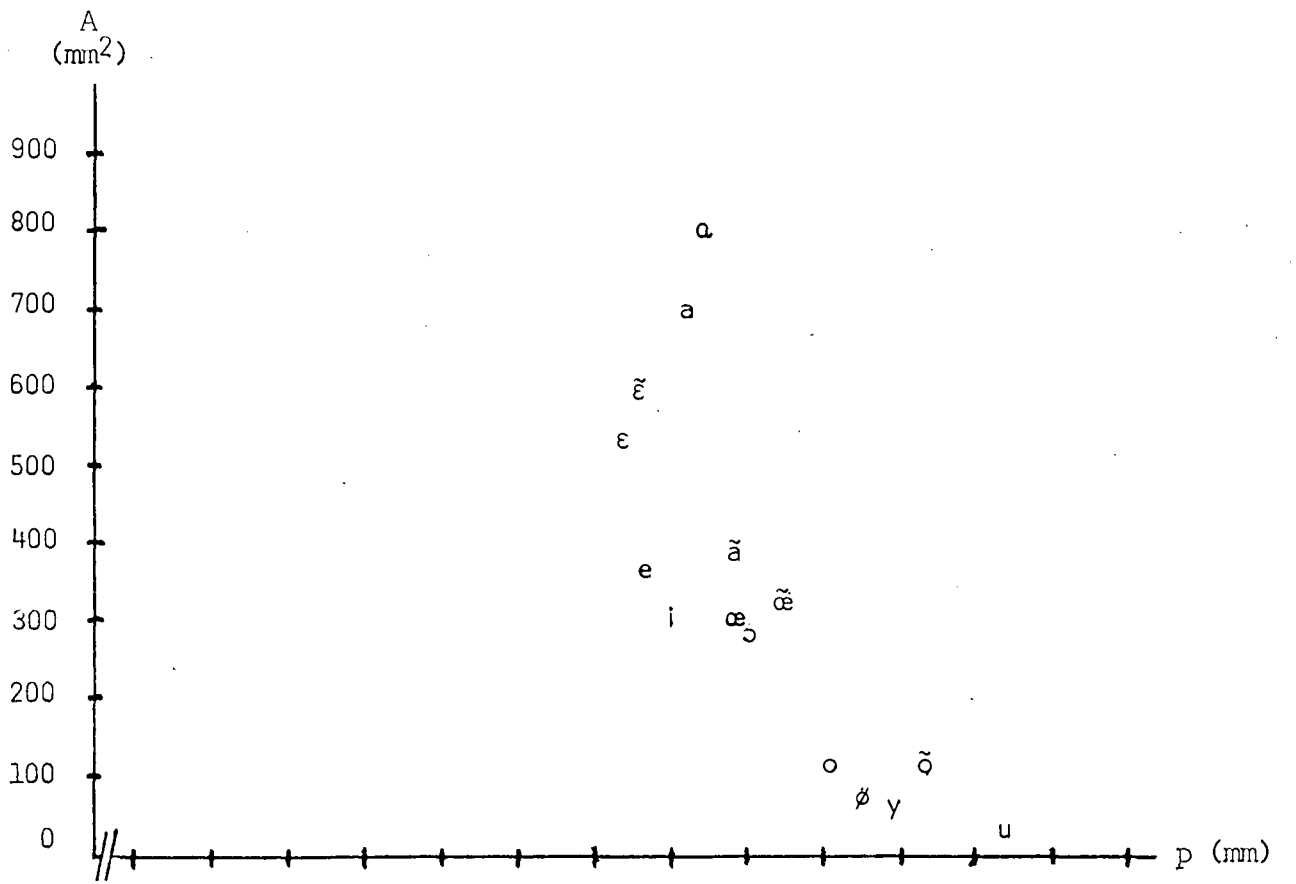

Figure 5.7. Area of lip opening (A) versus lower lip protrusion (p) for steady-state French vowels. (Speaker 3, r = -0.8167)

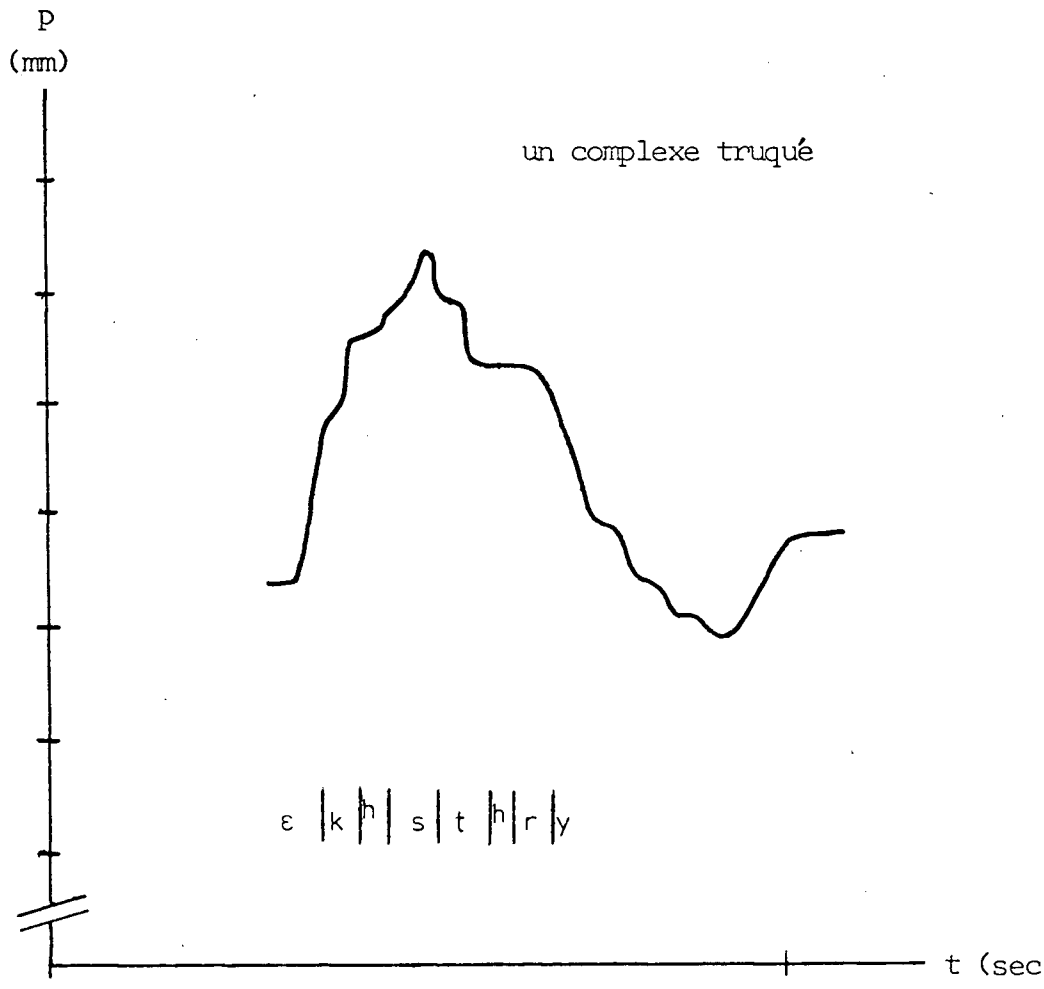

Figure 5.8. Lower lip protrusion (p) for the sequence "un complexe truqué" illustrating position of extremum protrusion found in most of the French sequences analyzed on film #1.

such a unit, but even that is considered unlikely since little variation was observed between the two repetitions of the sequences "une sinistr(e) structure" and "une sinistr(e) stricture". Since no information could be obtained from the data with reference to a unit of syllable size, a tentative hypothesis was made that a unit larger than the syllable may be in operation. When the corpus was analyzed from this point of view, it appeared that stress had an effect on the time of the extremum protrusion with respect to the vowel. Figure 5.9 illustrates the initial observation that the extremum position for each vowel (that is the maximum protrusion recorded for /y/, the minimum for /i/) does not occur during the vowel but immediately precedes or succeeds the vowel. In order to examine this observation more closely, three vowels for each utterance were plotted with reference to the time of extremum protrusion of each syllable as follows: (See Figure 5.10)

vowel 1 - vowel preceding /kstr/ sequence

vowel 2 - vowel following /kstr/ sequence

vowel 3 - final vowel of utterance.

In all sequences (except "une contexte russe") shown in Figure 5.10, vowel 1 is the last vowel in a rhythmic group which had rising intonation. Vowels 2 and 3 are the next to last and last vowels respectively in a rhythmic group which had falling intonation. From Figure 5.10 it appears that there is a trend for extremum protrusion to occur before the vowel when the vowel is unstressed (in all cases but one the syllable containing vowel 2). When the vowel is stressed (i.e., is the last vowel of the rhythmic group) the extremum point tends to occur within or after the vowel. A further indication of the possible

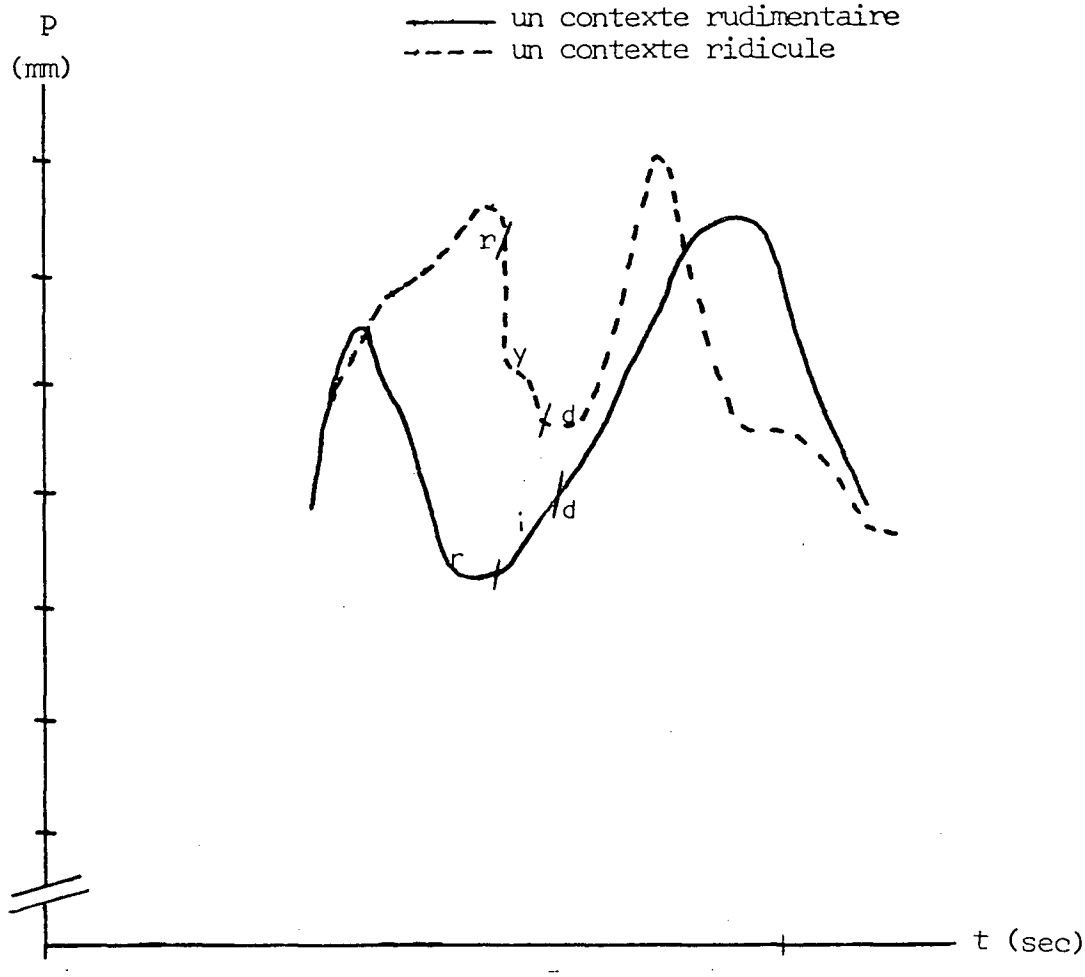

Figure 5.9. Lower lip protrusion (p) illustrating time of vowel with reference to the extremum of protrusion. (French film #1)

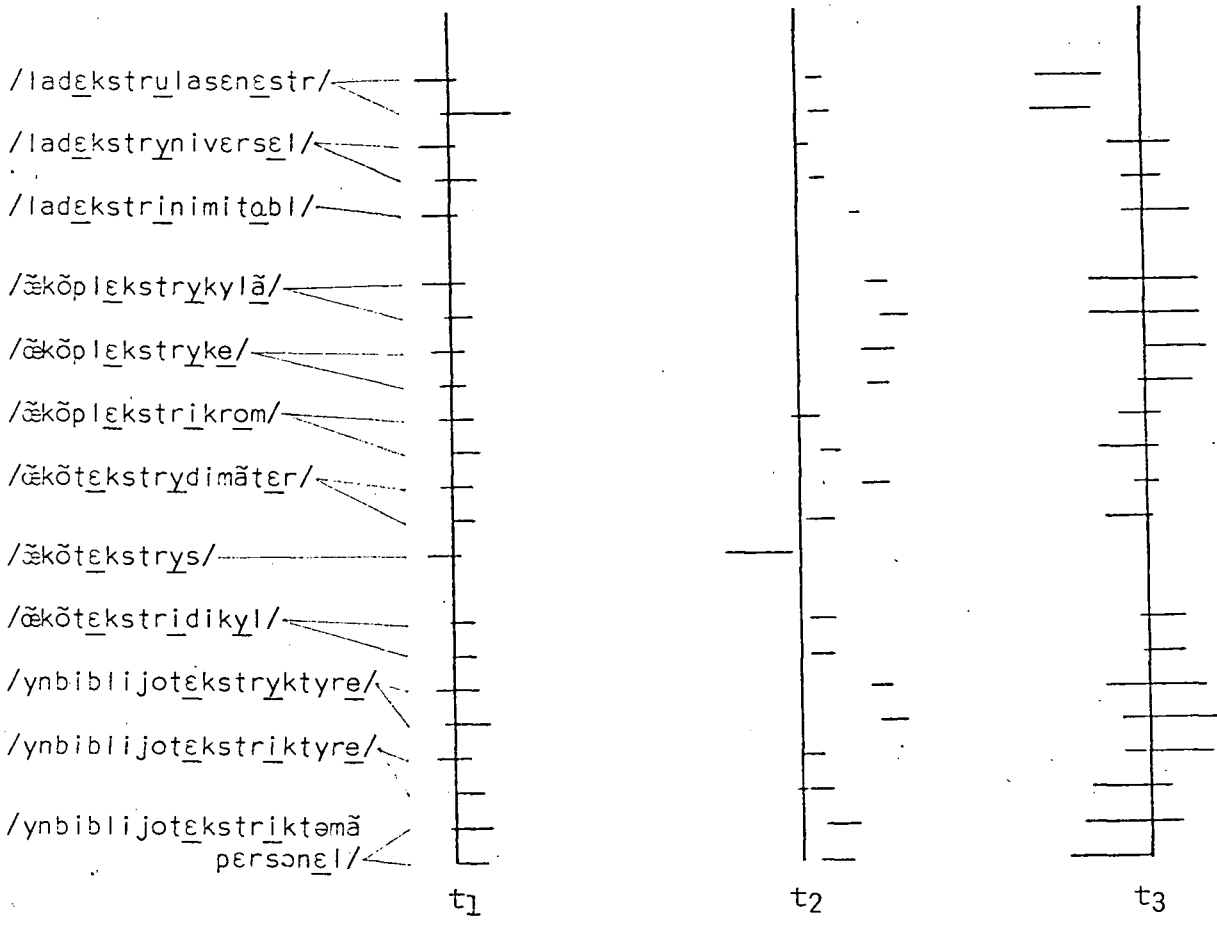

Figure 5.10. Onset and offset of vowels plotted with reference to the extremum of protrusion of each syllable. (French film #1)

t_1 = time of extremum of protrusion of the syllable containing the vowel preceding the /kstr/ sequence.

t_2 = time of extremum of protrusion of the syllable containing the vowel following the /kstr/ sequence.

t_3 = time of extremum of protrusion of the syllable containing the final vowel.

dependence between stress and protrusion is the position of extremum protrusion in the sequence "une contexte russe". Vowel 2 was stressed in this sequence and extremum protrusion occurred after the vowel. It also appears that there is a difference in timing of protrusion between final vowels of rhythmic groups with rising versus falling intonation. In particular, in sequences in which intonation is rising (vowel 1) extremum tends to occur relatively earlier than in sequences in which intonation is falling. An explanation for the difference in timing of protrusion may be the dependence between intonation and lengthening of the last vowel of a rhythmic group relative to the penultimate vowel (Benguerel, 1971). Benguerel found that (in French) with falling intonation the ratio between duration of the vowel in the last syllable and duration of the vowel in the penultimate syllable is most of the time greater than 1.5, especially in the case of closed syllables. In sequences with rising intonation, this ratio tends to be less than 1.5, especially in the case of open syllables. If timing of protrusion depends on vowel lengthening then it may be that extremum protrusion occurs later as vowel duration (due to lengthening) increases. Although there was evidence that intonation and stress affect the timing of protrusion in the way described above, conclusive statements cannot be made from the data of film #1 since these parameters were not controlled in the corpus. In order to test the hypothesis further, a second, more specific corpus was made for film #2.

5.23 Film #2

The corpus of film #2 was constructed in order to: 1) observe intersubject variability on repetitions of utterances from film #1, and

2) test the hypothesis derived from film #1 that intonation and stress affect timing of lip rounding in some way. Two sets of utterances (See Appendix) were included in the corpus of film #2 to study the latter hypothesis. One set of utterances contained rounded and spread sequences in which emphatic stress was gradually increased. Repetition 1 was said with no emphatic stress. Repetition 2 was said with moderate emphatic stress and repetition 3 was said with strong emphatic stress. The second set of utterances contained pairs of utterances in which one had rising intonation, the other falling intonation, over the sequence of interest. In order to apply the results of Benguerel's study (1971) concerning lengthening of final vowels with respect to penultimate vowels, sequences were constructed in which the two vowels were the same. In addition, in order to minimize the influence of consonants on vowel lengthening in the case of closed syllables, the consonants following these two vowels were identical.

Lower lip protrusion and area of lip opening were plotted for sequences "une sinistr(e) structure" and "une sinistr(e) stricture" and compared with similar plots for Speaker 1. There was greater agreement between the two subjects on the area graphs than on those of protrusion. It appeared that, on the protrusion graphs the difference in amount of protrusion between the rounded vowel / y / and the spread vowel /i/ was larger for Speaker 2 than for Speaker 1. In addition, although vowels are separable on the basis of protrusion when they are said in isolation (See Figure 5.7), there is only a small difference in both area and protrusion between the vowels when they occur in the running speech of Speaker 1. Because the distinction made between rounded and spread vowels in running speech is so small for Speaker 1, interpretation of

protrusion graphs on utterances made by this speaker is more difficult than that of comparable graphs of utterances said by Speaker 2.

Results of the set of sequences in which pairs of utterances differed with respect to rising versus falling intonation were difficult to interpret because there was considerable consonantal influence on the protrusion gesture. Since, in addition, there was only a limited amount of data, the plot comparable to that shown in Figure 5.10 for film #1 was not revealing and was therefore not presented. From the data that was available, it appeared that extremum protrusion occurred within or before the vowel for both vowels of the rhythmic group (See Figure 5.11). There was no evidence to suggest that there is a difference in timing of extremum protrusion between sequences with rising versus falling intonation.

An example of the pattern of protrusion observed for utterances said with increasing emphatic stress is shown in Figure 5.12. There is no indication that the point of extremum protrusion shifted in relation to the onset of the vowel as a result of increased stress. As seen in Figure 5.12, the effect of increased stress is an increase in amount of protrusion rather than a change in the time of occurrence of the extremum point of protrusion.

5.24 Film #3

Intersubject variability and the effect of intonation and stress on timing of lip rounding were investigated in film #3. The corpus of utterances included sequences with rising and falling intonation, and sequences with variation in degree of emphatic stress. The emphatic stress sequences were identical to those used in film #2. In the rising

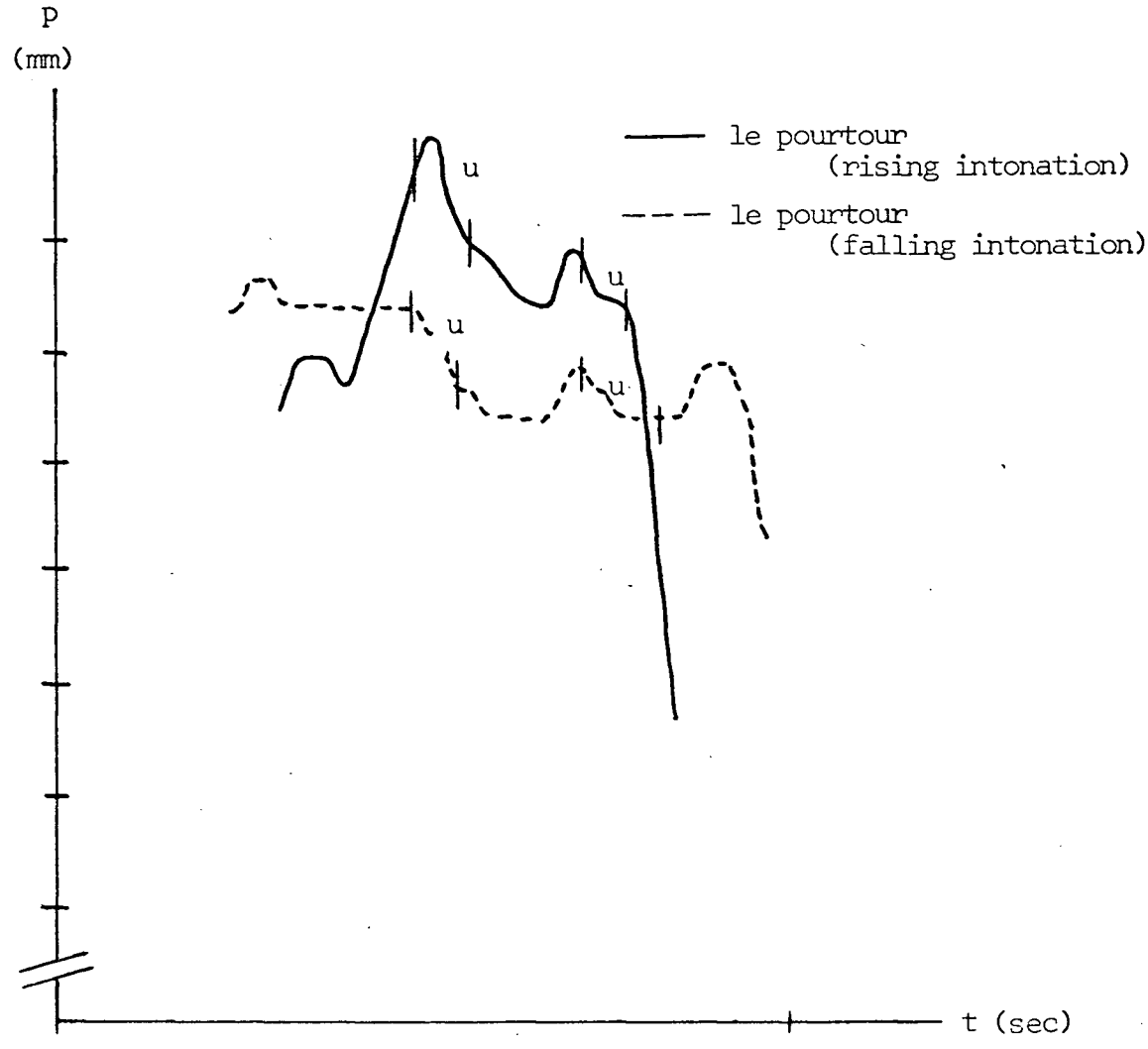

Figure 5.11. Comparison of lower lip protrusion (p) for two similar sequences, one with rising intonation, the other with falling intonation. (French film #2)

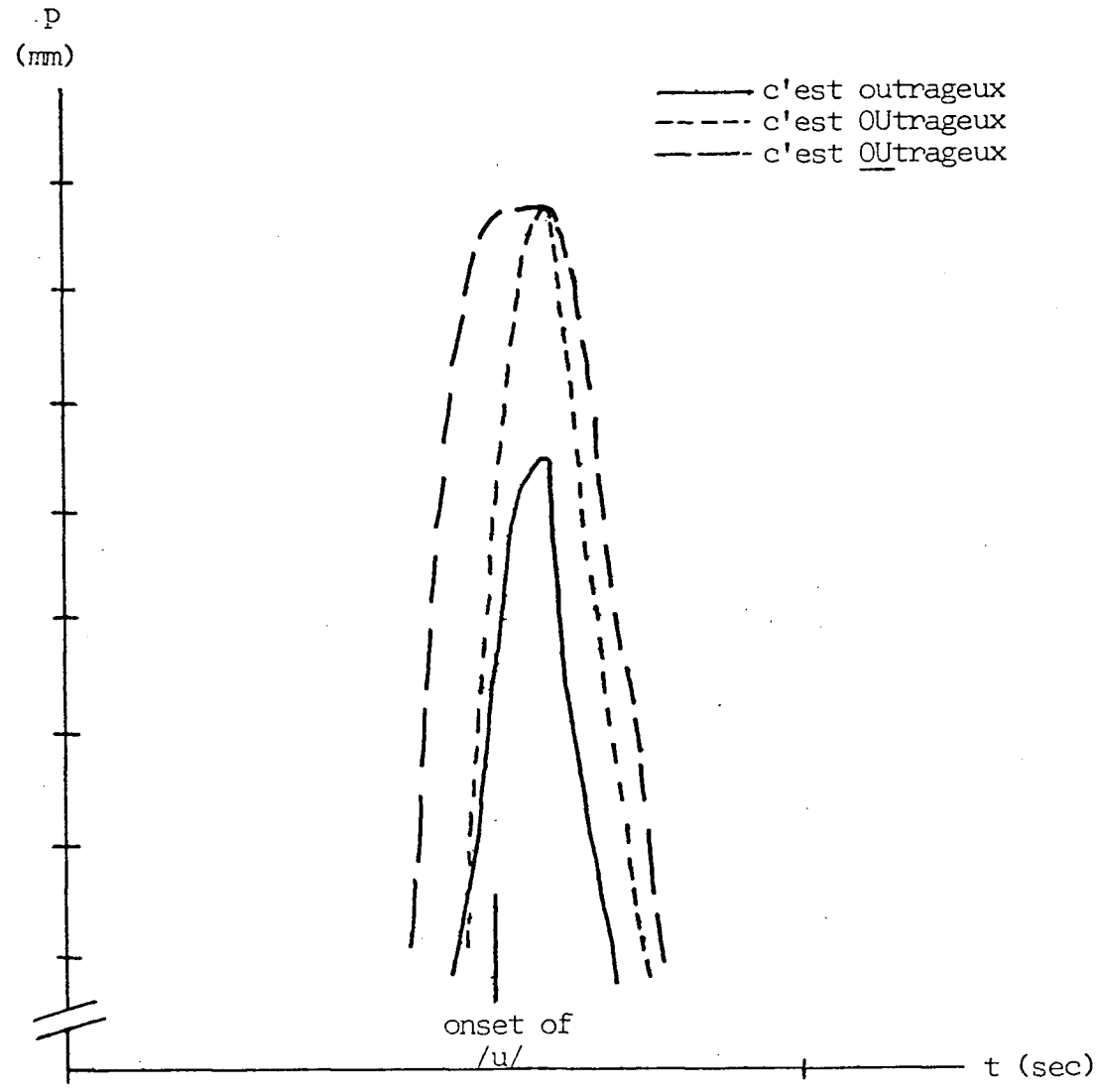

Figure 5.12. Comparison of lower lip protrusion (p) for French sequences said with increasing emphatic stress. (French film #2)

versus falling intonation sequences, the same vowel and final consonants were again used in both syllables of the rhythmic group of interest. In film #3, however, care was taken to minimize the consonantal influence observed in film #2, by avoiding the use of consonants which appear to have an associated protrusion gesture, particularly bilabial consonants. Also included in the corpus were the utterances "une sinistr(e) structure" and "une sinistr(e) stricture" which were used on the previous two films.

The graphs of lower lip protrusion for sequences "une sinistr(e) stricture" and "une sinistr(e) structure" showed greater agreement between the two sequences when said by Speaker 3 than when said by either of the two other French speaking subjects. In particular it can be seen from Figure 5.13 that initially there is a high correspondence between the two graphs. The similarity extends to a point within the consonant cluster /kstr/ where it appears that the vowel influence takes effect. From these graphs it may be possible to conclude that, for French, rounding does not start at the first consonant of the cluster preceding the vowel but at some point within the cluster. This conclusion differs from that made by Kozhevnikov, et al., (1965) and Daniloff and Moll (1968) who found that for Russian and English respectively, the coarticulatory unit includes the whole CC...V complex. The possible difference in timing of protrusion observed for English and Russian on the one hand, and French on the other, suggests that coarticulation of lip rounding may be phonemic rather than phonetic. The observation on French, however, was evident for only one pair of sequences for one speaker in this study and requires further evidence before any strong claim can be made.

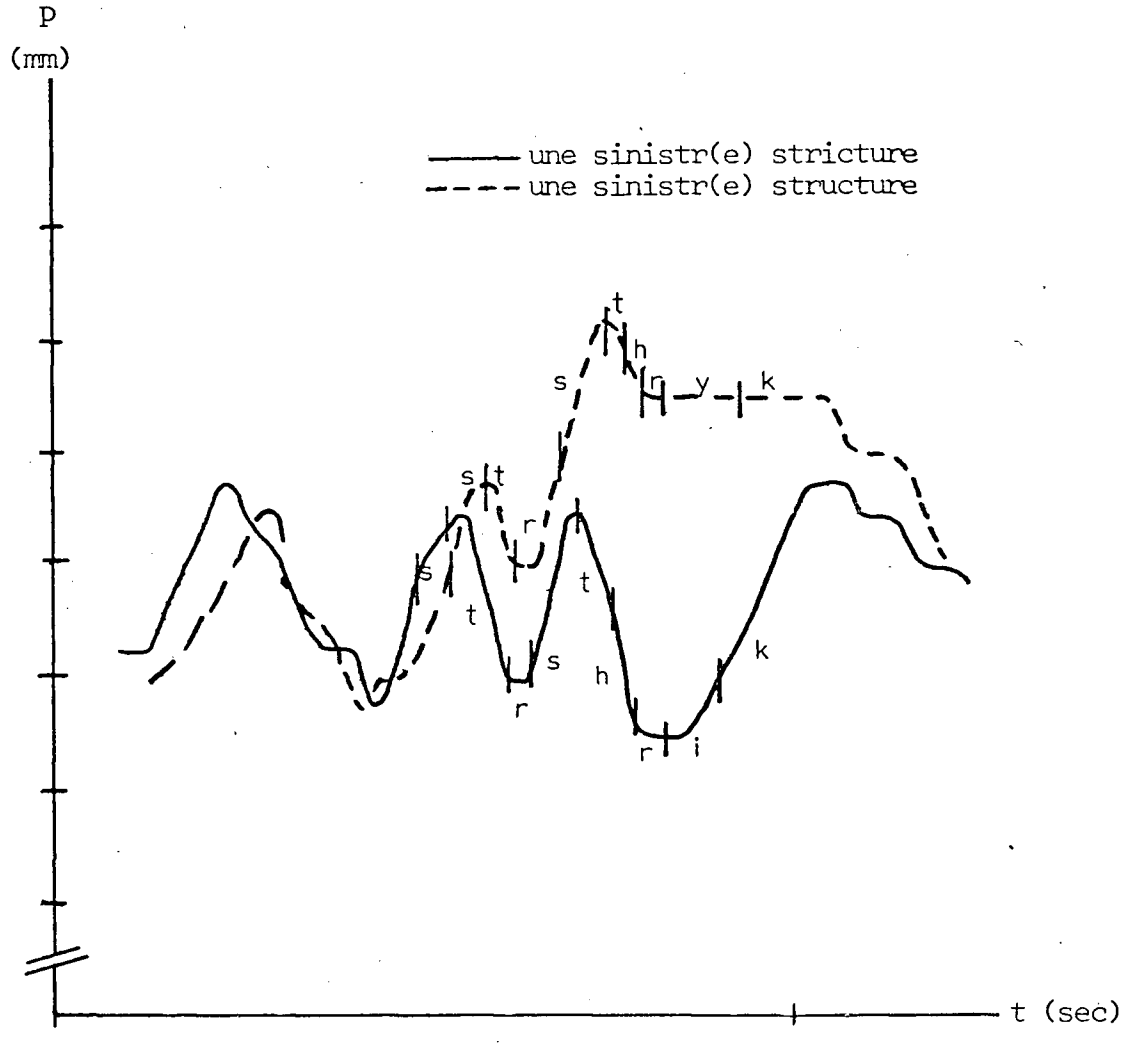

Figure 5.13. Comparison of lower lip protrusion (p) for the two sequences "une sinistr(e) structure" and "une sinistr(e) stricture". (French film #3)

No consistent patterns were evident on the protrusion graphs of sequences in which intonation was varied. It appeared that extremum protrusion occurred within (rather than before or after) one of the vowels of the rhythmic group (See Figure 5.14) but extremum protrusion did not occur with any regularity on one vowel rather than the other. In addition, in most cases two extrema (one for each of the vowels in the rhythmic group) could not be determined. There appeared to be, instead, a single protrusion gesture for those sequences in which the intervening consonant presented no articulatory opposition to the gesture. The original hypothesis therefore could not be tested from the corpus of film #3 and the data could not be compared to that displayed in Figure 5.10.

In order to examine the relationship, if any, between timing of protrusion and one or all of fundamental frequency, intensity and vowel duration, each parameter was measured for both vowels in the rhythmic group of interest. The utterances were divided into two samples--one compared sequences with rising versus falling intonation, the other compared sequences with rounded versus unrounded vowels. For each of the sequences, each of the parameters were paired separately with extremum protrusion to see if extremum protrusion consistently occurred with the extremum of any one of the other parameters. There was no evidence to support such an hypothesis.

Film #3 utterances which were said with increasing emphatic stress had the same point of extremum protrusion (relative to the onset of the vowel) as seen in film #2 (i.e., extremum occurred within the vowel). In order to study the relationship, if any, between stress, vowel duration and amount and timing of protrusion, the following

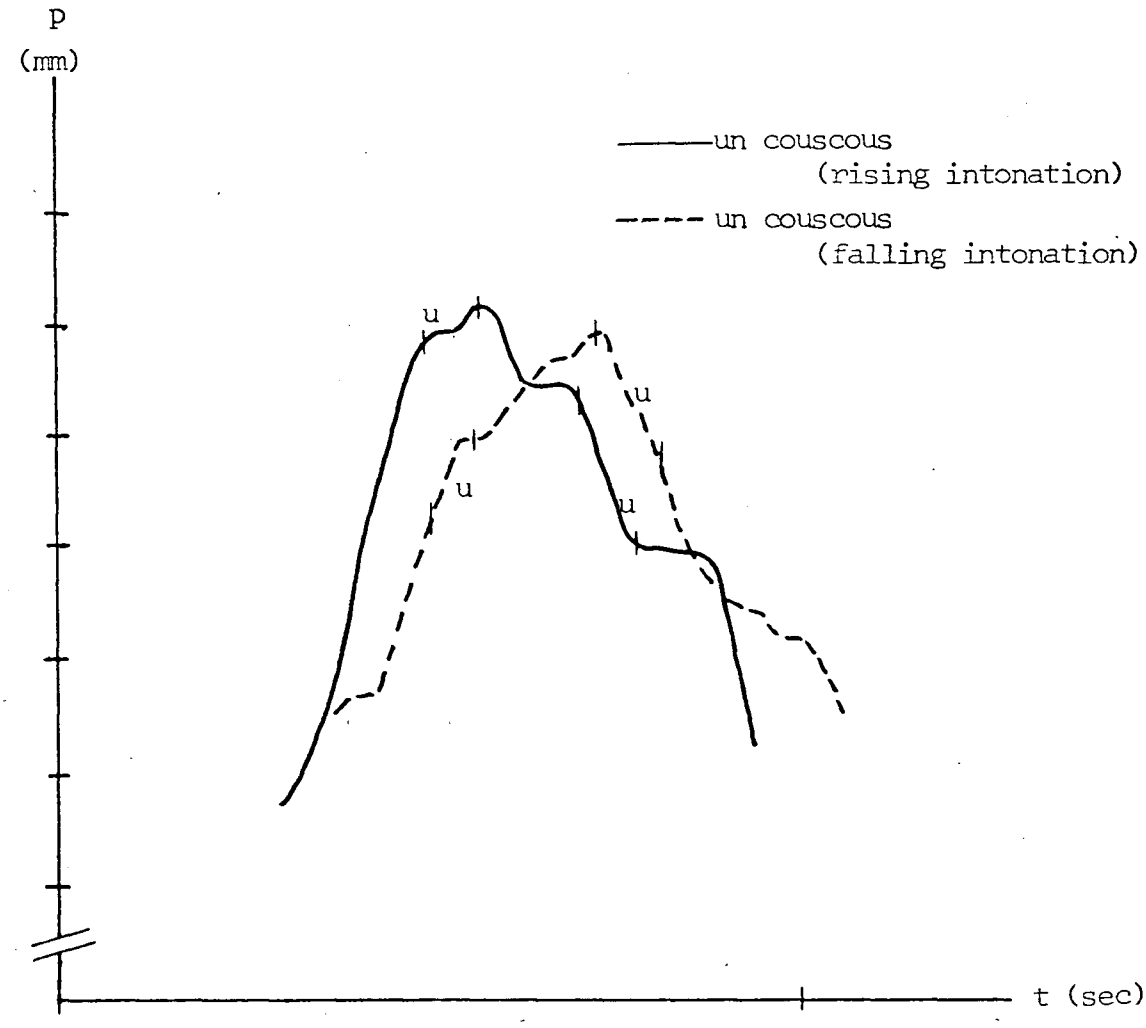

Figure 5.14. Comparison of lower lip protrusion (p) for two similar sequences, one with rising intonation, the other with falling intonation. (French film #3)

parameter values were compared in miscellaneous pairings:

(1) duration of stressed vowel

(2) duration of final vowel

(3) ratio between (1) and (2)

(4) change in protrusion between minimum and maximum points of the gesture ($\Delta p = P_{max} - P_{min}$)

(5) duration of protrusion gesture

  (a) from minimum point of protrusion to maximum point of protrusion

  (b) from minimum point of protrusion to the first minimum point (on the graph) after the maximum point

(6) average velocity between minimum and maximum points of protrusion gesture.

It appears that, for rounded vowel sequences, an increase in stress produces an increase in amount of protrusion. The difference in protrusion (Δp) between minimum and maximum for the moderately stressed case (repetition 2) is on the average 1.5 mm greater than the unstressed case (repetition 1). The strongly stressed case (repetition 3) is on the average 2.5 mm greater than the previous sequence (repetition 2). As expected there is an increase in the duration of the vowel when it is emphatically stressed. The ratio between the duration of the emphatically stressed vowel and the duration of the final vowel is also increased. Similarly the duration of the protrusion gesture is greater for the two emphatically stressed cases (repetitions 2 and 3) compared to the non emphatically stressed case (repetition 1). There was no evidence that velocity increased with increased emphatic stress.

5.25 Conclusions

With one exception, a point of onset of lower lip protrusion for French sequences could not be determined from the procedures used in this experiment. The one exception was observed for the sequences "une sinistr(e) structure" and "une sinistr(e) stricture" spoken by Speaker 3. In this case it appeared that the onset of protrusion occurred at a point within the preceding consonant cluster rather than at the beginning of the cluster as hypothesized by Kozhevnikov, Chistovich, et al., (1965) and Daniloff and Moll (1968).

Since the method used was not found to be a reliable means of investigating the original hypothesis (i.e., that "coarticulatory syllable" exists and can be delimited) the data was interpreted according to the possible influence of intonation and stress on the timing of extremum protrusion. Results, however, were inconclusive. It is apparent from the present investigation that, in order to study the relationship between protrusion and intonation and stress more effectively, the experimental corpus should be constructed with greater emphasis on minimizing variations in context. Although all films were analyzed with respect to the influence of intonation and stress, for example, these factors were controlled in films #2 and #3, but were uncontrolled in film #1. In film #1, however, sequences were included which had a constant consonant cluster. In all films the uncontrolled parameter affected the interpretation of the data. A test which was beyond the time limitations of the present study but which may provide relevant information about the hypothesis studied would be to compare repetitions of the corpus used on film #1 said with rising and falling

intonation. As was recommended above for English, a systematic study of consonants before, after and between rounded and unrounded vowels would provide certain basic information necessary for future research on coarticulation of lip rounding in French.

CHAPTER 6

SUMMARY

The study of lip rounding presented in this paper is an analysis of six high-speed (66 frames/sec) cinephotographic films: three of spoken English and three of spoken French. One English speaker and three French speakers were used for this investigation. It was found that, with some limitations, lower lip protrusion provided an adequate measurement of lip "rounding" and was therefore used synonomously with it throughout the description of the experiment. Frame-by-frame measurements of protrusion were made directly from the projected image for the sequences of interest.

A corpus of utterances was constructed for each film separately using results and hypotheses derived from previous film(s). The original English corpus (films #1 and #2) sought to compare the influence of rounded versus unrounded vowels on a progressively longer preceding consonant cluster. In addition, the effect of syllable and word boundaries on coarticulation patterns was studied. No reliable method of determining the onset of rounding could be established using the technique described above. There was some evidence that stress influenced the timing of extremum protrusion. This hypothesis was tested in film #3 as well as in the French films. The corpus for film #3 included: 1) pairs of words in which stress on the first vowel of interest shifted from secondary to primary stress, and vice versa on the second vowel of interest, and 2) sentences in which position of emphatic stress varied.

Results indicated that there was no significant difference in the timing of extremum protrusion with reference to vowel onset when stress changed--in all cases extremum occurred at a point within the vowel. It was suggested that the position changes observed in films #1 and #2 were a result of the consonantal context rather than of the degree of stress on the vowel.

The first French corpus included utterances to compare the influence of rounded versus unrounded vowels on a preceding constant four-consonant cluster. Word boundary position was also varied within the consonant cluster. It was apparent that timing of protrusion could not be established by means of the methods used in this experiment. There was an indication that position of extremum protrusion (with reference to vowel onset) varied with the position of the vowel within the rhythmic group--i.e., extremum occurred earlier (in general before vowel onset) when the vowel did not carry any unemphatic stress ("accent tonique"). In order to test this possibility two sets of sequences (one containing pairs of utterances with rising versus falling intonation, the other containing utterances said with increasing emphatic stress) were included in the corpus of films #2 and #3. Two different speakers were used. Analyses of these films revealed there was no obvious difference in timing of extremum protrusion for any of the stressed conditions.

Included on all the French films were the sequences "une sinistr(e) structure" and "une sinistr(e) stricture." For Speaker 3 it appeared that the onset of rounding could be established at a point within the preceding consonant cluster, an observation which conflicted with the conclusions made by other researchers (Kozhevnikov, Chistovich, et al., (1965) and Daniloff and Moll (1968) for languages

other than French. Since the observation was made only once in the present study it requires further investigation. Research on these two sequences as well as other pairs differing in only one parameter, namely, the vowel, appears to be the most useful direction for future studies.

It was concluded that for both English and French the basic assumptions of the experiment (which were based on conclusions made by Daniloff and Moll (1968)) were untenable. In particular, it is questionable that a point of onset of rounding within or at the onset of a consonant cluster can be specified without first systematically determining the amount of protrusion which is associated with each consonant in isolation and then in various vowel contexts. It was apparent from the data that coarticulation of rounding is likely influenced by other parameters including intonation, stress and phonetic (in particular consonantal) context, and future research should attempt to control as many of these parameters as possible before significant patterns (if they exist) can be observed.

BIBLIOGRAPHY

ALLEN, G. D. (1970). "Two Behavioral Experiments on the Location of the Syllable Beat in Conversational American English," Unpublished Doctoral Thesis, Univ. of Michigan.

AMERMAN, J. D., DANILOFF, R., and MOLL, K. L. (1970). "Lip and Jaw Coarticulation for the Phoneme / æ /," J. Speech Hearing Res., 13, 147-161.

BENGUEREL, A-P. (1971). "Duration of French Vowels in Unemphatic Stress," Language and Speech 14, 383-391.

BOLINGER, D. (1968). Aspects of Language (Harcourt, Brace and World Inc., New York).

CARNEY, P. J., and MOLL, K. L. (1972). "A Cinefluorographic Investigation of Fricative Consonant Vowel Coarticulation." Phonetica 23, 193-202.

CHAFE, W. L. (1970). Meaning and the Structure of Language (Univ. of Chicago Press, Chicago).

CHOMSKY, A. N. (1965). Aspects of the Theory of Syntax (MIT Press, Cambridge).

CRYSTAL, D. (1969). Prosodic Systems and Intonation in English (University Press, Cambridge).

DANILOFF, R. and MOLL, K. L. (1968). "Coarticulation of Lip Rounding," J. Speech Hearing Res., 13, 707-721.

DELATTRE, P. C., LIBERMAN, A. M., and COOPER, F. S. (1967). "Acoustic Loci and Transitional Cues for Consonants," in Readings in Acoustic Phonetics Ilse Lehiste, Ed. (MIT Press, Cambridge). pp. 283-287.

EGGERMONT, J. (1970). "Relations Between Vowel Confusions in Lip Reading and the Dimensions of the Mouth Aperture," Institute for Perception Research Ann. Rep. 5, 44-50.

FROMKIN, V. A. (1964). "Lip Positions in American English Vowels," Language and Speech 7, 215-225.

FROMKIN, V. A. (1965). Some Phonetic Specifications of Linguistic Units: An Electromyographic Investigation. U.C.L.A. Working Papers in Phonetics, No. 3.

FROMKIN, V. A. (1971). "The Non-Anomalous Nature of Anomalous Utterances," Language 47, 27-52.

FRY, D. B. (1964). "The Function of the Syllable," Sprachwissenschaft und Kommunikationsforschung Zeitschrift für Phonetik 17, 215-221.

FUJIMURA, O. (1961). "Bilabial Stop and Nasal Consonants: A Motion Picture Study and its Acoustical Implications," J. Speech Hearing Res., 4, 233-247.

FUJIMURA, O. (1972). "Speech Acoustics," to appear in Speech and Cortical Functioning J. Gilbert, Ed. (Academic Press, New York).

GREENBERG, J. H. (1966). Universals of Language (MIT Press, Cambridge).

HARRIS, K. S., SCHVEY, M. M., and LYSAUGHT, G. F. (1962). "Component Gestures in the Production of Oral and Nasal Labial Stops," J. Acoust. Soc. Am. 34, 743.

HOUDE, R. A. (1968). "A Study of Tongue Body Motion During Selected Speech Sounds," Spch. Comm. Res. Laboratory Monograph No. 2.

KLAUSENBURGER, J. (1970). French Prosodics and Phonotactics (Max Niemeyer Verlag Tübingen, Germany).

KOZHEVNIKOV, V. A., CHISTOVICH, L. A., et al. (1965). Speech Articulation and Perception (translated from Russian), Joint Publication Research Service, U.S. Dept. Commerce No. 30 (Washington).

LADEFOGED, P., DRAPER, M. H., and WHITTERIDGE, D. (1958). "Syllables and Stress," Miscellanea Phonetica 3, 1-14.

LADEFOGED, P. (1967). Linguistic Phonetics. U.C.L.A. Working Papers in Phonetics, No. 6.

LEHISTE, I. (1971). "Temporal Organization of Spoken Language" in Form and Substance - Phonetic and Linguistic Papers Presented to Eli Fischer-Jørgensen. L. L. Hammerich, R. Jakobson, and E. Zwirner, Eds. (Akademisk Forlag, Odense). pp. 159-170.

LEHISTE, I. and SHOCKEY, K. (1972). "On the Perception of Coarticulation Effects in English VCV Syllables," J. Acoust. Soc. Am. 51, 101.

LINDBLOM, B. (1965 a). "Analysis of Labial Movement," Spch. Trans. Lab. Quart. Prog. and Status Rep. 2, 20-23.

LINDBLOM, B. (1965 b). "Jaw Dependence of Labial Parameters and a Measure of Labialization," Spch. Trans. Lab. Quart. Prog. and Status Rep. 3, 12-15.

LINDBLOM, B. (1965 c). "Studies of Labial Articulation," Spch. Trans. Lab. Quart. Prog. and Status Rep. 4, 7-9.

LUDVIGSEN, C. (1969). "An Attempt to Register Lip Pressure and Lip Rounding by Means of The Electro-glottograph," An. Rep. of Inst. of Phonetics of Univ. of Copenhagen 4, 1-7.

MacNEILAGE, P. F. (1963). "Electromyographic and Acoustic Study of The Production of Certain Final Clusters," J. Acoust. Soc. Am. 35, 461-463.

MacNEILAGE, P. F. and DeCLERK, J. L. (1969). "On the Motor Control of Coarticulation in CVC Monosyllables," J. Acoust. Soc. Am. 45, 1217-1233.

MacNEILAGE, P. F., KRONES, R., and HANSON, R. (1969). "Closed Loop Control of the Initiator of Jaw Movement for Speech," Mimeographed Manuscript.

MacNEILAGE, P. F. (1970). "Motor Control of Serial Ordering of Speech," Psych. Review 77, 182-196.

MacNEILAGE, P. F. (1972). "Speech Physiology," to appear in Speech and Cortical Functioning J. Gilbert, Ed. (Academic Press, New York).

MALMBERG, B. (1967). "The Phonetic Basis for Syllable Division," in Readings in Acoustic Phonetics Ilse Lehiste, Ed. (MIT Press, Cambridge), pp. 293-300.

MALMBERG, B. (1963). Phonetics (Dover Publications, New York).

MALMBERG, B. (Ed.) (1968). Manual of Phonetics (North Holland Publishing Co., Amsterdam).

MANSEL, P. and ALLEN, R. (1970). "A First Report on the Development of a Capacitance Transducer for the Measurement of Lip Excursion," Univ. of Essex Language. Centre Occasional Papers No. 9, 88-115.

MORIN, Y. (1971). Computer Experiments in Generative Phonology--Low Level French Phonology, Natural Language Studies No. 11. (Univ. of Michigan Phonetics Laboratory Publication, Ann Arbor).

NOOTEBOOM, S. G. (1970). "The Target Theory of Speech Production," Institute for Perception Research Ann. Rep. No. 5, 51-55.

NOOTEBOOM, S. G. and SLIS, I. (1970). "A Note on the Degree of Opening and the Duration of Vowels in Normal and 'Pipe' Speech," Institute for Perception Research Ann. Rep. No. 5, 55-58.

ÖHMAN, S.E.G. (1966). "Coarticulation in VCV Utterances: Spectrographic Measurements," J. Acoust. Soc. Am. 39, 151-168.

ÖHMAN, S.E.G. (1967). "Numerical Model of Coarticulation," J. Acoust. Soc. Am. 41, 310-320.

PERKELL, J. S. (1969). Physiology of Speech Production: Results and Implications of a Quantitative Cineradiographic Study. Research Monograph No. 53 (MIT Press, Cambridge).

PETERSON, G. E., and McKINNEY, N. P. (1961). "The Measurement of Speech Power," Phonetica, 7, 65.

PIKE, K. L. (1943) Phonetics - a Critical Analysis of Phonetic Theory and a Technic for the Practical Description of Sounds (Univ. of Michigan Press, Ann Arbor).

PULGRAM, E. (1965). "Consonant Cluster, Consonant Sequence and the Syllable," Phonetica 13, 76-81.

ROSETTI, A. (1959). Sur la Théorie de la Syllabe Janua Linguarum No. 9. (Mouton, 's - Gravenhage).

SAUSSURE, F. De. (trans. 1959). Course in General Linguistics C. Bally and A Sechehaye, Eds., W. Baskin (translator). (Philosophical Library, New York).

SPREEN, J. (1970). Aspects of the Control and Production of Speech. U.C.L.A. Working Papers in Phonetics, No. 15.

STETSON, R. H. (1945). Bases of Phonology (Science Press Printing Co., Lancaster, Penn.).

STETSON, R. H. (1951). Motor Phonetics - A Study of Speech Movements in Action (North Holland Publishing Co., Amsterdam).

STEVENS, K. N. and HOUSE, A. S. (1963). "Perturbation of Vowel Articulation by Consonantal Context: An Acoustical Study," J. Speech Hearing Res. 6, 111-128.

SWEET, H. (1908). The Sounds of English - An Introduction to Phonetics (Clarendon Press, Oxford).

TATHAM, M.A.A. and MORTON, K. (1968). "Further Electromyographic Data Towards a Model of Speech Production," Univ. of Essex Language Centre Occasional Papers No. 1, 25-27.

TRNKA, B. (1966). A Phonological Analysis of Present Day Standard English. Univ. of Alabama Linguistic and Philological Series No. 17.

ULDALL, E. (1970). "Instrumental Investigations of Articulatory Phonetics: An Annotated Bibliography," Edinburgh Univ. Dept. of Linguistics Work in Progress No. 4, 1-43.

APPENDIX

Corpus of utterances used for English films #1 and #2

and the koo
and the key
and the crew
and the cree
and the skoo
and the ski
and the screw
and the scree
and the skud
and the skied

and this crew
and this cree
and unscrew
and none screw
and Hans' crew

Corpus of utterances used for English film #3

say multitude now
say hygiene now
say lucid now
say fecundity now
say platitude now
say multitudinous now
say hygienic now
say calvinistic now
say placid now
say calvinist now
say lucidity now
say fecund now
say placidity now
say platitudinous now

Did you say he was kidnapped?
I'd rather have a kidsister .
I said cooed already.
I said cooed already.
No, I'm not keyed up.
No, I'm not keyed up.
What could come next?
What could come next?
When could they come?
When could they come?

Corpus of utterances used for French film # 1

une sinistr(e) structure
une sinistr(e) stricture

la dextre ou la senestre
la dextre universelle
la dextre inimitable

une bibliothèque structurée
une bibliothèque stricturée
une bibliothèque strictement personnelle

un compexe truculent
un complexe truqué
un complexe trichome

un contexte rudimentaire
un contexte russe
un contexte ridicule

Corpus of utterances used for French film #2

une sinistr(e) structure
une sinistr(e) stricture

le pourtour n'est pas fortifié
il y en sur tout le pourtour

les douze blouses vont arriver
elle vient d'acheter douze blouses

que Denis(e) lis(e) peut tout changer
je n(e) crois pas que Denis(e) lis(e)

sa tire-lire n'est pas pleine
il l'a mis dans sa tire-lire

ou c'est outrageux	ou c'est irritant
ou c'est courageux	ou c'est enquiquinqnt
c'est OUtrageux	c'est Irritant
c'est COUrageux	c'est enQUIquinant
c'est <u>OU</u>trageux	c'est <u>I</u>rritant
c'est <u>COU</u>rageux	c'est en<u>QUI</u>quinant

Corpus of utterances used for French film #3

une sinistr(e) structure
une sinistr(e) stricture

ce doux toutou s'appell(e) Totor
j'aim(e) beaucoup ce doux toutou
cett(e) goug(e) roug(e) lui appartient
je voudrais cett(e) goug(e) roug(e)
un couscous serait délicieux
nous avons mangé un couscous
ce ouistiti est très petit
il a trouvé ce ouistiti
que Denis(e) lis(e) me surprend
je n(e) crois pas que Denis(e) lis(e)
une couliss(e) liss(e) faciliterait les choses
j'ai besoin d'une couliss(e) liss(e)

ou c'est outrageux	ou c'est irritant
ou c'est courageux	ou c'est enquiqiunant
c'est OUtrageux	c'est Irritant
c'est COUrageux	c'est enQUIquinant
c'est <u>OU</u>trageux	c'est <u>I</u>rritant
c'est <u>COU</u>rageux	c'est en<u>QUI</u>quinant