DEVELOPMENT OF VOWEL NORMALIZATION PROCEDURES: ENGLISH AND KOREAN

Byunggon Yang

To Drs. Lindblom and Diehl

For their persistent quest in human speech.

To Kyungsim and Moonjung

For their patience and care.

DEVELOPMENT OF VOWEL NORMALIZATION PROCEDURES: ENGLISH AND KOREAN

by

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PROCEDURES: ENGLISH AND KOREAN

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The acoustic correlates of vowel quality are the formant frequencies. However, vowels spoken by different native speakers show great variation in formant values. This complicates the acoustic comparison of vowels produced by speakers of different dialect and language backgrounds and necessitates the use of normalization procedures to remove the effect of non-linguistic factors.

The goals of the present study were (1) to develop linguistically relevant normalization procedures for specifying vowel quality, (2) to apply these procedures to sets of new formant frequency data collected from four linguistically homogeneous groups of American and Korean males and females, and (3) to make a comparative study of normalized English and Korean vowels.

In a review of the literature various non-linguistic speaker-dependent sources of variation and previous normalization procedures are examined.
On the basis of the review this study proposes SRE (Scaling by Regression Equation), a new normalization method made possible by the observation that for a given language female formant frequencies can be predicted with high accuracy from male values using linear regression equations. Then, this study evaluates two versions

of this method: one using formant values in Hz, the other using the values in Bark units, and compares the two versions with other procedures in terms of minimization of male and scaled female differences in the several data bases.

The principal findings were as follows: (1) A strong positive correlation between male and female formant values was observed for Dutch, English, Korean, and Swedish. (2) This finding suggested a new normalization method, SRE which was found to be superior to previous proposals both with respect to simplicity and accuracy. (3) SRE based on Bark calibration of formants showed a further reduction of male-female differences in the five language sets.

From a comparative study of the normalized English and Korean vowels, this study proposed a research agenda to further improve the SRE method for a cross-linguistic comparison. The results of the present study should be relevant to phonetic research, foreign language teaching, and automatic speech recognition.

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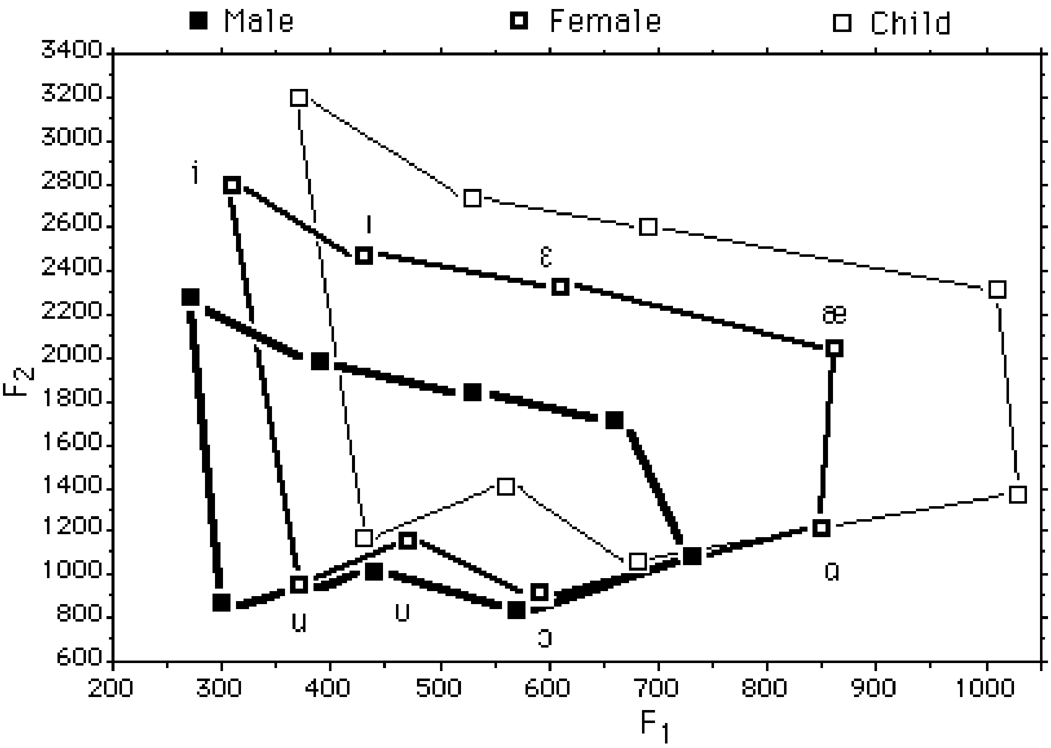
CHAPTER 1. INTRODUCTION

1.1 Statement of the Problem

According to the acoustic theory of speech production (Fant, 1960), all speech sounds can be analyzed as a product of a "source" and a "filter." In vowels the sound source is the vibration of the vocal cords and the filter is the system of resonators or cavities whose shapes depend on the positions of the various articulators. The source provides the raw material which is modified by the vocal tract filtering so as to produce the desired vowel quality. The vibrations at the glottis are responsible for the fundamental frequency (F_0) which represents "the first harmonic and the distance between the following harmonics" (Syrdal and Gopal, 1986:1087). The filter is responsible for the formation of acoustic "formants," or spectral energy peaks. In the vowel spectrum, F_1, F_2, and F_3 represent the first, second, and third prominent spectral maxima. By positioning articulators such as the tongue, the jaw, and the lips, the speaker controls the formant frequencies of each vowel. For example, the forward movement of the tongue tends to increase the second formant frequency (F_2). If the jaw moves down, the first formant frequency (F_1) tends to increase. Lip rounding is sometimes invoked to lower formant frequencies.

Previous studies have shown that formant frequencies are important factors in determining the perceptual quality of a vowel. Hence, each vowel phoneme has its characteristic formant patterns within a given language. However, spectrographic studies of vowels produced by different speakers of a given language show great variation in formant frequencies dependent on age and gender. This speaker variation causes many problems in determining the acoustic correlates of the vowel qualities of a language. For example, using Peterson and Barney (1952), the following vowel chart (in Fig. 1) illustrates the average formant frequencies (F_1 and F_2) for eight English vowels produced by each group of males, females, and children.

Fig. 1 Peterson and Barney Vowel Chart for Average Male, Female, and Child Values



In Fig. 1, F_1 is plotted along the abscissa and F_2 along the ordinate. It can be seen that, although perceptually comparable vowel qualities are examined, the absolute values of the formant frequencies differ. They increase from male through female to child. The vowel space formed by connecting vowel points of a group expands from male through female to child. This expansion seems quite regular.

Suppose one wanted to compare the vowel qualities produced by native and non-native speakers of English in terms of the formant frequencies from those two groups, the following questions arise:

1. What aspects of the acoustic measurements reflect genuine phonetic quality differences indicative of a "foreign accent" and interference from the learner's L_1?

2. What aspects reflect linguistically unimportant idiosyncracies?

3. How can these linguistically irrelevant differences be factored out?

Failure to answer these questions will make it impossible to compare two sets of phonetic measurements of vowels from two different speaker or language populations. To solve these questions, sources of speaker variation should be diagnosed. These can be divided into linguistic and non-linguistic factors. Linguistic factors are dialectal, sociolectal, idiolectal, and phonostylistic differences (Traunmüller, 1988). Non-linguistic factors are the differences in age, gender, and emotional state of the speakers. Measurement errors are a minor factor in view of today's sophisticated analysis tools. Since the vowel formants depend on the length and shape of the vocal tract, a major source of non-linguistic speaker differences is the individual speaker's vocal tract anatomy (Fant, 1966; Nordstrom and Lindblom, 1975; Nordström, 1975).

The goal of factoring out these non-linguistic factors is to establish a "pure," linguistically relevant acoustic specification of the vowel qualities of any given language. This procedure has been called "normalization" (Fant, 1966). Various proposals for the normalization of vowel qualities have been explored, but the problem has not yet received its definitive solution. Some proposals are articulatorily-based (Nordstrom and Lindblom,1975; Fant, 1975), while others are auditorily-based (Miller, 1980, 1989; Syrdal and Gopal, 1986), involving the transformation of the formant values into auditory units.

Articulatorily-based proposals attempt to adjust the observed data to a reference vocal tract by the ratio of a female or child vocal tract to that of a male. Two approaches to normalization have been favored: uniform and non-uniform. Nordstrom and Lindblom (1975) proposed a uniform scaling based on an estimate of the length of the speaker's vocal tract. According to their claim, all observed speaker-dependent formant frequency differences can be satisfactorily accounted for solely in terms of vocal tract length. Since overall vocal tract length variations affect all formant frequency values by the same scale factor (that is, in a uniform way), normalization implies applying the same scale factor to all formants. Therefore, the term "uniform scaling" was used. Fant (1966) observed that female speakers have proportionately shorter pharynges and argued that the scaling of formant values must be non-uniform. In other words, it must consider not only differences in overall vocal tract length between male and female speakers but also the complex formant-cavity relationships. Therefore, he recommended to use scale factors that are both vowel- and formant-specific. Fant (1975) claimed that such non-uniform scale factors did a better job in normalizing inter-speaker variations. Recently, O'Leary (1989) observed that there is a lawful numerical relationship between scale factors and formant frequencies. He proposed a scaling method based on the relationship between male and female formant frequencies as observed on logarithmic scales. The present study attempts to elaborate on this suggestion.

On the other hand, auditorily-based procedures for speaker normalization have been proposed by Miller (1980, 1989), Syrdal (1985), and Syrdal and Gopal (1986). As for auditorily-based procedures, there is an open debate about the choice of auditory scale: logarithmic scale vs. the Bark or critical-band-rate scale. 'Critical band' refers to the bandwidth of the internal filters of the human auditory system. The critical-band scale was proposed on the basis of several psycho-acoustical studies (Sharf, 1970). Miller's log-ratio approach (1980) was rated by Syrdal (1985) as "significantly poorer" than the bark-difference approach. Syrdal and Gopal (1986) claim that through the application of the Bark-difference approach speaker variation can be much reduced. However, Miller (1989: 2120) adhered to the use of the logarithmic scaling as "fundamental to hearing" in his Auditory-Perceptual theory.

1.2 Significance of the Study

This study is significant in several respects. Various proposals for speaker normalization are reviewed to evaluate their merits and drawbacks and to find an improved method. In so doing, the study provides firmer ground for future research in this area. Benefits of a proper normalization procedure are numerous. A proper normalization procedure can be a "valuable tool for the classification of vowels" (Disner, 1980:253). The confounding elements introduced by heterogeneity among speakers can be effectively removed by normalizing the formant frequencies of the vowels produced by the different speakers. The standard vowel qualities of a language, then, can be established. This makes the acoustic vowel chart a valuable tool for clearly representing the linguistic aspects of the vowels. One can also arrive at an objective comparison of vowel qualities produced by different speakers in a language. The extension of this procedure makes possible a comparison of vowels of any number of languages by applying the same procedure to each language. This cross-linguistic information could be a valuable tool in foreign language classroom. For example, the vowel chart contains much information on the physiological movement of the speaker's tongue, jaw, and lips. Normalized data on vowel qualities would be helpful because such information would be representative of a large number of different speakers. For foreign language teachers, a comparative study of vowel qualities in the foreign and the native language may prove valuable in teaching the language and correcting student's errors efficiently. Also, quantitative criteria, if handled properly, could be used to evaluate student's achievement of correct pronunciation skills in the foreign language.

Once the normalized vowel qualities of two or more languages are established, research on these languages can be made simpler and less costly. For example, different groups of males, females, and children will be required to pursue a complete study of any two or more languages. The research may lose its importance with three different conclusions for males, females, and children, which could have been collapsed into one for all the groups by normalization. However, the conclusion from a few speakers whose vowels are evaluated by a normalization to the reference vowel system of the language, could be generalized to the other speakers of the language if their vowel systems are equal to the reference system.

Normalization is an important topic in the area of automated speech recognition and computer synthesis of speech. Currently, speech technology devices perform best on a single speaker since too little is known about speaker variations. The present study also makes an indirect contribution to this area.

Lastly, a data analysis on Korean vowels will promote further study of Korean phonology. Since the development of a sound spectrograph, much work has been done on the acoustic phonetics of English and many other languages. However, few acoustic phonetic studies exist on Korean. In Korea, instrumental studies on Korean are rare because of the lack of proper instruments. Most phonetic observations have been made impressionistically and auditorily.

1.3 Objectives of the Study

The objectives of this study are to

1. investigate the extent and systematic structure of speaker-dependent variations in formant frequencies,

2. review previously proposed articulatorily- and auditorily-based normalization procedures and to develop a normalization method for the purpose of the present project,

3. establish linguistically significant qualities of English and Korean vowels by applying normalization, and

4. make a comparative study of normalized English and Korean vowels.

1.4 RESEARCH QUESTIONS

Accordingly, this study will focus on the following research questions:

1. What is the nature of the speaker-specific variation in the formant frequencies of vowels of four groups of speakers: English males, English females, Korean males, and Korean females?

2. In view of previous proposals and the results obtained in this study, what is the best way of normalizing the data?

3. Can we get vowel charts (F_2 against F_1 plots) to describe linguistic differences that are not confounded by speaker-specific factors?

4. How do we compare the vowel qualities of the two languages in terms of formant patterns?

1.5 ASSUMPTIONS

The assumptions of this study are as follows:

1. Languages can be compared in terms of quantitative phonetic measurements.

2. The qualities of vowels are completely specified by the first three formants.

3. Within each language group the population (male and female speakers) is homogeneous. Speakers have similar dialects.

4. If all non-linguistic factors can be corrected and if the vowel samples are linguistically homogeneous (Speakers use the same set of vowel qualities.), then the normalized female formant frequencies should closely match those of the male speakers.

CHAPTER 2. REVIEW OF THE LITERATURE

This chapter reviews the non-linguistic, speaker-dependent sources of variation in the formant frequencies of vowels from the perspectives of the talker and the listener. Data from Dutch, English, and Swedish speakers are analyzed from these viewpoints. Then, auditorily-based and articulatorily-based scaling methods are reviewed. Based on these earlier proposals for speaker normalization, two versions of a new scaling method are proposed: (1) a scaling by a regression equation (SRE) that expresses female formant frequencies (F_nf) as a function of corresponding male values (F_nm) and that combines features of both uniform and non-uniform scaling, (2) an SRE that relates female formant frequencies in Bark units (B_nf) to the corresponding male values (B_nm). Lastly, the various proposals of normalization are evaluated and compared in terms of scatter reduction for the scaled versions of the Dutch, English, and Swedish data.

2.1 Speaker Variation

In real life, speech signals vary greatly between and within speakers, but human beings seem to have little difficulty communicating. For instance, a speaker never produces a word in physically the same way on two occasions or in two different contexts (intra-speaker variation). Moreover, no two speakers produce a word in exactly the same way, articulatorily or acoustically (inter-speaker variation). This speaker variation has been attributed to (1) linguistic factors such as dialectal, sociolectal differences and to (2) non-linguistic factors such as physical anatomy, age, gender, and emotional state of the speaker (Traunmüller, 1988). Similarly, Brown (1987:14) made a distinction of extrinsic and intrinsic factors: extrinsic factors are the manipulable, learned, habitual ones, while intrinsic factors are the uncontrollable, organic ones. However, talkers also adaptively change their speech output depending on the listener or the environment (Lindblom, 1989). Thus, non-linguistic factors can be subdivided into talker- and listener-oriented sources of variation. Some of these factors are systematic so that their effects may be theoretically separable from linguistically relevant properties of speech by systematic transformations, while others may be minimized by methods of statistical inference (Fujisaki, 1972). Because the ultimate goal of this study is to achieve a cross-linguistic comparison of normalized vowels, this section will mainly focus on those non-linguistic factors which are so problematic in establishing the phonetically significant correlates of vowel quality.

2.1.1 Talker-Oriented Variation

This section describes talker-based, non-linguistic dimensions of phonetic variation, including individual differences in the physical anatomy, age, sex, and emotional state of the speaker. First, the fundamental frequency as source and the vocal tract as filter are studied in detail. Fundamental frequency (F_0) depends on many factors, especially the length of vocal cords. Eguchi and

Hirsh (1969) suggested that a sharp decrease in fundamental frequency occurred between the ages of three and six years. Then, the change is gradual up to thirteen years when the child's voice is changed by the rapid development of the larynx. At thirteen years, the fundamental frequency of girls reaches the value typical of adult females, while that of boys continues its decrease toward the value of adult males. A study by Negus (1949) supports this observation: vocal cord length averages 3 mm at birth, 5.5 mm at one year, 7.5 mm at 5 years, 8 mm at six and a half years, 9.5 mm at fifteen years, 12.5 to 17 mm in the adult females and 17 to 23 mm in the adult males. The speed of the vocal fold vibration or F_0 can be regarded as inversely proportional to the mass and length of the vocal fold and proportional to the tension [i.e., F_0 = {(tension)^$^{1/2}$ } / {(Mass)*(Length)^$^{1/2}$}]. Thus, the vocal fold vibration of females with smaller vocal cords is predictably faster than that of males. The average vibration of males' F_0 is about 125 Hz but that of females is around 200 Hz. F_0 also varies as the speaker changes the tension of laryngeal muscles and to some extent the subglottal pressure (Lieberman, 1967). Anatomically, the vocal folds can be lengthened with increased tension when the cricothyroid muscle contracts causing the cricoid to tilt back and thereby stretching the vocal folds. Boothroyd (1986) reported that F_0 varied between a low value of about 70 Hz and a high value of about 200 Hz in men. In women, the range is from 140 to 400 Hz, and in children it is between 180 to 500 Hz.

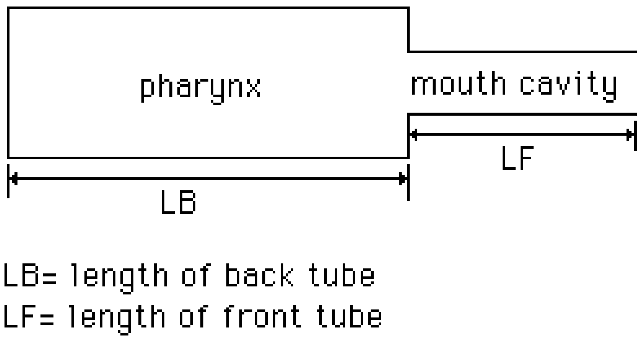
Furthermore, formant frequencies are inversely related to the overall length of speaker's vocal tract. Vocal tract size varies according to age and gender. Females usually have shorter vocal tracts than males. Children have much shorter vocal tracts than adult female speakers. Chiba and Kajiyama (1941) estimated overall vocal tract length, assigning the relative numbers of 1.0 to males, 0.87 to females, 0.80 to a boy of nine, and 0.70 to a girl of eight. Therefore, although a vowel phoneme may be articulated with the relatively identical vocal tract configuration, the formant frequencies increase from males through females to children. The overall vocal tract length can be estimated directly from formant frequency measurements. Assuming the cross-sectional area of the human vocal tract to be almost uniform for the vowel [ʌ] as in an English token *Hudd*, one can obtain the length of the speaker's vocal tract (L) by introducing a measurement of F_3 of [ʌ] into the well-known formula (Fant, 1960).

[1.] $L = (5*C) / (4*F_3)$

(C=34,000 cm/sec: speed of sound)

Furthermore, the ratio of pharynx to mouth cavity lengths is another factor contributing inter-speaker variation. Chiba and Kajiyama (1941:188-193) stated that mouth cavity length of an eight-year-old girl was 30% shorter than that of an adult male while the length of the girl's pharynx was 56% shorter than that of the male. Again, the length of pharynx and mouth cavity can be estimated from the formant frequencies of the vowel [i]. In a two-tube simplified model of vowel [i], F_2 depends on the back tube or pharynx while F_3 depends on the front tube or mouth cavity (Fant, 1973). Fig. 2.1 illustrates the configuration of vowel [i].

Fig. 2.1 Configuration of Vowel [i]



The pharynx spans the region from the glottis to the soft palate, while the mouth cavity extends from the incisors to the back pharynx wall. Because F_2 and F_3 of the vowel [i] are half-wavelength resonances of the back tube and front tube, respectively, the length of the back tube (LB) and that of the front tube (LF) can be approximated by the following:

[2.] $LB = C / (2 * F_2)$

[3.] $LF = C / (2 * F_3)$

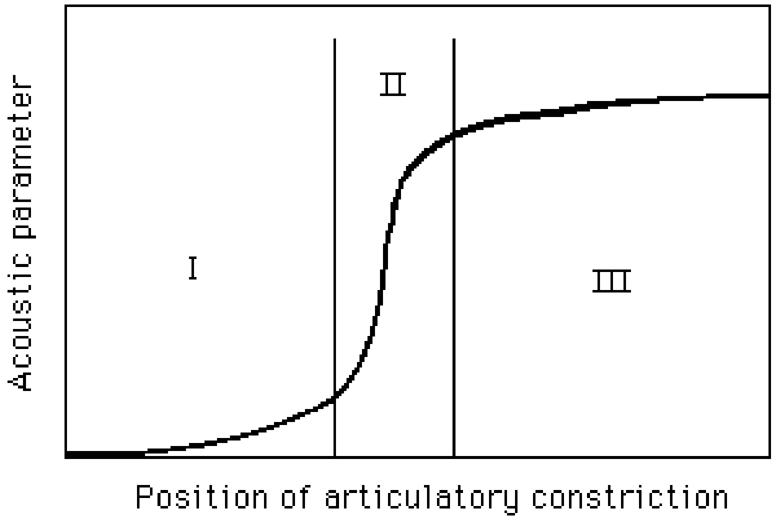
These are only approximate values given the simplicity of the model. For Swedish speakers, Fant (1973:90-91) reported that the female pharynx was 2.1 cm shorter than the male pharynx; and the female mouth cavity was 1.25 cm shorter than the male mouth--this observation fitted well the physiological data. From these differences in pharynx-to-mouth-cavity ratios Fant predicted that male-female formant values would be related by non-uniform scale factors.

2.1.2 Listener-Oriented Variation

Most studies of human speech have put much emphasis on the articulation and have tended to neglect perceptual aspects and the interaction between speaker and listener. Nooteboom (1983) criticized current phonetic investigations of speakers for this reason. He claimed that speech is "goal-oriented behavior, directed by a speaker at a particular listener or audience" (*op. cit.,* 183). Because speech production presupposes the listener, it makes sense to consider perceptual process when attempting to explain some particular patterns of variation across speakers. This section looks at the possible perceptual role of such patterns.

There are two competing theories which consider both the speaker and listener in the speech event. In an attempt to provide a phonetic basis for distinctive features, Stevens (1989) proposed the Quantal Theory (QT). He begins with the observation that there is a non-linear relationship between articulatory and acoustic parameters as shown in Fig. 2.2.

Fig. 2.2 Schematization of the Relationship between Articulatory Parameters and Acoustic Parameters



For certain speech sounds the human vocal tract can be compared to a uniform tube with a single constriction. When the place of this constriction is systematically varied, the acoustic output will exhibit unstable regions (Section II in Fig. 2.2) where small changes in an articulatory parameter lead to large changes in acoustic output. Also, there are acoustically stable regions (Section I and III) where relatively large articulatory changes lead to small acoustic changes. For the listener, the stable regions bounded by unstable regions provide constancy within categories and contrast between categories and can thus enhance the perception of speech sounds. Within the stable regions, phonetic features are almost invariant, which facilitates the decoding task of the listener. For the talker, the stable regions make speech production easier and less costly. Acoustic stability implies reduced need for articulatory precision since gestures produced within the stable regions sound roughly the same.

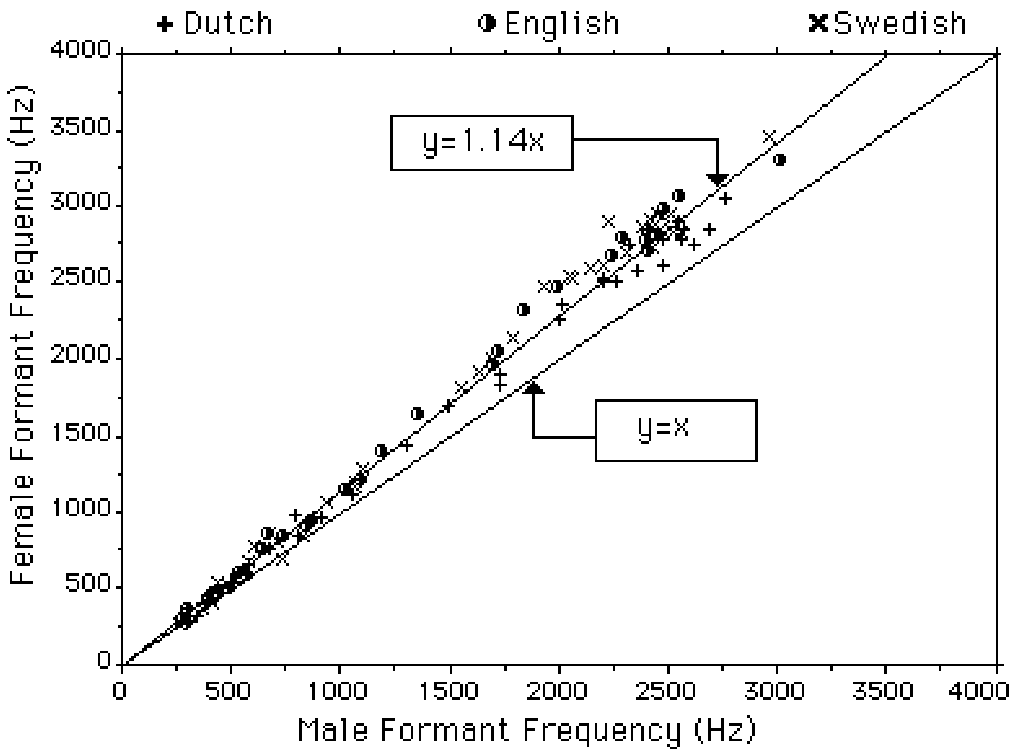
An alternative view has been explored by Lindblom and co-workers who propose the Theory of Adaptive Dispersion (TAD) to account for the content of phonetic inventories (Lindblom and Maddieson, 1988; Lindblom and Engstrand, 1989) and who draw attention to the adaptive gesture of speech production and the phenomena of hypo- and hyper-speech (Lindblom, 1989). Speakers are assumed to control not the acoustic invariance of speech sounds, but "sufficient perceptual contrast." The speaker thus monitors a trade-off between articulatory economy and perceptual distinctiveness. Speakers tend to raise their vocal effort and speak more precisely in a noisy environment. They invoke a style that could be called hyper-speech. Under other quiet and favorable communicative conditions, they make themselves understood more easily. Their speech becomes more relaxed. They invoke a hypo-mode since speakers adapt with ease to the situation and the listener. Their speech tends to vary along the hypo- and hyper-dimension. Nooteboom (1983:193) suggested that the production of words depends partly on "speaker's internalized model of the perceptual and interpretative processes in the listener." In other words, a speaker continuously shapes his production in relation to the process of perception.

In assessing both the QT and TAD, Diehl (1989) compared them in terms of the predictive accuracy of vowels and consonants of major world languages. The point vowels [i, a, u] were well predicted in both theories. But, for languages with larger inventories, both tended to predict too many high vowels and underestimated the occurrence of the vowels [ʌ,ə]. The QT was the poorer predictor: Too many high vowels were predicted. Schwa was not predicted because it does not meet the quantal requirements. Both theories carry implications for the production of vowel quality by male and female speakers.

2.1.3 Observation on Dutch, English, and Swedish Vowels

In this section an observation is made on the male and female formant frequency data of Dutch, English, and Swedish vowels. The sources are van Nierop et al. (1973) and Pols et al. (1973) for Dutch, Peterson and Barney (1952) for English, and Fant (1975) for Swedish. Speaker variation between males and females in the three languages is illustrated in Fig. 2.3, which plots the female/male F_1, F_2, and F_3 values of all vowels. A line of identity (y=x) was drawn on which male and female formant frequencies are identical.

Fig. 2.3 Relationship between Female and Male Formant Frequencies for Dutch, English, and Swedish.



This scattergram shows a universal trend toward higher formant frequencies for female speakers. The inter-speaker variation seems quite regular. However, on closer inspection some vowels deviate systematically from the regression line, as pointed out by Fant (1975). Presumably, this tendency is largely due to non-linguistic factors such as differences in vocal tract length.

The difference between male and female vocal tract lengths seems to be the main determinant of the deviation from the line of identity. The vocal tract ratios of female to male in the three languages were determined according to equation **[1.]** and were found to be 0.89 for Swedish, 0.89 for Dutch, and 0.86

for English. These numbers all indicate that female vocal tracts are 11-14% shorter than those of males. The line superimposed on the data points has a slope of 1.14 corresponding to 14% uniformly shorter female vocal tracts.

2.2 Vowel Normalization

This section reviews both auditorily-based (Miller, 1980, 1989; Syrdal and Gopal, 1989) and articulatorily-based (Nordstrom and Lindblom, 1975; Fant, 1975) proposals for speaker normalization.

2.2.1 Auditorily-Based Scaling

Auditorily-based procedures for speaker normalization have been proposed by Miller (1980, 1989), and Syrdal and Gopal (1986). As previously pointed out, there is an open debate about how to transform the raw data in these proposals: logarithmic scaling versus the Bark or critical-band-rate scaling. There are also other scaling methods based on the Mel, and the Konig scales. This study will be confined to the Bark and log scales.

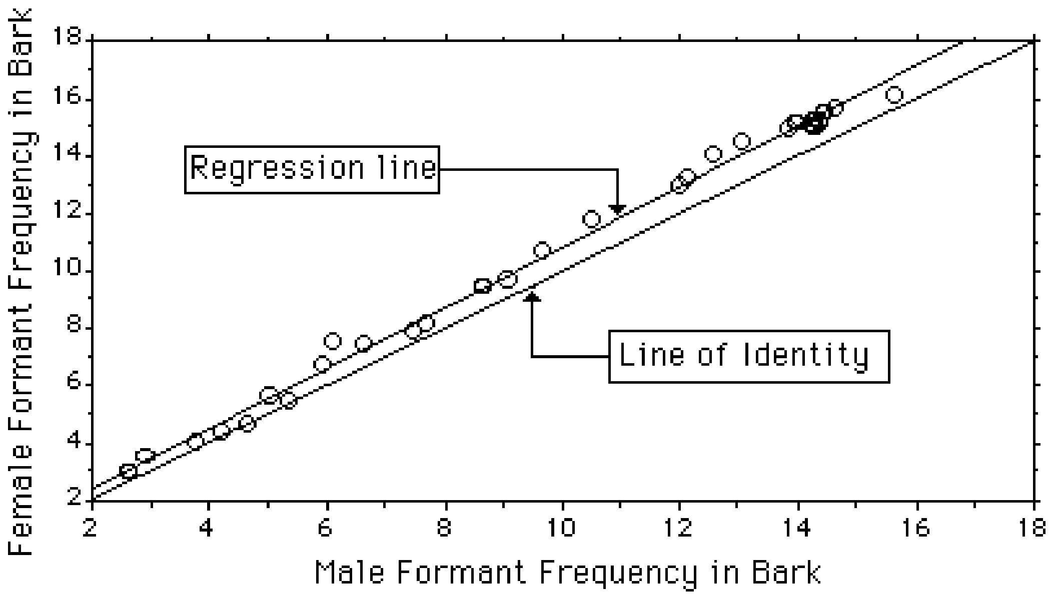
The critical band scale was derived from a series of psycho-acoustical studies (Scharf, 1970; Zwicker and Terhardt, 1980). The critical band is defined as "that bandwidth at which subjective responses rather abruptly change" (Scharf, 1970:159). A critical band is taken to represent the bandwidth of the filters of the human auditory system. One critical band equals a constant length of about 1.3 mm along the basilar membrane and about 1300 cochlear neurons

(Syrdal and Gopal, 1986). The band increases proportionally with frequency at low frequencies up to 500 Hz; it is proportional to the logarithm of frequency at higher frequencies (Zwicker and Terhardt, 1980). Zwicker and Terhardt (1980:1524) proposed a critical-bandwidth formula as follows:

[4.] $Zc = 13 \arctan(0.76 * F) + 3.5 \arctan(F/7.5)^2$

where Zc is critical-band rate in Bark, arctan is applied to numbers in radians, and F is frequency in kHz. Since the formula is obtained by empirical curve fitting, the transformed values still show some error but the difference nowhere exceeds 0.2 Bark across the frequency range. Fig. 2.4 presents the data from Peterson and Barney (1952) in Bark units. The regression line of the transformed male/female data deviates proportionately from the line of identity.

Fig. 2.4 Average Values for Males, Females, and Children in Bark Units from Peterson and Barney (1952) .

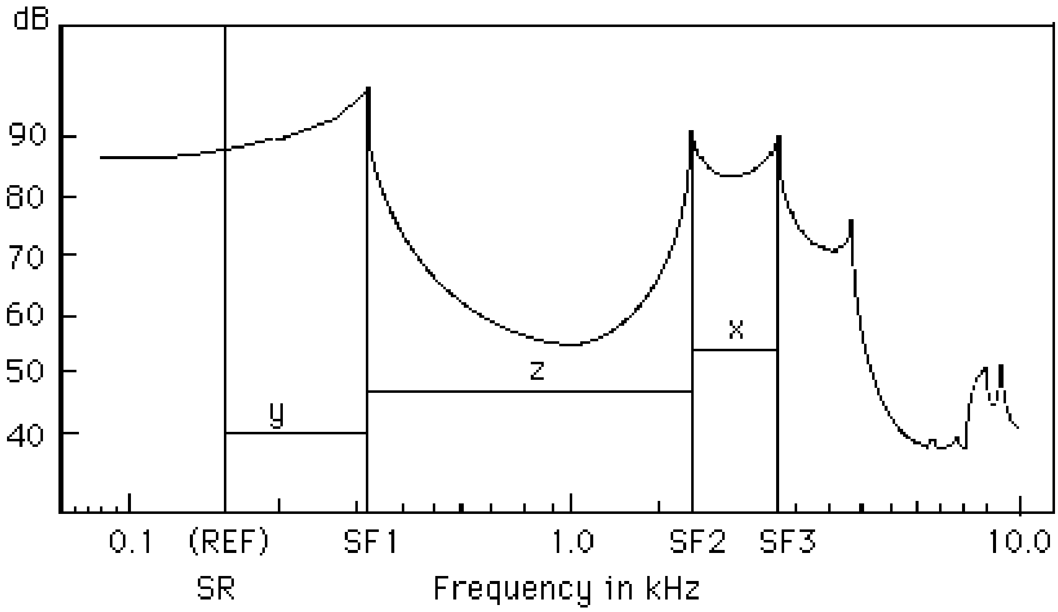


A logarithmic scale was advocated by Joos (1948). Bark units differ from the logarithmic scale in the low frequency region.

2.2.1.1 Auditory-Perceptual Theory

Miller (1989: 2120) proposed a theory, the Auditory-Perceptual theory, which has three stages: (1) the transformation of the waveform to auditory-sensory dimensions, (2) the transformation of the sensory data to perceptual values, and (3) the conversion of the perceptual variables to phonetic-linguistic categories. In this theory, a sensory reference is calculated from the fundamental frequency information. Miller relates the first three formant peaks to the reference and identifies them as sensory formant 1, SF_1; sensory formant 2, SF_2; and sensory formant 3, SF_3. These are illustrated in Fig. 2.5.

Fig. 2.5 Miller's Diagram of Sensory Formants and Their Spacing on a Logarithmic Scale for the Vowel [IY]



The sensory reference (SR) is defined in terms of talker's average F_0:

[5.] SR = 168* (GMF_0/168) ^1/3

where GMF_0 is the geometric mean of the speaker's F_0 values. This theory assumes that "like values of the ratios (SF_1/SR), (SF_2/SF_1), and (SF_3/SF_2)

produce like vowel percepts" (*op. cit.,* 2125). An auditory-perceptual vowel space was plotted using the following coordinates:

[6.] $y = \log (SF_1/SR)$

[7.] $z = \log (SF_2/SF_1)$

[8.] $x = \log (SF_3/SF_2)$

According to Miller's Auditory-Perceptual theory, constant distances between adjacent formants on a log scale correspond to constant formant ratios in the linear domain. The Auditory-Perceptual theory thus implies that normalization should be based on the constancy of formant ratios. It is thus seen to suggest uniform scaling augmented by the sensory reference concept which might help eliminate such non-linguistic factors as vocal tract size, age, and gender.

O'Leary (1989) proposed that the scaling of formant values of females and children should be based on the relation between male and female data on logarithmic coordinates: $\log (F_n f) = \log K + \log (F_n m)$. Using equations of this form, he was able to normalize his female data to produce a tighter clustering within vowel phoneme categories.

2.2.1.2 Bark-Difference Scaling

Syrdal and Gopal (1986) proposed a perceptual model of vowel recognition. There are two stages of processing. At the earlier stage vowels are represented by the formant values along a Bark scale. At the second phonetic stage, vowels are classified into binary categories along the following dimensions: (1) $B_1 - B_0$, which represents a continuum of high to low vowels, high vowels having less than a 3 Bark difference and low vowels having more than 3 Bark difference, and (2) $B_3 - B_2$, which represents the front-back distinction, front vowels having less than a 3 Bark difference and back vowels having more than a 3 Bark difference. The 3 Bark difference was derived from experimental estimates by Chistovich et al. (1979) and Chistovich and Lublinskaya (1979). Their experiments showed that within a 3 to 3.5 Bark difference, listeners tended to adjust the frequency of a one-formant vowel to a value intermediate between the F_1 and F_2 of the reference vowel. If the difference exceeded 3 Barks, listeners chose one or the other of the two formants, but not an intermediate position. Thus, Syrdal and Gopal (1986) included the $F_1 - F_0$ distance in their auditory model. This distance combines F_0 and F_1 into a single measure of vowel height or openness. They noticed that both F_0 and F_1 varied inversely across vowels: high vowels had lower F_1 and higher F_0 , while the opposite was the case for lower vowels. Syrdal and Gopal did a discriminant analysis on the vowels of Peterson and Barney (1952) along the proposed auditory dimensions. They suggested that their matrix for classifying vowel tokens in terms of critical distance was "not significantly" (*op. cit.,* 1092) different from a comparable classification which Peterson and Barney (1952) obtained from a group of listeners. In addition, Syrdal and Gopal reported that inter-speaker variation was much reduced through the transformation into Bark units. They claimed that the Bark-difference procedure retained linguistic distinctions while reducing inter-speaker variability, since the Bark-difference or the log-ratio normalizations proposed by Miller et al. (1980) are "speaker-independent" procedures (*op. cit.,* 1095). Therefore, they avoid a direct criticism of speaker-dependent measures presented by Disner (1980) based on the fact that speaker-dependent measures may eliminate linguistic factors. Syrdal and Gopal did not exclude the possibility of incorporating speaker-dependent variables into a more complete perceptual model.

2.2.2 Articulatorily-Based Scaling

In an experiment involving computer simulation, Nordstrom and Lindblom (1975) proposed a method for uniform scaling based on the length of the speaker's vocal tract derived from the F_3 values of the subject's open vowels. Fant (1975) drew attention to the deviations of the uniformly scaled female data from the male formant patterns. He claimed that his non-uniform scaling method produced more accurate results. He recommended the use of different scale factors depending on vowel identity and formant number. Recently, O'Leary (1989) observed a linear relationship between Fant's scale factors and female formant frequencies. He extended this observation to propose a scaling method based on a function of male and female frequencies transformed in the logarithmic scale. The average and scaled data of the three languages in the following discussion are attached in Appendix A.

2.2.2.1 Uniform Scaling

Nordstrom and Lindblom (1975) proposed a uniform scaling method. It involved estimating the total length of a subject's vocal tract from an average of F_3 in vowels with F_1 greater than 600 Hz. The ratio of the length of the average male vocal tract (Lm) to the average female vocal tract length (Lf) can be written:

[9.] $k = Lf / Lm$

This ratio can be determined from average values of F_3 for the male and female groups. Using equation **[1.]**

[1.] $L = (5 * C) / (4 * F_3)$

The present study applied this formula to F3 of the vowel [ʌ], which comes close to a uniform schwa-like configuration. For open vowels, Fant (1975) suggested that the physical length of the vocal tract should be corrected by $0.8 * (Ao/p)^{1/2}$ on the assumption that the lip opening of those vowels is about 5 cm^2 and is independent of vocal-tract length. As a result of this procedure, the physical length of the vocal tract is corrected by adding 1 cm to Lf and Lm. Fant showed that the end-corrected ratio closely approximated F_3f / F_3m although the difference between Lf/Lm and end-corrected ratio of (Lf+1) / (Lm+1) was about 2.3% with Lf=12 cm and Lm=17 cm. According to Fant, F_3f / F_3m corresponds to (Lm + 1) / (Lf + 1).

[10.] $F_3f / F_3m = (Lm + 1) / (Lf + 1)$

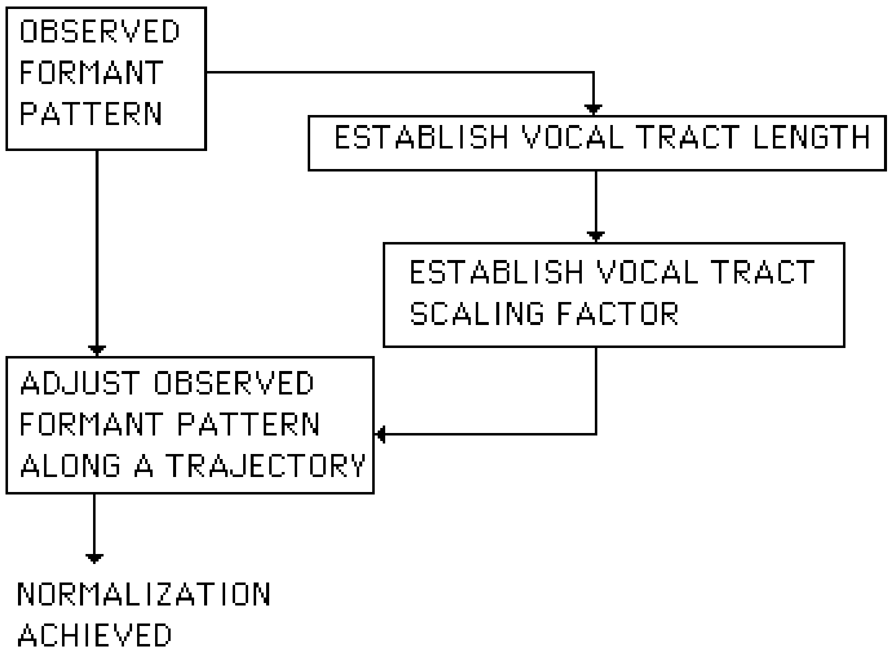
[11.] $k = F_3m / F_3f$

Equation **[11.]** is used for the uniform scale factor k in this paper. In Nordstrom and Lindblom's procedure, the female formant frequencies are adjusted along a trajectory to a position within the male reference system by multiplying by the scale factor k. The normalized n-th female formant frequency is denoted as F_nf (scaled) and can be determined according to

[12.] $F_nf \text{ (scaled)} = k * F_nf$

Fig. 2.6 summarizes this procedure (Nordstrom and Lindblom, 1975, their Fig. 7).

Fig. 2.6 Block Diagram for the Nordstrom and Lindblom Normalization Procedure



Applying this procedure to Peterson and Barney (1952), values for F_3f and F_3m are obtained from

F_3f = 2990+2850+2810+2780 / 4

= 2857.5

F_3m = 2410+2440+2390 / 3

=2413.3

Then, k is obtained according to

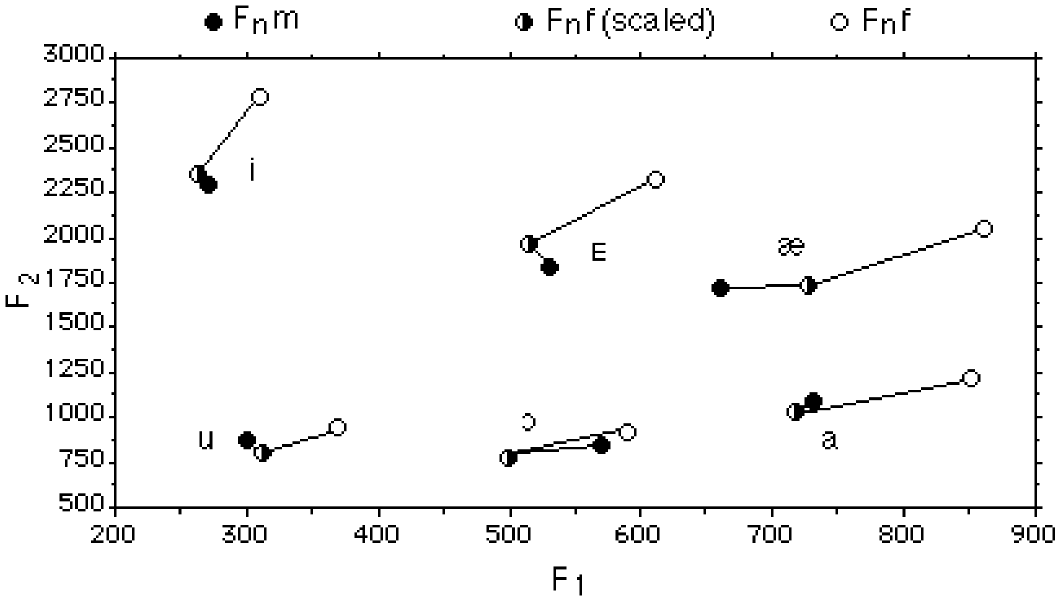
$$k = F_3m / F_3f$$
$$= 2413.3 / 2857.5$$
$$= 0.8445$$

For example, for the vowel [a] with F_2f =1220 Hz, a scaled value is calculated as follows:

$$F_2f \text{ (scaled)} = k * F_2f$$
$$= 0.8445 * 1220$$
$$= 1030$$

Application of this uniform scaling method to Peterson and Barney (1952) produces the plot shown in Fig. 2.7. The half-filled circles indicate the scaled F_nf values.

Fig. 2.7 Peterson and Barney Vowel Chart for Male, Female and Uniformly-Scaled Female Values.



The author adopts in the present work equation **[11.]** for the determination of the scale factor k, which also agrees with the uniform scaling method originally proposed by Nordstrom and Lindblom (1975).

2.2.2.2 Non-Uniform Scaling

In a study of female/male vowel formant differences in eight different languages, Fant (1975:1) observed "universal tendencies of departure from a simple uniform scaling." He proposed incorporating more language data to find universal scale factors in order to eventually reach the goal of separating language and dialect variation from speaker-dependent variation. His method applies a different scale factor k for each individual formant and individual vowel category. A tentative reference table of universal scale factors was proposed based on the statistical study of six languages: Swedish, American English, Danish, Estonian, Dutch, and Serbo-Croatian (Fant, 1975:5, Table I-A-I). This table shows average formant frequency differences for male and female vowels and the average male formant frequencies for those six languages. Fant's non-uniform procedure starts out by computing a scale factor k in percent from

[13.] $k = \{(F_3f / F_3m) - 1\}*100$

Next, k_nf, a reference scale factor specific to each formant number and vowel category, is chosen from Fant's Table I-A-I. From k and k_nf, the non-uniform scale factor k_n is determined by

[14.] $k_n = k_nf * (k/17)$

where 17 is a standard, language-independent reference term. Lastly, scaled F_nf values are obtained according to:

[15.] $F_nf \text{ (scaled)} = F_nf / \{1 + (k_n / 100)\}$

Applying this procedure to Peterson and Barney (1952) for F_1 of the vowel [a], the scale factor k comes out as

$$k = \{(F_3f / F_3m) - 1\} * 100$$
$$= \{(2857.5 / 2413.3) - 1\} * 100$$
$$= 18.4$$

The scale factors, k_nf, for the vowel [a] in Fant's Table I-A-I are $k_1f= 17$, $k_2f= 12$, $k_3f=15$. Application of $k_1f=17$ in equation **[14.]** yields

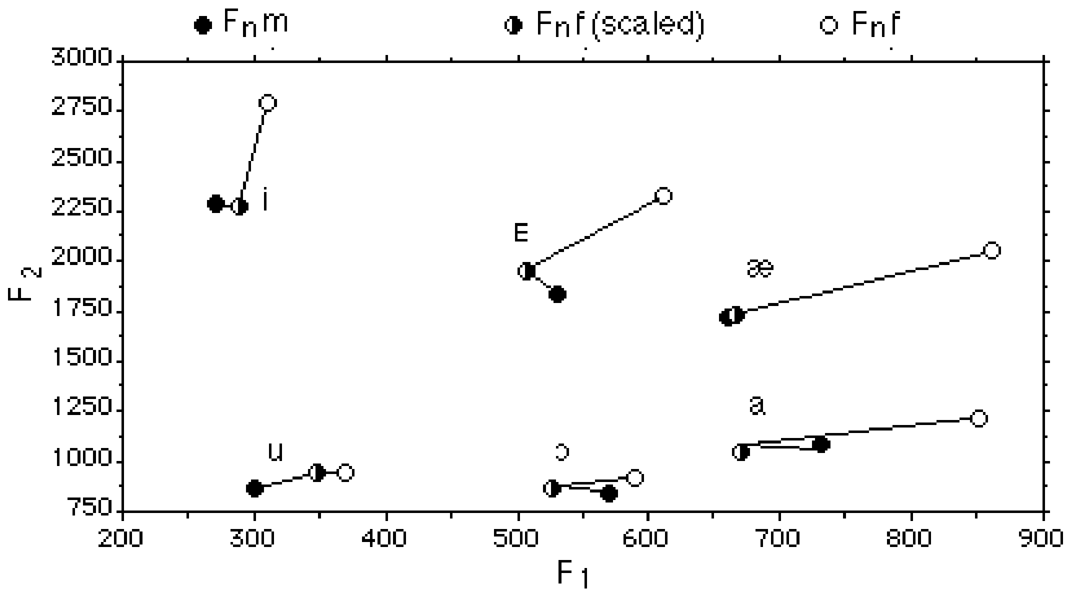
$$k_1 = k_1f * (k / 17)$$
$$=17 * (18.4 / 17)$$
$$=18.4$$

From this, the scaled F_1f is determined from equation **[15.]** by

$$F_1f \text{ (scaled)} = F_1f / \{1+ (k_1 / 100)\}$$
$$= 850 / \{1+ (18.4 / 100)\}$$
$$= 718$$

Applying this non-uniform scaling procedure to Peterson and Barney (1952) results in Fig. 2.8. The half-filled circles indicate the scaled F_nf values.

Fig. 2.8 Peterson and Barney Vowel Chart for Male, Female, and Non-Uniformly Scaled Female Values



2.2.3 Scaling by Regression Equation (SRE)

A linear relationship between X and Y coordinates is written

[16.] $Y = \underline{a} + \underline{b}\,X$

where b is the slope and a is the Y-intercept of the line. The SRE method makes use of the fact that linear relationships exist between male and female formant values. The first step is to establish the regression equation that provides a best fitting line of the form shown in equation **[16.]**. The scaling of female values is performed according to

[17.] Y (scaled) = (Y - a) / b

where Y (scaled) is the scaled value and Y the input number. If the linear relationship is perfect, these adjusted values will be arranged along the Y=X line, the line of identity. In this paper, the term scaling by regression equation (SRE) refers to the procedure stated in equation **[17.].**

2.2.3.1 SRE Based on k_n and F_nf

O'Leary (1989) observed a good correlation between scale factors obtained with Fant's scaling method and female formant values ($r^2 > 0.64$ for F_1 and F_2; $r^2 = 0.01$ for F_3). Fant's scale factors k_n were higher than the average for high vowels while those for low vowels were lower. Using the regression equations relating k_n factors to female formant frequencies, O'Leary (1989) scaled female formant frequencies to match more closely those of males. The scaling procedure can be summarized as follows:

1. Determine k_n by Fant's non-uniform scaling method.

2. Find the regression equation for k_n and F_nf, the individual formant of each vowel.

3. Normalize the female data to match the male reference patterns.

Applying this procedure to the Peterson and Barney data yields the following regression equations for F_1, F_2, and F_3:

$k_1 = 0.036 * F_1f - 7.58$ $r^2 = 0.65$

$k_2 = 0.009 * F_2f + 0.895$ $r^2 = 0.64$

$k_3 = - 0.0008 * F_3f + 20.645$ $r^2 = 0.01$

The value of k_1 for the vowel [a] with $F_1f=850$ is obtained from

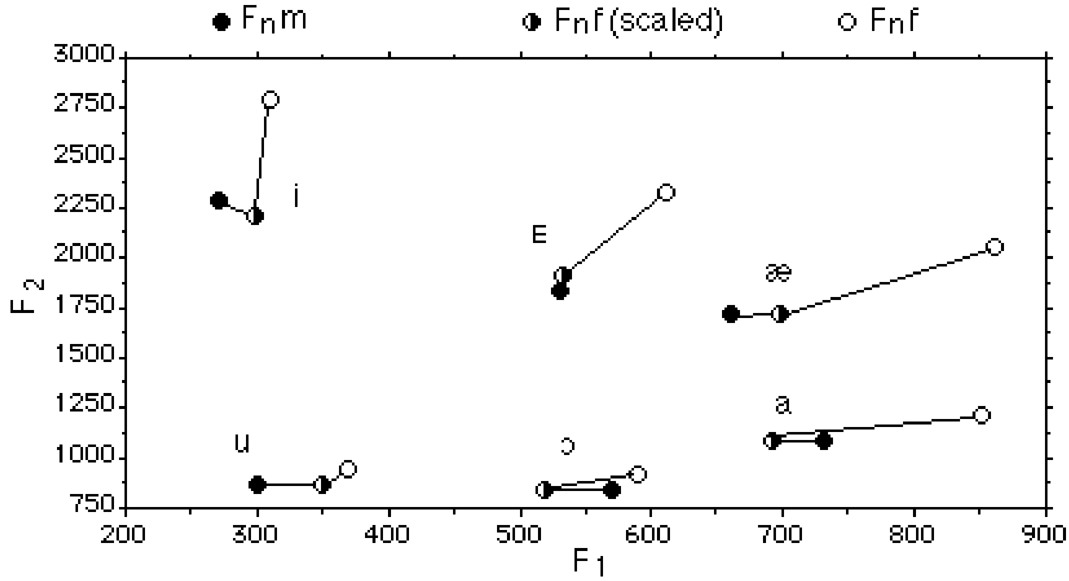
$$k_1 = 0.036 * F_1f - 7.58$$
$$= 0.036 * 850 - 7.58$$
$$= 23.02$$

Inserting k_1 into equation **[15.]** yields the scaled F_1f value:

$$F_1f\ (scaled) = 850 / \{1+ (23.02 / 100)\}$$
$$= 691$$

This simplifies Fant's look-up procedure. It derives k_n as a linear function of F_nf. It provides a compromise between the uniform and non-uniform scaling methods. Applying this procedure to the Peterson and Barney corpus results in Fig. 2.9. The half-filled circles show the scaled F_nf values.

Fig. 2.9 Peterson and Barney Vowel Chart for Male, Female and Scaled Female Values by SRE Based on k_n and F_nf.



2.2.3.2 SRE Based on log (F_nf) and log (F_nm)

O'Leary (1989:5) went on to ask "whether $F_nf = K (F_nm)$ is the most useful relationship between F_nf and F_nm for scaling purposes." $F_nf=K (F_nm)$ can be transformed into $\log (F_nf) = \log K + \log (F_nm)$, which implies a linear equation with a slope of 1. He found that the regression lines had slopes greater than 1 for F_1 and F_2, and less than 1 for F_3. The scaling method based on a straight-line approximation for log (F_nf) versus log (F_nm) can be summarized as follows:

1. Transform female/male data to logarithmic values.
2. Find the regression equation for log (F_nf) and log (F_nm) for each individual formant.

3. Scale the female data to obtain a number representing log (F_nf, scaled).

4. Convert the log (F_nf, scaled) to linear frequency values.

For example, the application of the first two steps to the Peterson and Barney data yields the following regression equation for each formant:

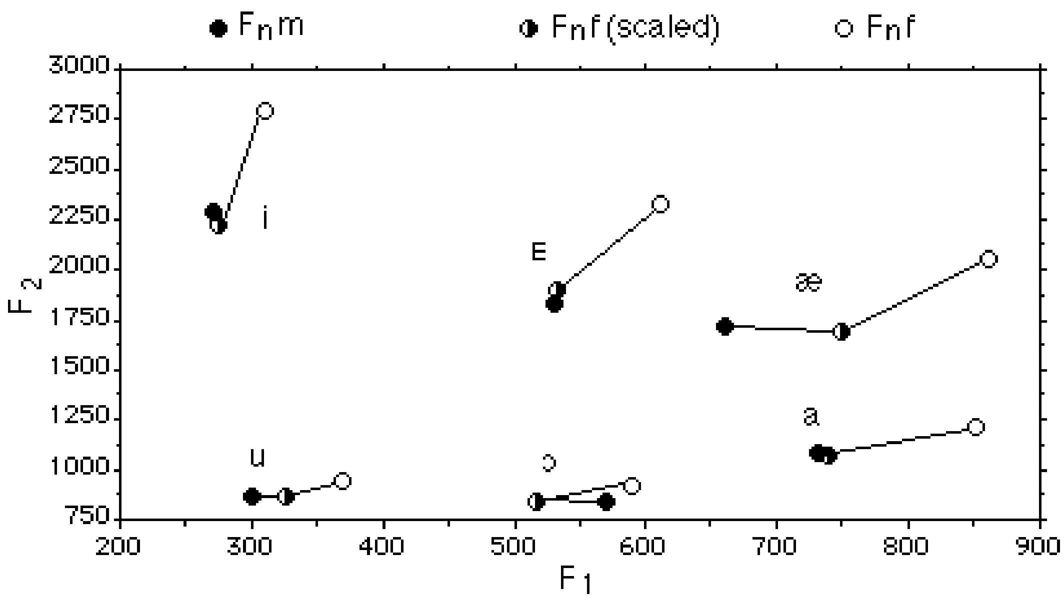
$$\log (F_1f) = 1.017 \log (F_1m) + 0.012 \qquad r^2=0.951$$
$$\log (F_2f) = 1.134 \log (F_2m) - 0.351 \qquad r^2=0.997$$
$$\log (F_3f) = 0.937 \log (F_3m) + 0.28 \qquad r^2=0.955$$

As explained in Section 2.2.3, the scaled value for [a] is:

$$\log (F_1f, \text{scaled}) = \{ \log (F_1f) - 0.012\} / 1.017$$
$$= \{ 2.929 - 0.012\} / 1.017$$
$$= 2.868$$

Transforming 2.868 to a linear value results in 739. Fig. 2.10 shows the Peterson and Barney data scaled by this method. The half-filled circles show the scaled F_nf values.

Fig. 2.10 Peterson and Barney Vowel Chart for Male, Female and Scaled Female Values by SRE Based on log (F_nf) and log (F_nm)



2.2.3.3 SRE Based on F_nf and F_nm

To further simplify the O'Leary's procedure, the author also explores using SRE for F_nf and F_nm. F_nf and F_nm show a strong correlation. For the Peterson and Barney data, the regression equations for F_nf and F_nm are:

$F_1f = 1.232\ (F_1m) - 43.289$ $\qquad r^2 = 0.942$

$F_2f = 1.329\ (F_2m) - 193.155$ $\qquad r^2 = 0.996$

$F_3f = 1.047\ (F_3m) + 285.265$ $\qquad r^2 = 0.94$

Then, $F_1f = 850$ for the vowel [a] can be normalized according to

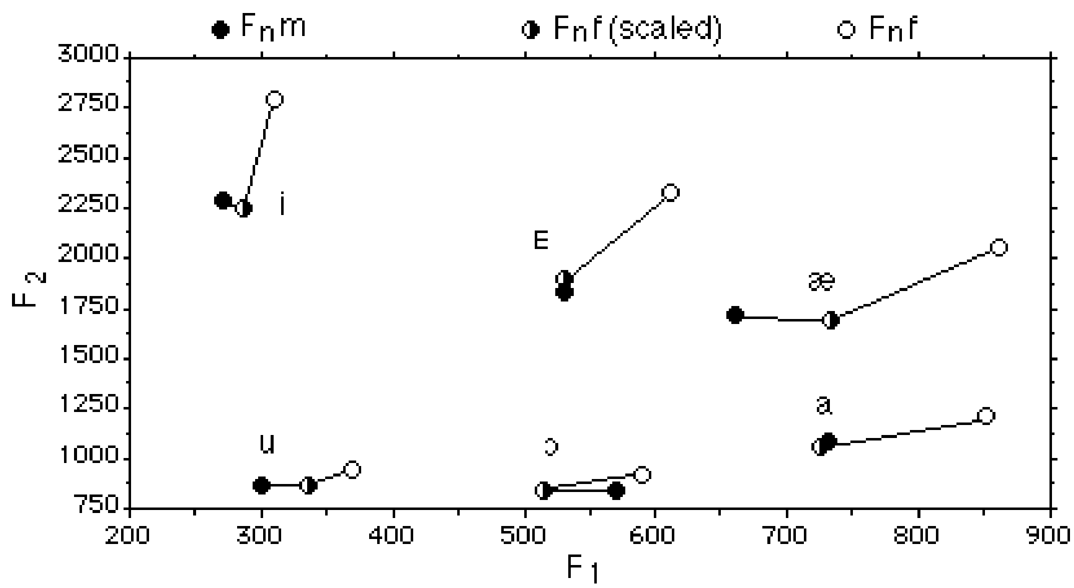
$$F_1f\ (\text{scaled}) = (F_1f + 43.289) / 1.232$$

$$= (850 + 43.289) / 1.232$$

$$= 725$$

Fig. 2.11 shows the Peterson and Barney data scaled by this method. The half-filled circles are the scaled F_nf values.

Fig. 2.11 Peterson and Barney Vowel Chart for Male, Female and Scaled Female Values by SRE Based on F_nf and F_nm



2.2.3.4. SRE Based on B_nf and B_nm

This section pursues the consequencies of transforming the raw data into Bark units. Then, the SRE method will be applied using the regression equations based on female formant frequencies in Bark units (B_nf) and the corresponding male values (B_nm). The scaling procedure is summarized:

1. Transform male and female data into Bark units.
2. Find the regression equation for each vowel formant number.
3. Derive B_nm (scaled).

Applying this procedure to the Peterson and Barney data, the following regression equations were found:

$B_1f = 1.168\ (B_1m) - 0.203$ $\quad r^2 = 0.942$

$B_2f = 1.127\ (B_2m) - 0.3$ $\quad r^2 = 0.996$

$B_3f = 0.913\ (B_3m) + 2.179$ $\quad r^2 = 0.959$

For the vowel [a], B_1f=7.5, it is normalized according to

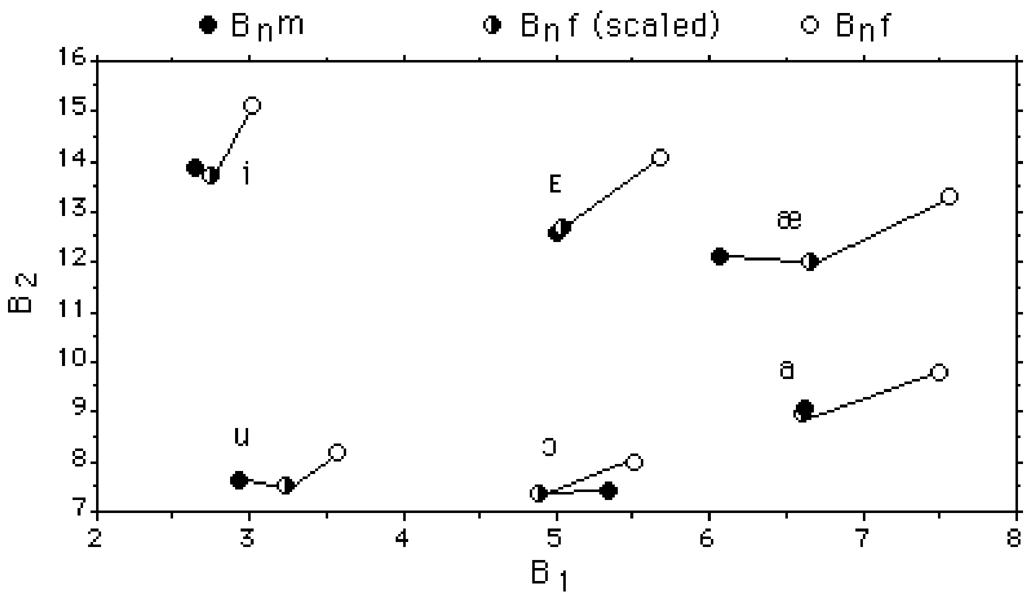
$$B_1f\ (\text{scaled}) = (B_1f + 0.203) / 1.168$$

$$= (7.5 + 0.203) / 1.168$$

$$= 6.595$$

Fig. 2.12 shows the Peterson and Barney data scaled by this method. The half-filled circles show the scaled $F_n f$ values.

Fig. 2.12 Peterson and Barney Vowel Chart for Male, Female, and Scaled Female Values by SRE Based on $B_n f$ and $B_n m$



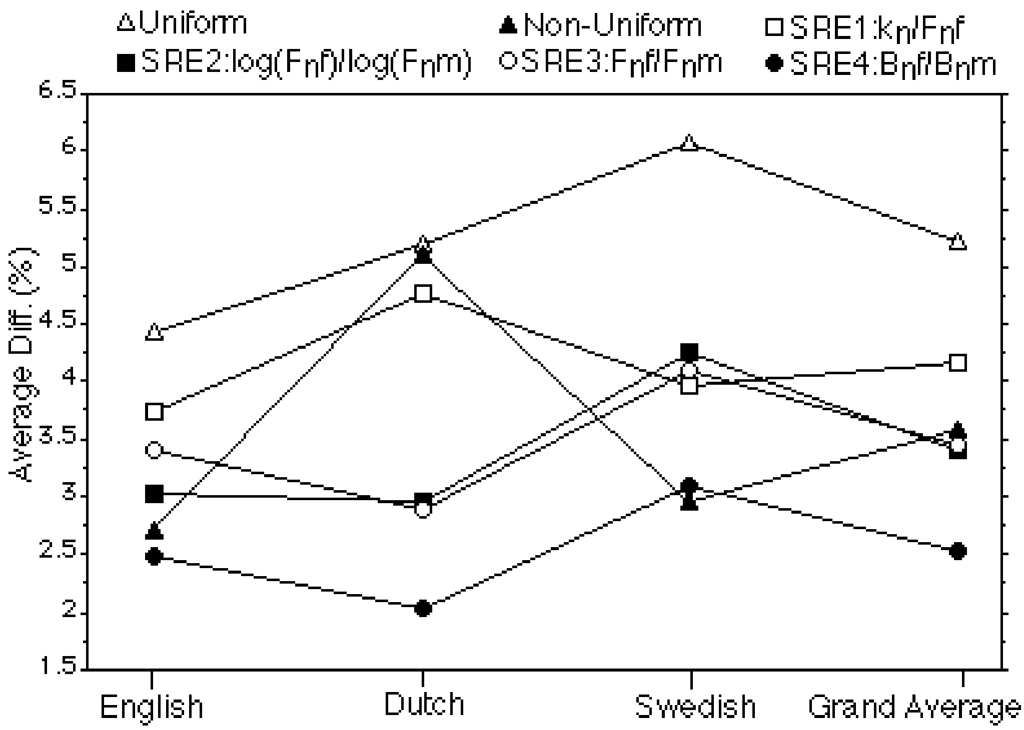
2.2.4 Evaluation of the Scaling Methods

In the preceding sections articulatorily- and auditorily-based proposals for speaker normalization have been reviewed. Which method is best suited for the purpose of removing non-linguistic factors within a language? This study shall use a numerical criterion to evaluate the proposals. Assuming that there will be no difference in the reference data and perfectly-scaled data, the evaluation can be made by simply assessing the differences in the male and scaled female formant frequencies. The average difference (Diff.) in percent across vowel formants can be calculated by

[18.] Diff. (%)= $\{(F_n f \text{ (scaled)} - F_n m) / F_n m\} * 100$

A lower average Diff. may indicate a more successful normalization only if the scaled $F_n f$ values still retain linguistic factors. Using equation **[18.]**, an evaluation has been made on the scaled data of Dutch, English, and Swedish. Fig. 2.13 shows the average Diff. of each scaling method.

Fig. 2.13 Average Difference of Each Scaling Method Applied to the Dutch, English, and Swedish Data



On the average, SRE4 based on B_nf and B_nm is superior to other proposals. The uniform scaling method has the highest Diff. in the three languages. However, one must give credit to the simple procedure with such a good result. The difference from the other scaling methods is about 3 to 4%. This method can be useful for preliminary data processing or vast amounts of data processing from the obtained F_3 of open vowels of the given group. In Dutch, the uniform and non-uniform scaling methods have little difference. In Swedish, as Fant (1975) claimed, the non-uniform scaling reduces the female/male variance to one half of the uniform scaling method. Despite the complicated procedure to obtain the normalized frequencies, Fant's non-uniform method does not always promise the best result, although it is better than the uniform method. Worse still, Fant's method requires much time and cost to obtain a table of universal scale factors by an exhaustive study of world languages. The more languages the table includes, the higher Diff. the scale factor would yield.

On the other hand, all the SRE proposals except SRE1 based on Fant's k_n and F_nf show more scatter reduction than uniform and non-uniform proposals. SRE1 fell between the uniform and non-uniform proposals except in Dutch. This discrepancy came from the third formant in Dutch: In the regression of log (F_3f) and log (F_3m) in Dutch, the r^2 was 0.63, while that of the first and second formant was 0.994. The SRE based on F_nf and F_nm is as simple as the uniform scaling and does not require the table of scale factors as with non-uniform scaling. The SRE based on F_nf and F_nm comes close to the SRE based on log

(F_nf) and log (F_nm). The SRE based on B_nf and B_nm does the best job. This procedure includes all the merits of the uniform and non-uniform methods and incorporates the feature of the auditory Bark units.

Applying this procedure to the auditory-perceptual theory (Miller, 1989), improvement has been made with an average of 2.17% scatter reduction: 4.6 % reduction for x-axis, 1.59% for y-axis, 0.3% for z-axis (See Appendices B-1-1 and B-1-2.). In Syrdal and Gopal's Bark-ratio, a general improvement of 6.35% has been made; 8.92% for the dimensions of B_1m - B_0m and B_1f - B_0f, 3.52% for B_2m - B_1m and B_2f - B_1f, and 6.61% for B_3m - B_2m and B_3f - B_2f (See Appendices B-2-1 and B-2-2.). The scatter reduction by the SRE method will be almost doubled if the formant values of children are included in both log-ratio or bark-difference approach (See Fig.1 for the distance between F_1 and F_2 in males, females, and children). Thus, vowel prediction in both log-ratio and Bark-difference approach will be more precise than before because inter-speaker differences have been greatly reduced by normalization.

CHAPTER 3. METHOD

This chapter describes the subjects, the speech materials, the instruments, and the data gathering procedures used in the study.

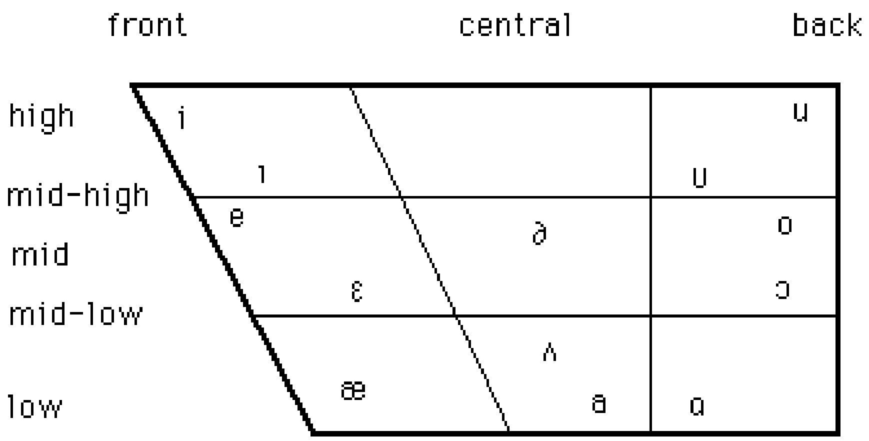
3.1 Subjects

A total of forty subjects were chosen from a larger group participating in recording sessions at the University of Texas at Austin. They were selected from an age range of eighteen to thirty-seven and formed four groups: ten American males, ten American females, ten Korean males, and ten Korean females. The selection was based on a questionnaire from each subject (See Appendix C for a background questionnaire) and on the judgments on randomly chosen speech samples by peer listeners. These procedures are described in Section 3.3. Subjects were students attending UT-Austin and all had normal hearing and health. American subjects were limited to those who indicated Southern or Southwestern as the area where they spent most of their lives. All of them speak Southern or Southwestern dialects. All the Korean subjects were born and educated in Seoul. All of them speak Standard Korean. The characteristics of each subject are listed in Appendix D.

3.2 Speech Samples

The speech samples were sixty-seven English and fifty-two Korean words. Each English vowel occurred in a [h __ d] context. In this context the following vowel formant can be easily identified because the [h] noise on the spectrogram shows similar patterns of the following vowel formants. Each Korean vowel occurred in a [h __ dɑ] context to approximate the text frame chosen for English. In Korean this is a typical form. For example, each verb stem combines with the particle *-da* or *-h__da* to form a root infinitive. Assuming that subjects needed time to adapt to the circumstances, extra tokens were added at the beginning of each English and Korean list. In this way thirteen English and ten Korean vowels were studied. In American English, 11 monophthongs / i , ɪ, ɛ , æ, ə, ʌ, ɑ, u, ʊ, a, o/ in *heed, hid, head, had, herd, Hudd, hod, who'd, hood, hard,* and *hawed,* and two diphthongs / eɪ, ou/ in *hayed* and *hoed* were chosen. Fig. 3.1 shows relative qualities of these vowels (Ladefoged, 1982).

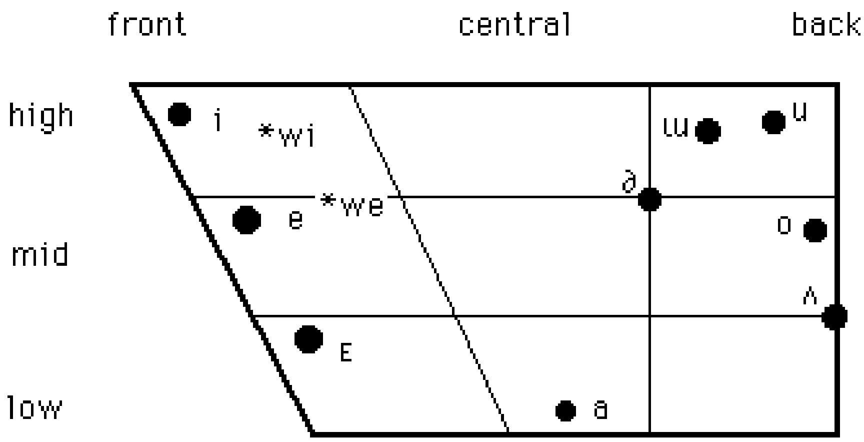
Fig. 3. 1 English Vowel Chart



The symbols [e, o] are the first elements of the diphthongs. Vowel transcriptions according to Kenyon & Knott's (1953) were adopted.

According to an official notice (March, 1989) issued by the Ministry of Education, Standard Korean is defined as the Seoul dialect currently spoken by educated people. The same notice lists the following ten monophthongs in Standard Korean: /a, ᴇ, ʌ, e, o, ø, u, y, ɨ, i / in *hada, hᴇda, hʌda, heda, hoda, hweda, huda, hwida, huuda,* and *hida.* It adds that / ø , y/ are also produced as diphthongs. Nam et al. (1984) observed that most people produce them as [we, wi]. In the acoustic study of Korean vowels the author found that almost all of the Korean subjects produced these vowels with the approximant [w]. Therefore, [we] and [wi] were used in orthography. Fig. 3.2 shows relative vowel positions (Nam et al., 1984: vi). The asterisks were inserted to indicate relative positions for [we, wi].

Fig. 3.2 Korean Vowel Chart



These thirteen English and ten Korean vowels appeared five times in random order. Later, three out of the five productions of each vowel were chosen for the actual data set. The selection was made from the sixth token in English and the eleventh token in Korean to avoid unnatural tokens at the beginning of the recording session. The speech samples of English and Korean are listed in Appendix E .

3.3 Description of Instruments

Two screening instruments were used to make each group homogeneous. First, subjects were rejected on the basis of collected information from a questionnaire. The questionnaire included subjects' name, age, sex, height, native language, fluency in other languages, dialect, and history of speech and hearing disorders. Second, subjects who were perceived by their peers as having a deviant dialect were rejected. These listeners were randomly chosen from the subjects and asked to rate the other male and female subjects by marking deviant words from the language group. All the marks were added and tabulated to find four Korean and four American subjects (two males and two females for each language) who scored lower. Finally, those marks made by these four subjects were used to reject subjects who scored more than 80% of the total tokens as deviant. The listening materials for the judges were produced as follows. Four vowels [i, æ, a, u], peripheral in the vowel chart, were chosen for the assessment since these vowels seem to represent individual vowel system and dialectal variation. In Korean, [E] was chosen instead of [æ]. Using a program called MAKETAPE , one token per vowel from each male and female subject was chosen. Then, the stimuli were randomized and recorded on a TDK Type-I tape from a Yamaha Model KX800U cassette deck. The tape was organized as follows:

1. Play the ten sounds in a row, twice, with 0.1-second inter-stimulus interval to help each listener establish a frame of reference.

2. Play Subjects 1-5 with 2.5-second final pause.

3. Play Subjects 6-10 with 2.5-second final pause.

4. Play odd numbered Ss with 2.5-second final pause.

5. Play even numbered Ss with 2.5-second final pause.

6. Repeat steps 1 to 5 across the four vowels with three-second intervals.

The speech samples were played back from a Superscope Model CD-330 cassette recorder. The stimuli were presented to the peer listeners in a quiet room in the UT Phonetics lab at a level that seemed comfortable. A session lasted about 20 minutes. The answer sheet for listening task, and scores for the final forty subjects are listed in Appendix F.

3.4 Data Gathering Procedures

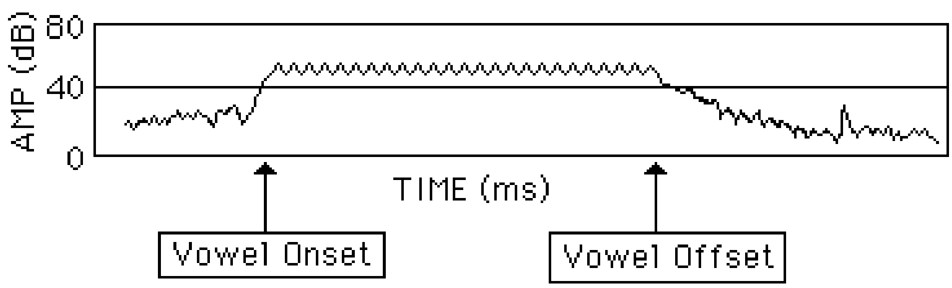
The recording was done in a sound-proofed booth in the Phonetics Lab of the University of Texas at Austin. The experimenter asked the subjects to produce each word at normal speed and as naturally as possible. Speech samples were picked up by a condenser microphone at a distance of about 15 cm. The professional cassette recorder Model CD-330 was used to record the tokens on TDK-Type I tapes. The recording level was carefully monitored by the experimenter throughout the recording session to avoid too weak or over-loaded signals. The recording took two to three minutes per subject.

The recorded samples were analyzed using the VAX computer in the UT Phonetics Lab. The KLSPEC software package written by D.H. Klatt and modified by Jerry Lame was used to interactively examine, measure, and analyze the recorded samples. The samples were played from the Yamaha Model KX-800U cassette deck. The input samples were low-pass filtered at 4 kHz and digitized at a 10,000 Hz sampling rate. They were examined word by word using RECORD, a waveform editing program, and saved as separate wave files. Then, a command file listing all the wave files was created to produce a spectrogram and an amplitude tracing of each word. The spectrogram was

made using a 256-point Discrete Fourier Transform (DFT) analysis with a 6.4-millisecond (msec) Hamming window every
one millisecond. The spectrogram and the amplitude tracing were studied to determine four time points during each vowel for spectrum printouts.

The four time points were systematically calculated from the total duration of each vowel, avoiding the initial and final portions, to capture both the nucleus or steady part of the vowel, and the glide of a diphthongal movement. Preliminary examination of the spectrograms showed that there were formant transitions before and after the steady state. Most spectrograms showed steady states between onset and offset points, but some showed continuous changes in the formant frequencies across the entire vowel. Furthermore, a durational difference was observed between English and Korean. The average duration of vowel in English was 251 msec with a standard deviation (SD) of 61 while that of Korean was 86 msec with an SD of 32. This difference might come from syllable structure. Korean samples form two-syllable words. Also, Korean *d* in *h_da* context was often produced as voiceless. Korean vowels with a shorter duration often show sharp transitions within the vowel segment. The dynamics of the formant pattern made it difficult to find consistent time points for spectrum analysis. Therefore, the author adopted the following approach: Equidistant time points were selected within each vowel segment. Segmentation was made by observing both spectrograms and amplitude tracings. The procedure for finding vowel onset and offset points was to observe simultaneously the spectrogram and the amplitude tracing. On the spectrogram each vowel tended to begin with a glottal pulse and clear formant bars following the weak noise of [h]. On the amplitude tracing, each vowel is represented by a periodic oscillation at about 40 dB preceded and followed by a nonperiodic consonant waveform as illustrated in Fig. 3.3. The vowel onset point was determined by placing a ruler to see where the 40 dB threshold was crossed. The vowel offset was assigned to the point where the steady state ends on the amplitude tracing and the formant bars terminate on the spectrogram.

Fig. 3.3 Vowel Onset and Offset Points on the Amplitude Tracing



From the vowel onset and offset time points, the total duration T was calculated. Then, T was divided by six. The first time point A was determined by adding T/6 to the vowel onset point. The subsequent time points B, C, and D were determined by adding T/6 to the immediately preceding time point. The procedures are summarized as follows:

1. Determine the total vowel duration (T),

   T = Vowel Offset - Vowel Onset,

2. Derive time point A = T/6 + Vowel Onset,

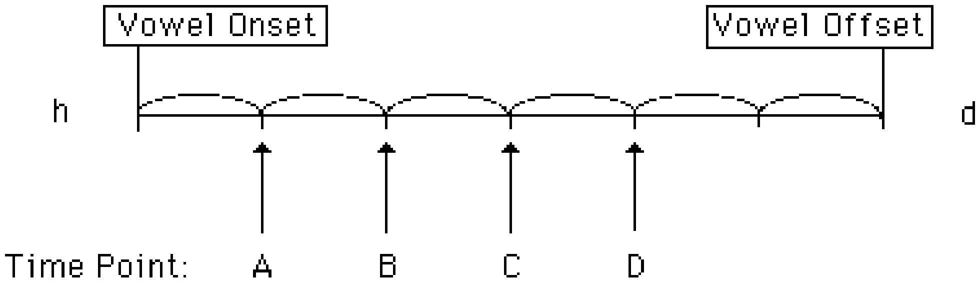
3. Derive time point B = T/6 + A,

4. Derive time point C = T/6 + B, and

5. Derive time point D = T/6 + C.

Fig. 3.4 illustrates the four time points determined in this way.

Fig. 3.4 Four Time Points for Spectrum Analyses



The four time points of each vowel were listed in a command file controlling the KLSPEC program which computed and printed spectral displays for each time point. One of the panels showed a harmonic spectrum (a DFT computed with a 25.6 msec window) and a spectral envelope derived by averaging the DFT with a 300 Hz window. The other panel presented the DFT spectrum and an envelope obtained by a Linear Predictive Coding (LPC) analysis. Each panel specified an estimate of F_0, and of frequency values and amplitudes of spectral peaks. Each printed page included four spectral display panels for two time points. By carefully comparing the eight spectra and the spectrogram of each given vowel, estimates of F_0, F_1, F_2, and F_3 were collected. All the data {English: (20 subjects) X (13 vowels) X (3 repetitions) X (4 time points) X (4 estimates: three formants and one F_0) = 12,480; Korean: (20 subjects) X (10 vowels) X (3 repetitions) X (4 time points) X (4 estimates:

three formants and one F_0) = 9,600; 22,080 data cells in grand total} were typed into the cells of STATVIEW 512+TM running on the Macintosh computer. The data file was transferred to MICROSOFT EXCEL, a Macintosh spreadsheet software. Then, the formant data were sorted by grouping the three productions of each vowel by individual subjects. Values which deviated more than 200 Hz from the average of the three productions repeated by the same subject were checked again. From a plot showing the ten speakers' pronunciation of each vowel, three outliers (English S_3, S_{13}, S_{17}) were removed before determining the average value of the English vowel in *who'd* . Their F_2 values deviated from the mean by more than 400 Hz which was taken to indicate phonetic rather than a speaker-dependent difference.

3.5 Formant Decisions

Criteria for making formant decisions were defined after reviewing procedures used by others. Fant (1959) located formant positions from the line spectra of sustained vowels (2- to 3-second duration) by eye. Some positions were determined in relation to the formant values of adjacent vowels. Peterson and Barney (1952) used a weighted average of the harmonics by the following:

[19.] $F = sum(A_i * F_i) / sum(A_i)$

A_i represents the amplitude of the i-th harmonic while F_i indicates its frequency. This formula looks simple, but, as Nierop et al. (1973) pointed out, it has problems in deciding: (1) the number of harmonics for a formant over the frequency range, (2) the selection of the harmonics for each formant in a vowel with two close formants, (3) a vowel with few or no adjacent harmonics. Therefore, Nierop et al. added the application of *apriori* knowledge of the identity of the vowel which in their judgment plays an important role in fine-tuning formant decisions. For the vowels / o/, /o/, /œ/, /ø/, /ı/, and /e/ they rejected the fundamental as a component of the first formant to avoid anomalous cases where F_1f is lower than F_1m in these vowels. However, they modified the same rule for the vowels /u, y, i/: The fundamental was included except the cases where the bandwidth of F_1 becomes " too large" (*op. cit.,* 115). Pols et al. (1973:1093) used the same *a priori* knowledge to determine the three formants by "drawing the envelope of the spectrum by eye."

In this study the source spectrogram of each vowel was used for the first reference and final decision on formant values. First, formant values on the spectrogram were estimated by drawing a pencil line at the center of each formant band by placing a ruler. Then, these values were examined from two DFT harmonic spectra (average envelope and LPC envelope). By carefully comparing eight spectra and a spectrogram of each vowel, F_0 and formant values were collected. Most of the time these methods converged. To avoid any wrong decision, the three productions of the same vowel of the same subject were compared to screen out those values which belong to apparently different target vowels. Moreover, a few values of obvious noises due to the disconnected formant transition across the four time points were also rejected. Special care was taken with respect to a few nasalized vowels. Pickett (1987) noted that the nasalized vowel has an altered spectrum because of a reduction in F_1 amplitude and the insertion of anti-resonances and extra formants in the transmission of the pharyngeal-oral tract. On the spectrogram, F_1 of the nasalized vowel occurs with weaker amplitude than the base formant. Sometimes reference was made to the other non-nasalized vowels of the same subject. Otherwise, the formant values were adjusted by extrapolating values backwards from the vowel offset region where the nasalization ends with the following consonant *d*. In the female speakers with F_1 near the first strongest harmonic, F_1 was obtained by adding a quarter or half of F_0 to the harmonic. After observing all the spectrograms of each language group, the proportion of F_0 for addition was determined and consistently applied. Similar correction was made when two formants were close together. However, the corrected values were always checked with the source spectrogram. Throughout the formant decision, Dr. Lindblom continuously guided the author to get the correct values. In his preliminary assessment of the author's decision, there was less than 5% disagreement. These systematic errors were immediately corrected after discussion. But, any mistakes in the formant decision are the author's responsibility.

CHAPTER 4. ANALYSIS OF DATA

This chapter presents the formant data collected from the forty English and Korean subjects, and discusses the findings. The analysis was focused on the following research questions:

1. What is the nature of the speaker-specific variation in the formant frequencies of vowels of four groups of speakers: English males, English females, Korean males, and Korean females?

2. In view of previous proposals and the results obtained in this study, what is the best way of normalizing the data?

3. Can we get vowel charts (F_2 against F_1 plots) to describe linguistic differences that are not confounded by speaker-specific factors?

4. How do we compare the vowel qualities of the two languages in terms of formant patterns?

To answer these questions, the average formant values of each language were determined. Then, the male and female data were compared. By the SRE-method the female data were normalized according to the equations derived from the regression analysis of F_nf versus F_nm and B_nf versus B_nm. As an extension of this procedure, normalization of data from individual speakers to the reference vowel system was also suggested. Then, English and Korean vowels normalized according to SRE were compared. An estimate of vocal tract length for the four groups of speakers was computed and was found to indicate further differences. This led to suggestions of ways of further refining and supplementing the SRE procedure for a cross-linguistic comparison. All calculations and data processing were done with MICROSOFT EXCEL, a Macintosh spreadsheet software. Statistical analyses were conducted using a Macintosh statistics software called STATVIEW 512+^{TM}.

4.1 English and Korean Vowel Formants

This section presents the English and Korean vowel formant data. Ratios were computed between male and female values to identify systematic patterns of variation. Then, the validity and reliability were assessed. Individual vowel formants and F_0 values for English and Korean subjects were tabulated in Appendix G. Appendix H lists line charts of these values.

4.1.1 English Vowel Formants

The average values of English vowel formants were derived from three productions from each subject. For each vowel spoken by male or female talkers, there were thirty measurements at each time point (3 repetitions X 10 subjects). The following analysis was performed on the data. For each vowel, formant, and time point, a female-to-male ratio (f/m-Ratio) was calculated according to

[20.] $\text{f/m-Ratio} = F_n f / F_n m$

Table 4.1 and Table 4.2 list the average formant values for the English male and female groups. Table 4.3 lists the f/m-Ratios.

Table 4.1 Average F_0 and Formant Values of English Vowels

at Time Points A & B

WORD	SEX	A0	A1	A2	A3	B0	B1	B2	B3
had	male	126	689	1740	2506	126	687	1743	2497
hard	male	124	637	1035	2423	125	638	1051	2318
hawed	male	127	652	1033	2522	128	663	1026	2527
hayed	male	127	500	1992	2616	128	469	2082	2636
head	male	132	529	1903	2566	132	531	1900	2561
heed	male	136	288	2306	3026	136	286	2317	3033
herd	male	130	503	1349	1819	130	490	1363	1787
hid	male	130	398	2035	2690	130	409	2012	2671
hod	male	126	685	1121	2536	127	694	1121	2548
hoed	male	129	513	1154	2379	129	498	1127	2375
hood	male	136	438	1321	2366	135	446	1331	2380
Hudd	male	129	594	1318	2484	127	592	1331	2494
who'd	male	136	338	1368	2268	136	330	1347	2268
had	female	215	830	2096	2943	209	825	2059	2928
hard	female	213	796	1245	2668	205	782	1287	2563
hawed	female	213	799	1137	2907	206	777	1140	2895
hayed	female	216	562	2459	2930	209	521	2536	2991
head	female	220	627	2268	2956	211	631	2244	2968
heed	female	230	385	2814	3410	221	390	2826	3416
herd	female	226	537	1530	1985	218	523	1550	1974
hid	female	224	448	2394	3029	216	466	2373	3014
hod	female	212	873	1253	2877	205	857	1255	2877
hoed	female	215	565	1285	2811	207	528	1206	2824
hood	female	223	479	1489	2828	214	491	1486	2836
Hudd	female	214	716	1605	2881	206	701	1641	2901
who'd	female	233	422	1505	2753	224	414	1511	2758

Table 4.2 Average F_0 and Formant Values of English Vowels

at Time Points C & D

WORD	SEX	C0	C1	C2	C3	D0	D1	D2	D3
had	male	126	685	1723	2510	125	685	1701	2528
hard	male	124	622	1128	2146	124	592	1269	1913
hawed	male	128	661	1039	2531	127	649	1069	2527
hayed	male	129	422	2143	2675	128	385	2172	2693
head	male	132	532	1870	2582	132	527	1842	2588
heed	male	134	281	2318	3023	133	282	2322	3002
herd	male	129	476	1375	1768	129	464	1392	1746
hid	male	129	430	1960	2654	128	443	1913	2640
hod	male	127	703	1146	2540	127	697	1206	2531
hoed	male	129	470	1091	2373	129	439	1072	2354
hood	male	134	459	1366	2388	133	463	1439	2395
Hudd	male	127	587	1357	2495	126	575	1423	2482
who'd	male	136	314	1321	2273	135	306	1319	2265
had	female	201	821	2018	2916	194	822	1958	2910
hard	female	196	722	1395	2241	191	646	1526	2089
hawed	female	198	772	1183	2870	194	783	1307	2848
hayed	female	201	455	2574	2998	196	415	2627	2998
head	female	203	637	2190	2977	197	639	2139	2980
heed	female	214	394	2821	3405	208	389	2825	3382
herd	female	207	512	1560	1964	199	496	1592	1957
hid	female	209	481	2287	3009	201	492	2219	3000
hod	female	198	838	1296	2866	194	824	1374	2855
hoed	female	200	495	1173	2810	196	456	1128	2790
hood	female	206	498	1578	2832	200	499	1681	2828
Hudd	female	199	678	1675	2910	195	644	1721	2887
who'd	female	214	412	1490	2749	207	397	1463	2725

Table 4.3 f/m-Ratios for English Vowels at Four Time Points

WORD	A0	B0	C0	D0	A1	B1	C1	D1	A2	B2	C2	D2
had	1.71	1.66	1.59	1.55	1.2	1.2	1.2	1.2	1.2	1.18	1.17	1.15
hard	1.71	1.65	1.58	1.54	1.25	1.22	1.16	1.09	1.2	1.23	1.24	1.2
hawed	1.67	1.6	1.55	1.53	1.23	1.17	1.17	1.21	1.1	1.11	1.14	1.22
hayed	1.7	1.63	1.56	1.53	1.12	1.11	1.08	1.08	1.23	1.22	1.2	1.21
head	1.67	1.6	1.54	1.5	1.18	1.19	1.2	1.21	1.19	1.18	1.17	1.16
heed	1.69	1.63	1.6	1.56	1.34	1.37	1.4	1.38	1.22	1.22	1.22	1.22
herd	1.74	1.68	1.61	1.55	1.07	1.07	1.08	1.07	1.13	1.14	1.13	1.14
hid	1.73	1.67	1.62	1.57	1.13	1.14	1.12	1.11	1.18	1.18	1.17	1.16
hod	1.68	1.62	1.56	1.53	1.28	1.23	1.19	1.18	1.12	1.12	1.13	1.14
hoed	1.67	1.6	1.55	1.52	1.1	1.06	1.05	1.04	1.11	1.07	1.08	1.05
hood	1.64	1.58	1.54	1.51	1.09	1.1	1.09	1.08	1.13	1.12	1.16	1.17
Hudd	1.66	1.62	1.57	1.54	1.21	1.18	1.15	1.12	1.22	1.23	1.23	1.21
who'd	1.71	1.64	1.58	1.54	1.25	1.25	1.31	1.3	1.1	1.12	1.13	1.11
Average Diff.												
	1.69	**1.63**	**1.57**	**1.54**	**1.19**	**1.18**	**1.17**	**1.16**	**1.16**	**1.16**	**1.17**	**1.16**

Word	A3	B3	C3	D3	Ave*F1	Ave*F2	Ave*F3	Ave*F1,F2,F3
had	1.17	1.17	1.16	1.15	1.2	1.18	1.16	1.18
hard	1.1	1.11	1.04	1.09	1.18	1.22	1.09	1.16
hawed	1.15	1.15	1.13	1.13	1.19	1.14	1.14	1.16
hayed	1.12	1.13	1.12	1.11	1.1	1.22	1.12	1.15
head	1.15	1.16	1.15	1.15	1.2	1.18	1.15	1.18
heed	1.13	1.13	1.13	1.13	1.37	1.22	1.13	1.24
herd	1.09	1.1	1.11	1.12	1.07	1.14	1.11	1.1
hid	1.13	1.13	1.13	1.14	1.12	1.17	1.13	1.14
hod	1.13	1.13	1.13	1.13	1.22	1.13	1.13	1.16
hoed	1.18	1.19	1.18	1.19	1.06	1.08	1.19	1.11
hood	1.2	1.19	1.19	1.18	1.09	1.14	1.19	1.14
Hudd	1.16	1.16	1.17	1.16	1.17	1.22	1.16	1.18
who'd	1.21	1.22	1.21	1.2	1.28	1.12	1.21	1.2
Average Diff.								
	1.15	**1.15**	**1.14**	**1.14**	**1.17**	**1.16**	**1.15**	**1.16**

For open vowels with an F_1 greater than 600 Hz (*had, hard, hawed, hod) ,* F_0 values were lower. This phenomenon is the well-known "vowel inherent pitch" effect (Lehiste, 1967) observed cross-linguistically. There was a strong negative correlation between F_1 and F_0 (r = - 0.79) for the male group. The correlation in female group was weaker (r = - 0.37).

From the f/m-Ratio table, it is seen that the f/m-Ratio in F_0 varied from an average of 1.69 to 1.54 across time points A and D. All the vowels were produced with a slightly higher F_0 initially, then F_0 decreased slowly as subjects reached the end of the syllable and the consonant [d]. For F_1, the average f/m-Ratio ranged from 1.19 to 1.16 across time points A and D. The f/m-Ratio shows the same decreasing trend as in F_0. This descending F_1 variation across time comes from the vowels in *hard* , *hod*, and *hudd*. For F_2 and F_3, there was not much variation across time. The f/m-Ratio in F_2 was 1.16 while that in F_3 was 1.15 to 1.14 across time points A and D. Thus, SRE can be applied across time points safely. The f/m-Ratio of individual vowel formants showed much variation from 1.1 in *herd* to 1.24 in *heed*. This variation has been attributed to differences in male and female vocal tract lengths (Nordstrom and Lindblom, 1975; Chiba and Kajiyama, 1941) and to the different relative sizes of mouth and pharynx cavities (Fant, 1975; Chiba and Kajiyama, 1941). When averages of A1 to D1, A2 to D2, A3 to D3 were computed (See columns of Ave*F1, Ave*F2, Ave*F3 of Table 4.3), a tendency towards formant-specific ratios was observed. This observation indicates that applying a single scale factor to female data will give rise to errors as pointed out by Fant (1975).

4.1.2 Korean Vowel Formants

The average values of Korean vowel formants were derived from three productions for each subject. For each vowel spoken by male or female speakers, there were thirty measurements at each time point (3 repetitions X10 subjects). Again, for each vowel, formant and time point, a female-to-male ratio (f/m-Ratio) was calculated according to equation **[20.]**. Table 4.4 and Table 4.5 list the average formant values for Korean male and female groups. Table 4.6 lists the f/m-Ratios.

Table 4.4 Average F_0 and Formant Values of Korean Vowels at Time Points A & B

WORD	SEX	A0	A1	A2	A3	B0	B1	B2	B3
hada	male	162	753	1368	2579	162	738	1372	2573
hEda	male	167	612	1879	2586	165	591	1849	2597
heda	male	168	484	1969	2653	167	490	1968	2644
hida	male	172	337	2230	3066	172	341	2219	3047
hoda	male	170	449	903	2665	170	453	945	2674
hweda	male	167	447	1797	2450	166	459	1817	2468
huda	male	175	362	948	2574	174	369	981	2565
hwida	male	175	334	2080	2665	174	338	2114	2729
h/\da	male	165	618	1107	2692	165	608	1121	2683
huuda	male	175	394	1487	2482	174	405	1488	2497
hada	female	270	1016	1796	2961	264	986	1794	2957
hEda	female	269	687	2281	3057	263	677	2285	3063
heda	female	268	660	2372	3047	263	650	2377	3068
hida	female	277	344	2840	3469	271	344	2814	3471
hoda	female	272	504	960	3083	269	499	1029	3068
hweda	female	269	606	2182	2994	265	602	2195	3013
huda	female	282	399	981	3012	278	422	1021	3024
hwida	female	276	369	2688	3195	272	373	2704	3222
h/\da	female	267	789	1349	3028	263	765	1371	3009
huuda	female	282	433	1666	3030	279	447	1703	2997

Table 4.5 Average F_0 and Formant Values of Korean Vowels

at Time Points C & D

WORD	SEX	C0	C1	C2	C3	D0	D1	D2	D3
hada	male	161	720	1390	2563	161	686	1421	2543
hEda	male	164	585	1826	2606	162	560	1809	2624
heda	male	166	490	1951	2647	164	478	1923	2651
hida	male	171	345	2221	3033	169	346	2199	3012
hoda	male	169	455	1019	2670	167	445	1089	2660
hweda	male	165	460	1830	2525	163	453	1826	2566
huda	male	172	375	1052	2555	170	375	1125	2576
hwida	male	172	343	2125	2783	170	343	2113	2798
h/\da	male	165	591	1144	2670	164	571	1186	2651
huuda	male	173	405	1508	2520	171	401	1552	2531
hada	female	261	952	1824	2967	259	919	1834	2939
hEda	female	260	654	2259	3069	258	630	2229	3088
heda	female	260	636	2362	3079	258	610	2324	3063
hida	female	268	348	2809	3459	266	346	2779	3437
hoda	female	267	496	1125	3037	265	490	1250	3025
hweda	female	262	583	2204	3035	260	577	2225	3055
huda	female	275	422	1116	3012	272	419	1242	3001
hwida	female	269	371	2701	3237	266	367	2693	3213
h/\da	female	261	737	1441	3029	259	709	1534	3041
huuda	female	276	456	1757	3007	274	457	1802	3002

Table 4.6 f/m-Ratios in Korean Vowels at Four Time Points

WORD	A0	B0	C0	D0	A1	B1	C1	D1	A2	B2	C2	D2
hada	1.66	1.63	1.62	1.60	1.35	1.34	1.32	1.34	1.31	1.31	1.31	1.29
hEda	1.61	1.60	1.59	1.59	1.12	1.14	1.12	1.12	1.21	1.24	1.24	1.23
heda	1.60	1.57	1.56	1.57	1.36	1.33	1.30	1.27	1.20	1.21	1.21	1.21
hida	1.61	1.58	1.57	1.57	1.02	1.01	1.01	1.00	1.27	1.27	1.26	1.26
hoda	1.60	1.59	1.58	1.58	1.12	1.10	1.09	1.10	1.06	1.09	1.10	1.15
hweda	1.61	1.59	1.59	1.59	1.35	1.31	1.27	1.28	1.21	1.21	1.20	1.22
huda	1.62	1.60	1.60	1.60	1.10	1.14	1.12	1.12	1.04	1.04	1.06	1.10
hwida	1.57	1.56	1.56	1.57	1.11	1.10	1.08	1.07	1.29	1.28	1.27	1.27
hʌda	1.62	1.59	1.58	1.58	1.28	1.26	1.25	1.24	1.22	1.22	1.26	1.29
huuda	1.61	1.60	1.60	1.60	1.10	1.10	1.13	1.14	1.12	1.14	1.17	1.16
Average Diff.	**1.61**	**1.59**	**1.58**	**1.59**	**1.19**	**1.18**	**1.17**	**1.17**	**1.19**	**1.20**	**1.21**	**1.22**

Word	A3	B3	C3	D3	Ave*F1	Ave*F2	Ave*F3	Ave*F1,F2,F3
hada	1.15	1.15	1.16	1.16	1.34	1.31	1.15	1.27
hEda	1.18	1.18	1.18	1.18	1.13	1.23	1.18	1.18
heda	1.15	1.16	1.16	1.16	1.32	1.21	1.16	1.23
hida	1.13	1.14	1.14	1.14	1.01	1.27	1.14	1.14
hoda	1.16	1.15	1.14	1.14	1.1	1.1	1.14	1.12
hweda	1.22	1.22	1.2	1.19	1.3	1.21	1.21	1.24
huda	1.17	1.18	1.18	1.16	1.12	1.06	1.17	1.12
hwida	1.2	1.18	1.16	1.15	1.09	1.28	1.17	1.18
hʌda	1.12	1.12	1.13	1.15	1.26	1.25	1.13	1.21
huuda	1.22	1.2	1.19	1.19	1.12	1.15	1.2	1.16
Average Diff.	**1.17**	**1.17**	**1.16**	**1.16**	**1.18**	**1.21**	**1.17**	**1.18**

For open vowels with more than 600 Hz in F_1 (*hada, hæda,* and *hʌda* in males) F_0 values were, the f/m-Ratios showed somewhat formant-specific variations across time. A strong negative correlation occurred between F_1 and

F_0 (r = - 0.84) for male group. The correlation in female group was weaker than males (r = - 0.57), but still strong.

The f/m-Ratios in F_0 range from an average of 1.61 to 1.59 across time points A and D. The f/m-Ratios decrease across time points A, B, C, and D, but the effect is smaller than in the English data. For F_1, the f/m-Ratio ranged from 1.19 to 1.16 across time points A and D. For F_2 the f/m-Ratio increased by 0.01 across the four time points. For F_3, there was not much variation across time. (See columns of Ave*F1, Ave*F2, and Ave*F3 of Table 4.6.).

The average f/m-Ratio of each vowel shows a wide variation from 1.04 of vowels in *huuda* to 1.40 in *hweda*. The average f/m-Ratio for the vowel in *hida* was 1.14 whereas for F_2 it was about 1.27. Since F2 of [i] depends on the length of the pharynx this value provides evidence for the non-uniform shortening of this cavity in the Korean data base.

4.1.3 Validity and Reliability of the Data

To check the validity, a correlation analysis was made between Peterson and Barney (1952) and the present English data. The Peterson and Barney data were chosen because of the corpus of male and female data, despite the criticism about the heterogeneous dialect of subjects involved (Nordstrom and Lindblom, 1975). The formant values of ten vowels in *had, hard, hawed, head, heed, herd, hid, hod, hood, Hudd,* and *who'd* at time point B were used for this analysis. Formant values at this time point were assumed to be comparable to those of Peterson and Barney (1952). Time point B fell at one third of the whole duration of each vowel from the vowel onset. There was a strong positive correlation between the two sets of data (r= 0.994 for F_nm; r= 0.992 for F_nf). The time point selection, modified methods of formant decision, and subjects with different dialects in both studies might lead to some variance in F_2 of *hard, hawed,* and *who'd*. The present data were collected using a visual procedure similar to that of Peterson and Barney who took a weighted average of the harmonics within a formant. These decisions were supported by automatically determined LPC-based estimates and by values for broad-band spectral peaks (the S-algorithm of KLSPEC). Because of the lack of comparable data, the Korean data could not be tested in the same way. However, since the method of data collection was the same as that for the English data, this study shall assume that its validity is comparable to that of the English data.

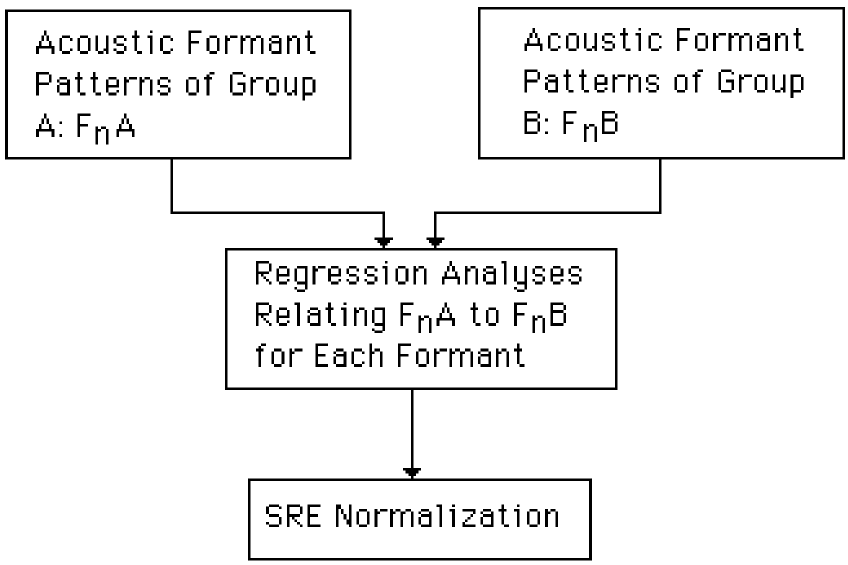
Only in a few cases such as nasalized vowels, harmonic interference, and missing formants within an expected range, formant values were rejected or recalculated. Between the two judges, there was a less than 5% disagreement on the formant position. This systematic disagreement was corrected after discussion. The four time points in the average data showed an almost perfect correlation (r > 0.99). Therefore, the time point selection did not have much affect on the formant values except for a few vowels followed by a consonant *r* or rounded vowels with rising F_2.

4.2 Vowel Normalization by SRE

The English and Korean data were normalized by SRE based on F_nf and F_nm. To see how the auditory scale, Bark, works in both sets of data, SRE based on B_nf and B_nm was also conducted. The two steps for the former version were as follows: (1) Find the regression equations that relate F_nf to F_nm for each formant, and (2) normalize the F_nf values to match the male reference patterns. For the latter version, an additional transformation of F_nf and F_nm into Bark units, was done before the two steps described above. After the normalization, an average Diff. (%) across the vowels was calculated by equation **[18.]** to see how successfully the normalized values match the male reference patterns.

The following diagram in Fig. 4.1 shows a model for normalization of two or more homogeneous groups within a language.

Fig. 4.1 Normalization of Vowels of Group A to Match Those of Group B within a Language



4.2.1 Normalized English Vowels

The thirteen English vowels were normalized as follows. First, the regression equations based on F_nf and F_nm were determined for each formant number.

$F_1f = 1.187 (F_1m) - 9.188$ $r^2 = 0.946$

$F_2f = 1.272 (F_2m) - 153.351$ $r^2 = 0.99$

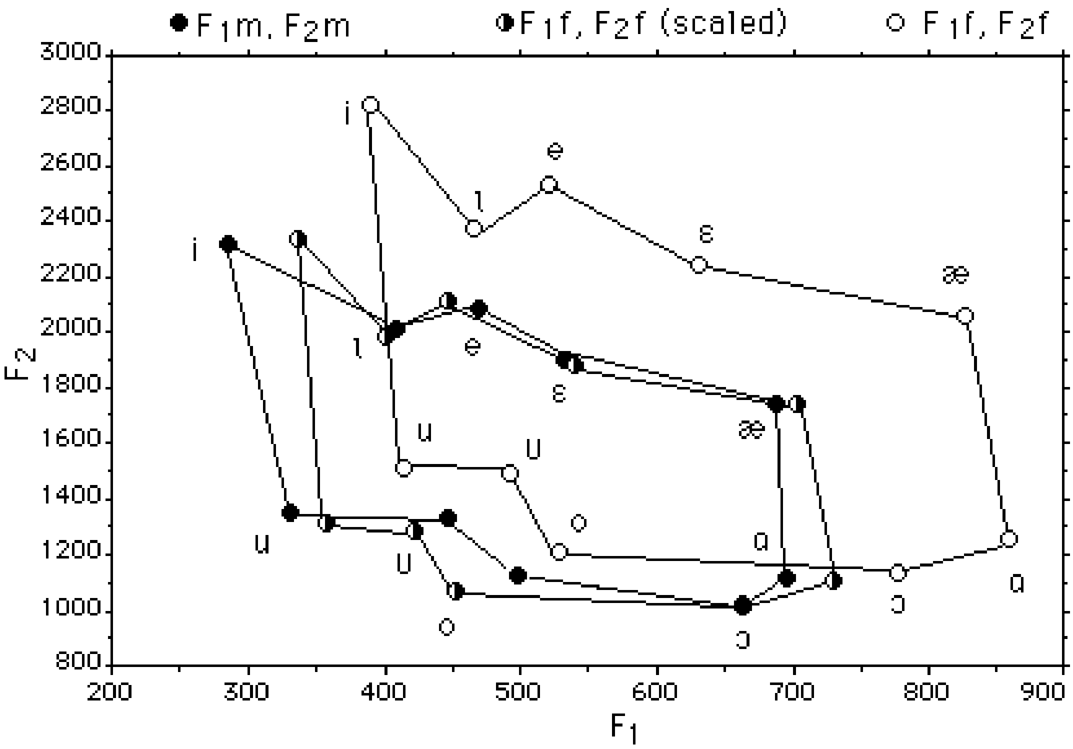
$F_3f = 1.132 (F_3m) + 36.533$ $r^2 = 0.942$

To exemplify F_1f= 796 for the vowel [a] at time point A. Its normalized value is denoted by F_1f (scaled) and is derived according to

$$F_1f\ (\text{scaled}) = (F_1f + 9.188) / 1.187$$
$$= (796 + 9.188)/ 1.187$$
$$= 678$$

The scaled values and Diff. (%) are tabulated in Appendix I-1-1. The grand average of Diff. was 3.71%. The major difference occurred in the vowel [i] with an average of 18% Diff. for F_1. This might come from the high F_0 of the female speakers. The first formant of [i] often coincided with the first harmonic which has negligible neighboring harmonics. Fig. 4.2 shows the English data scaled by this method. For clarity, only the formant values at time point B for ten vowels were plotted. F_nf (scaled) values are plotted as the half-filled circles.

Fig. 4.2 Chart for English Male, Female, and Normalized Female Vowels. The method is SRE based on $F_n f$ and $F_n m$.



Secondly, $F_n f$ and $F_n m$ were transformed into Bark units, B_1, B_2, and B_3 representing F_1, F_2, and F_3 in Bark. The regression equations for $B_n f$ as a function of $B_n m$ were determined for each formant number.

$B_1 f = 1.115\ (B_1 m) + 0.161$ $\quad r^2 = 0.945$

$B_2 f = 1.063\ (B_2 m) + 0.289$ $\quad r^2 = 0.983$

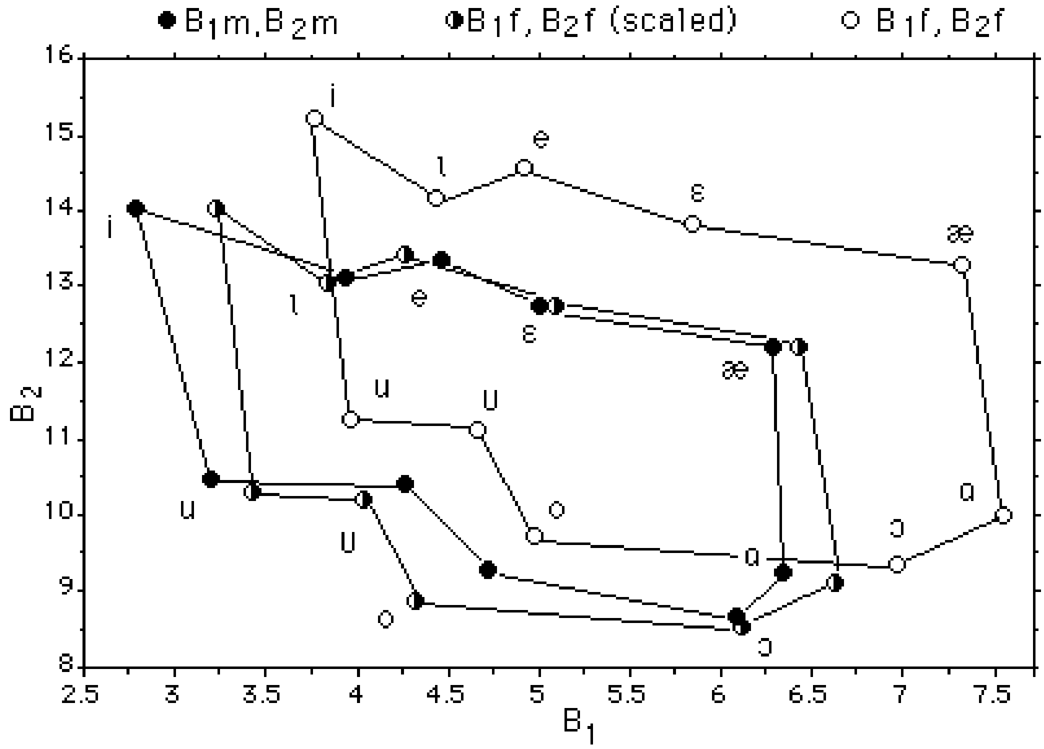
$B_3 f = 1.003\ (B_3 m) + 0.771$ $\quad r^2 = 0.947$

To exemplify, B_1f equals 7.11 for the vowel [a]. Its normalized value is denoted by B_1f (scaled) and is derived as follows:

$$B_1f\text{ (scaled)} = (B_1f - 0.161) / 1.115$$
$$= (7.11 - 0.161) / 1.115$$
$$= 6.232$$

The scaled values and Diff. (%) are listed in Appendix ł1-2. The grand average of Diff. was 2.76% which is 1% reduction in the grand average and the average Diff. of each formant number scaled by SRE based on F_nf and F_nm. Fig. 4.3 shows the English data scaled by this method. The half-filled circles represent the B_nf (scaled) values. B_1 and B_2 represent F_1 and F_2 in Bark units.

Fig. 4.3 Chart for English Male, Female, and Normalized Female Vowels. The method is SRE based on B_nf and B_nm.



4.2.2 Normalized Korean Vowels

The ten Korean vowels were normalized as follows. First, the regression equations for F_nf as a function of F_nm were determined for each formant number.

$F_1f = 1.506 (F_1m) - 146.854$ $\qquad r^2 = 0.957$

$F_2f = 1.359 (F_2m) - 224.922$ $\qquad r^2 = 0.982$

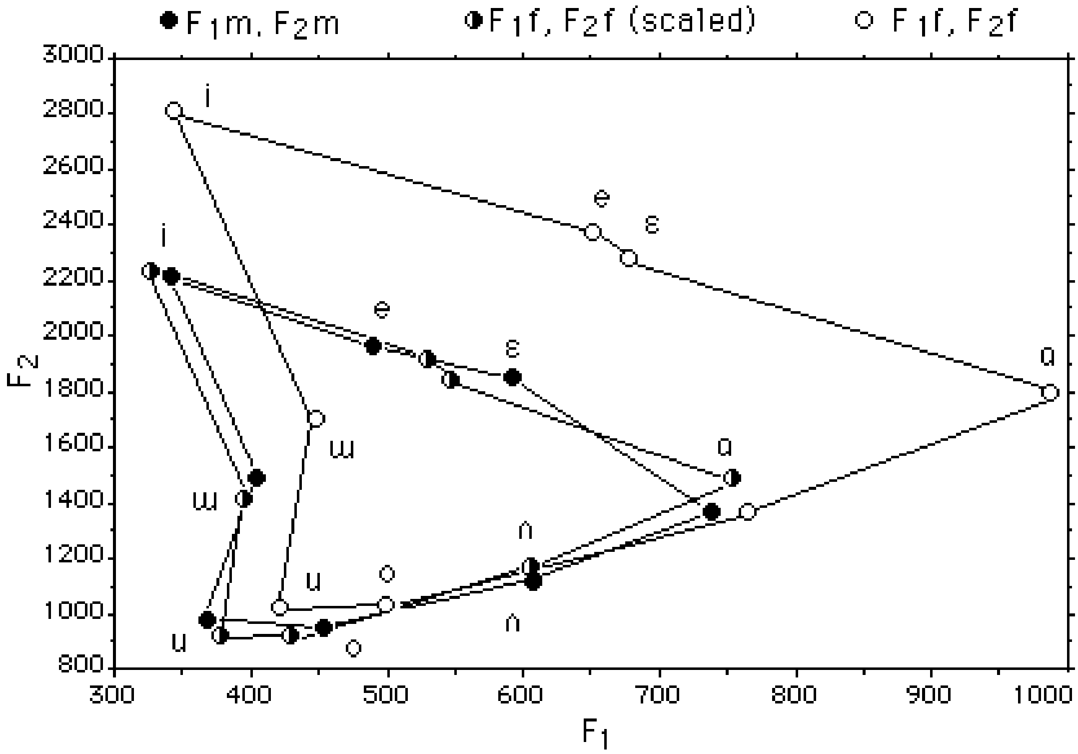
$F_3f = 0.864 (F_3m) + 797.933$ $\qquad r^2 = 0.863$

To exemplify, F_1f equals 1016 for the vowel [a] at time point A. Its normalized value is denoted by F_1f (scaled) and is calculated according to the following:

$$F_1f \text{ (scaled)} = (F_1f + 146.854) / 1.506$$
$$= (1016+146.854) / 1.506$$
$$= 772$$

The scaled values and average Diff. (%) are tabulated in Appendix I-2-1. The grand average of Diff. was 3.12%. The major Diff. comes from vowels in *heda and hEda*. The average F_1 values of [e] and [E] in Korean male were distinctive but not in females. The Diff. (%) in F_3 is less than 2 %. Fig. 4.4 shows the Korean data scaled by this method. The half-filled circles refer to the F_nf (scaled) values.

Fig. 4.4 Chart for Korean Male, Female, and Normalized Female Vowels. The method is SRE based on F_nf and F_nm.



Secondly, F_nf and F_nm were transformed into Bark units. The regression equations for B_nf as a function of B_nm were determined for each formant number.

$B_1f = 1.413\ (B_1m) - 1.094$ $r^2 = 0.956$

$B_2f = 1.126\ (B_2m) - 0.244$ $r^2 = 0.974$

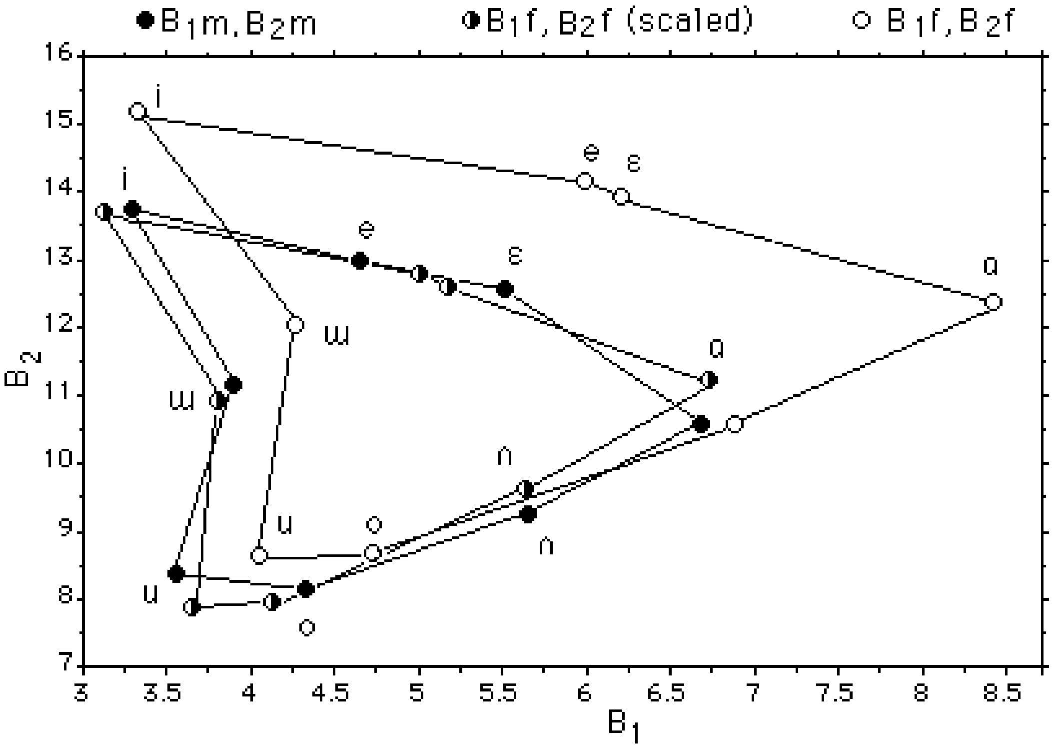
$B_3f = 0.685\ (B_3m) + 5.562$ $r^2 = 0.809$

For example, B_1f equals 8.61 for the vowel [a]. Denoting its normalized value by B_1f (scaled) one derives that value by means of

$$B_1f\text{ (scaled)} = (B_1f + 1.094) / 1.413$$
$$= (8.61 + 1.094) / 1.413$$
$$= 6.868$$

The scaled values and Diff. (%) are given in Appendix ł2-2. The grand average of Diff. was 2.27%. Here again, a further scatter reduction was observed compared with that of SRE based on F_nf and F_nm. Fig. 4.5 shows the Korean data scaled by this method. The half-filled circles are the B_nf (scaled) values.

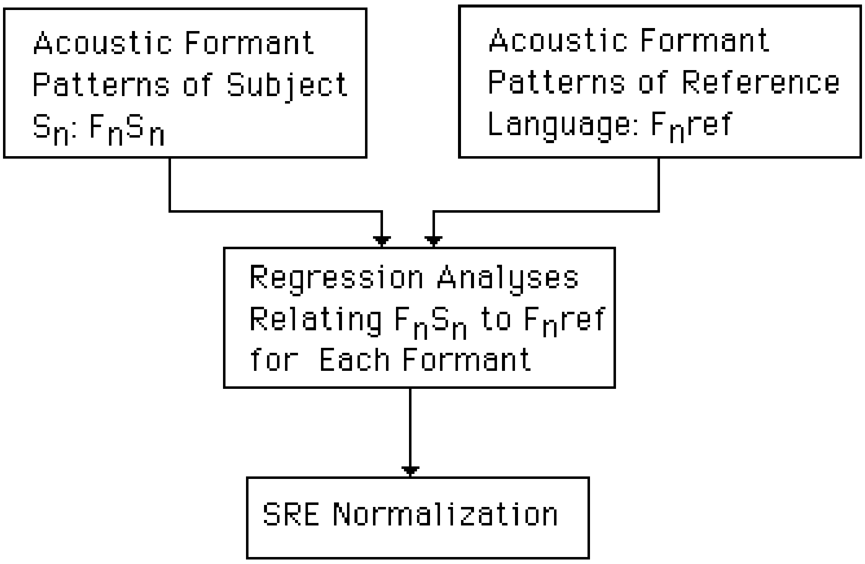
Fig. 4.5 Chart for Korean Male, Female, and Normalized Female Vowels. The method is SRE based on B_nf and B_nm.



4.3 Individual Speaker Normalization within a Language

In testing the performance of foreign language learners, not only group data need normalizing but more often the output of an individual speaker. The procedure works in the same manner as illustrated by the following discussion which is limited to a single American subject. The formant patterns of subject S_n (F_nS_n) were plotted against the average values ($F_n$ref) of the subject's language group. The regression line for F_nS_n as a function of $F_n$ref was determined for each formant. Then, the SRE normalization as described earlier was carried out. The following diagram in Fig 4.6 illustrates the conceptualization.

Fig. 4.6 Normalization of Vowels of an Individual Subject to Match Those of a Reference Vowel System of a Language



For example, the following regression equations were observed for English female subject 11 and the average male reference data:

$F_1S_{11} = 1.113\ (F_1ref) + 39.951 \qquad r^2 = 0.919$

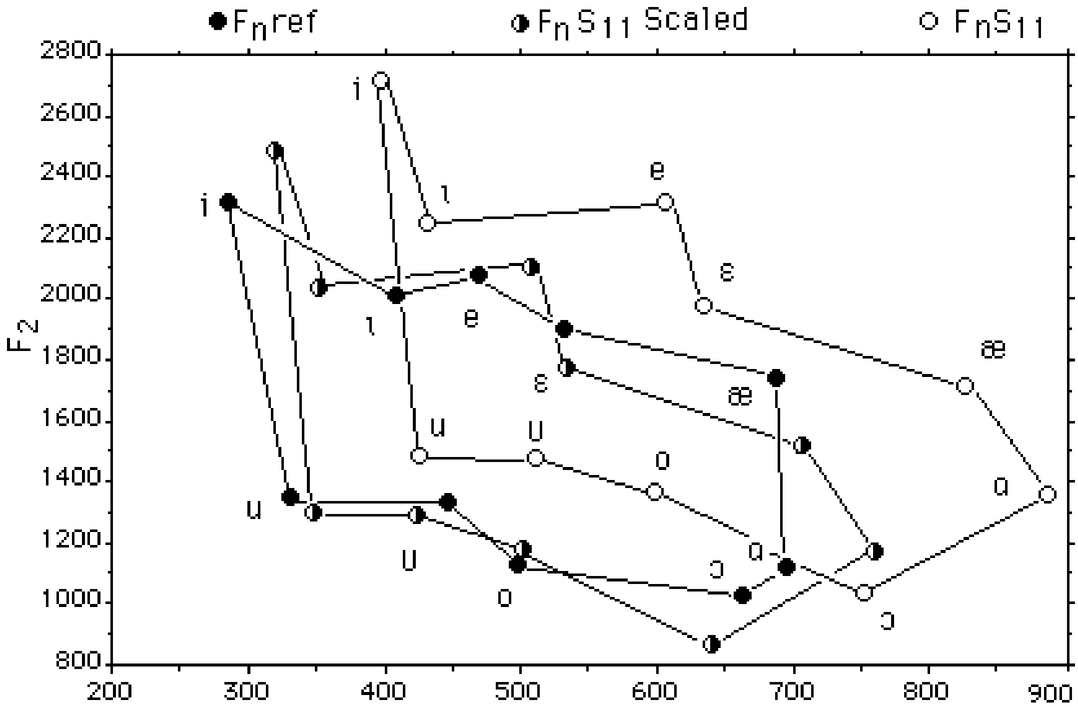
$F_2S_{11} = 1.032\ (F_2ref) + 145.682 \qquad r^2 = 0.941$

$F_3S_{11} = 0.866\ (F_3ref) + 703.626 \qquad r^2 = 0.74$

The explanatory power of these equations is strong with high r^2 values. The normalized values are tabulated in Appendix J. The grand average of Diff.

was 6.31%. Major difference is observed in the vowels [i, ɪ] due to the male-female pharyngeal difference. The following Fig. 4.7 shows how well the scaled F_nS_{11} match the male reference data.

Fig. 4.7 Chart for English Male, Female Subject 11 Normalized Individually to the Reference English Vowel System



The half-filled circles are clearly close to the male data points. However, certain differences remain. Are they significant or not? Do they indicate that the phonetic qualities of Speaker 11 are different from those of the reference system? Before answering these questions this study shall compare normalized English and Korean vowels and discuss the question whether SRE can be supplemented. Consideration of F_0 and vocal tract length will be recommended.

Although such additional factors no doubt merit serious attention, it is nevertheless of interest to touch upon the implications of this section for measuring "foreign accent." The relevant measure suggested by the present work is the differences between the reference system's values and those of the learner. More work is clearly needed to refine the procedures explored here. However, once an empirically validated normalization procedure is established, observed discrepancies between learner and reference vowels should offer a basis of quantification.

4.4 A Comparative Study of Normalized English and Korean Vowels

This section describes a comparative study of normalized English and Korean vowels and discusses some of the problems still remaining in the development of SRE for a cross-linguistic comparison. After the general comparison of normalized English and Korean vowels, the non-linguistic factors such as F_0, overall vocal tract length, and length of mouth cavity and pharynx will be discussed to illustrate some possible future research towards the goal of quantitative and acoustic cross-linguistic comparisons.

Fig. 4.8 shows a chart for English and Korean male vowels superimposed, while Fig. 4.9 illustrates a chart for normalized English and Korean female vowels. The filled squares indicate the English vowel positions. The filled circles show the Korean vowel positions. Also, the Korean vowels are underlined to distinguish them from the English vowels. To show the vowel space of each language, adjacent vowel points are connected peripherally. A thicker line connects English vowels, while a thinner line connects Korean vowels. The author notes a few large discrepancies, for example, the [u] vowels differ markedly. This difference is no doubt phonetically genuine since it matches informal auditory impressions of these vowels. Also the Korean vowel space as a whole appears to be displaced to higher F_1 values. This observation will be discussed below in connection with Fig. 4.7.

Fig. 4.8 Vowel Chart Comparing the English and Korean Vowels
of Male Speakers

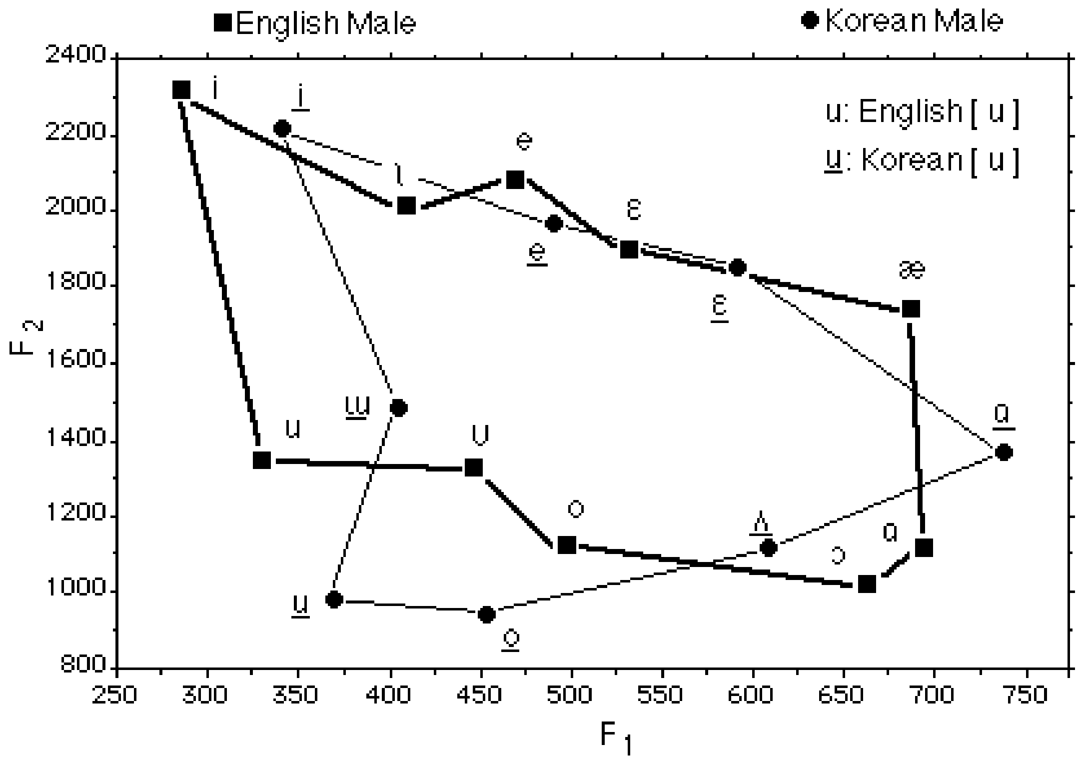
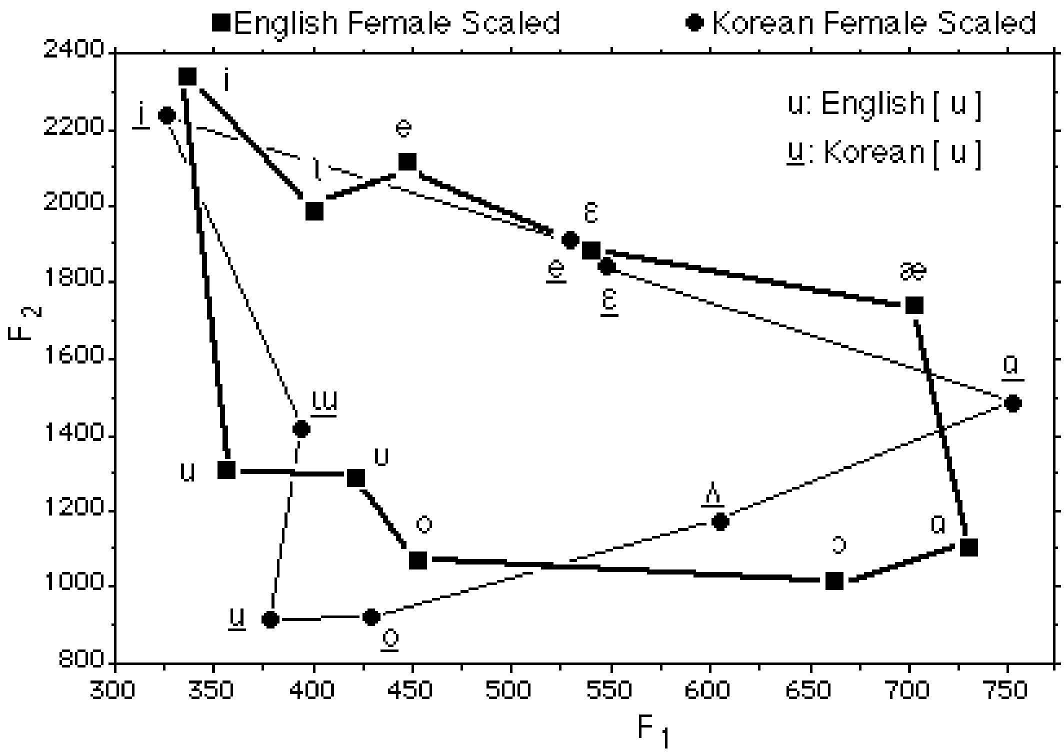


Fig. 4. 9 Vowel Chart Comparing the Normalized English and

Korean Vowels of Female Speakers



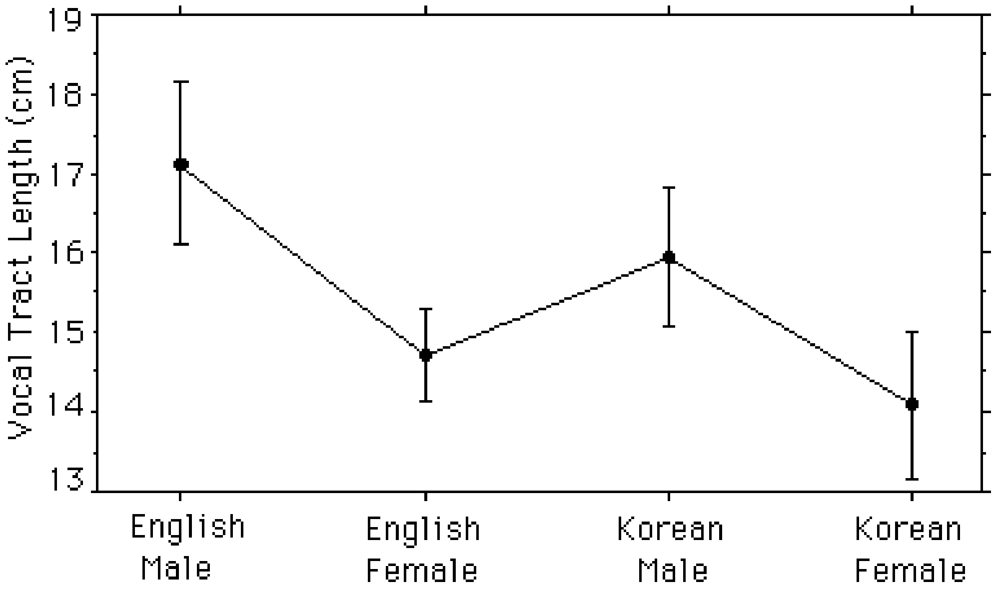
In the figure above, the English vowel space appears rectangular, while that of Korean appears triangular. For the open vowel [a] , the Korean value falls between English [æ] and [a]. The Korean vowel [i] is close to the English tense vowel [i]. The Korean vowel [e] is close to English [E] . Korean [E] is produced between English [E] and [æ]. Korean rounded vowels [u, o] are much lower in F_2 than those of English. [E] and [æ] in English are distinctive, but not in Korean spoken by females. Korean vowel [uu] is placed between English tense [u] and lax [U]. In general, the Korean vowel space appears systematically higher in the F_1 dimension than that of English. In the F_2 dimension, an expansion is observed in the vowels whose F_1 is lower than 550 Hz, while a contraction is observed in the vowels whose F_1 is higher than 550 Hz. From such observations one notes that there are still differences that are highly systematic between languages. Therefore, one can ask whether a further normalization may need eliminating all the non-linguistic factors for a cross-linguistic comparison.

The following discussion focuses on three factors that are not yet considered in the cross-linguistic comparison. The first is fundamental frequency. The average F_0 in English was 130 Hz for males and 208 Hz for females, while in Korean it was 168 Hz for males and 268 Hz for females (See Appendix K for individual and average F_0 for each group). Do slopes and intercepts for SRE's for individual female subjects compared with male reference data co-vary in systematic ways with F_0? If so, how can such observations be used to further refine SRE? If not, why is scaling of female formant values independent of F_0? These are possible and urgent questions for future investigations.

A possible answer can be made once the "F0-induced compensatory space expansion" hypothesis (Lindblom and Diehl in personal conversation) is tested and confirmed. They observed that the formants of female speakers were less well defined with sparsely-found harmonics. Thus, the high F_0 leads to a wide distance between the harmonics because harmonics are integral multiples of the F_0. Therefore, the females tend to disperse the peripheral vowels more peripherally to achieve a safety margin for "sufficient perceptual contrast." This way the formant peaks would be better defined with more supporting harmonics. This hypothesis suggests that this expansion seems somewhat non-uniform from a fixed point of vowel [u] corner on the vowel space. Thus, F_0 can serve an independent source of speaker normalization. The present data showed a strong negative correlation between F_0 and F_1 in males. But the correlation was almost negligible with F_0 versus F_2 or F_3. This low correlation might come from the homogeneous group setting and normal production of speech materials.

Another factor is overall vocal tract length. The overall vocal tract length of English subjects was estimated from the F_3 of the vowel in *Hudd* using equation **[1.]**. The vocal tract length of Korean subjects was estimated from the F_3 of the vowel in *hʌda.* To improve accuracy, the average value of F_3 at time points B and C was used to determine the estimated length. The individual vocal tract length estimates are presented in Appendix K. The average vocal tract length was 17.1 cm for American males and 14.6 cm for females while the corresponding Korean values were 15.9 cm for males and 14.1 cm for females. Fig. 4.10 shows average values and +/- one standard deviation.

Fig. 4.10 Average Vocal Tract Length of English and Korean Groups and +/- One Standard Deviation



From the figure above, one can clearly see that vocal tract length varies considerably across groups. This finding is fully compatible with the uniform shift of the Korean male vowel space to higher F_1 values observed in Fig. 4.8. The comparison of the English and Korean males shows about 1 cm difference in the figure above. For a more precise comparison, the vocal tract length of the two language groups should be normalized. If the difference of the mean vocal tract length is great between two languages, any comparison would be biased. This study adopts the Nordstrom and Lindblom model (1975) for this purpose. The vocal tract ratio of American and Korean subjects was calculated applying equation **[11.]**. The English vowels are set for a reference system for the normalization. Here, an average of open vowels whose F_1 is greater than 600

Hz for English males (F_3mEng) and the equivalent of Korean (F_3mKor) are calculated by

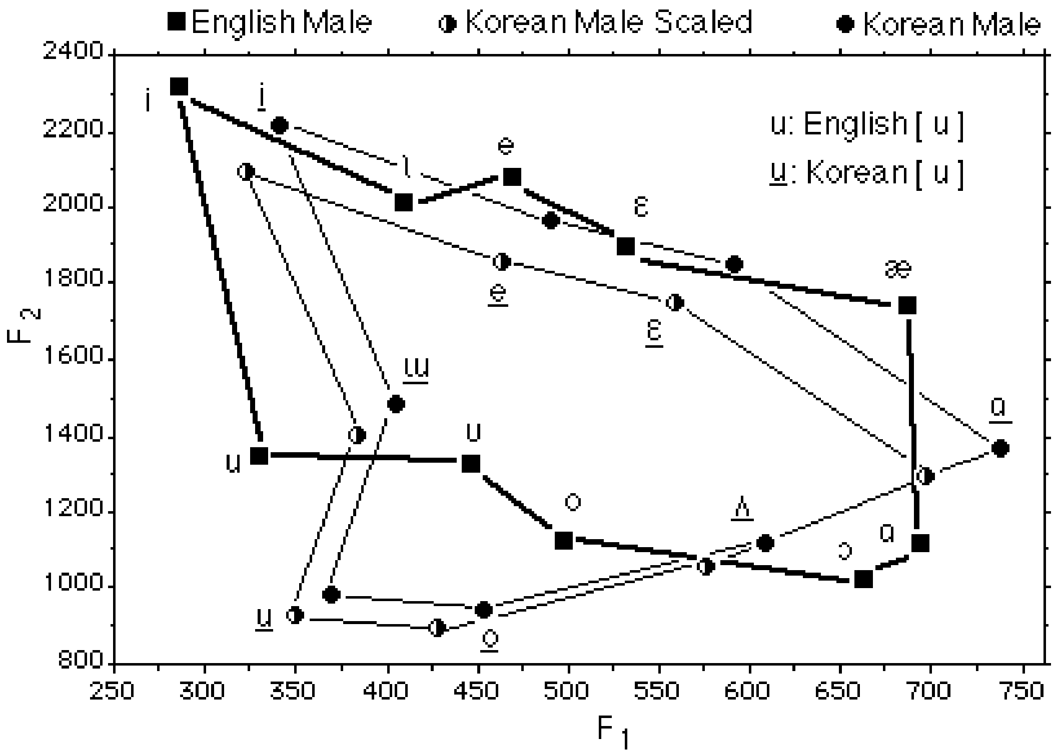
$$F_3mEng = (2497+2318+2527+2548)/4$$
$$= 2472.5$$
$$F_3mKor = (2573+2597+2683)/3$$
$$= 2617.7$$

Then, a uniform scale factor k was determined according to

$$k = F_3mEng / F_3mKor$$
$$= 0.945$$

This scale factor was applied uniformly to the Korean male data. Fig. 4.11 shows the vowel chart of English male and normalized Korean male data by this procedure.

Fig. 4.11 Vowel Chart of English and Korean Males, and Normalized Korean Males. The method is the uniform scaling for F_nmEng as a function of F_nmKor.



This figure shows that the overall vowel space of Korean approximates the English space in the F_1 dimension. However, the normalization results in the greater departure in the F_2 dimension from that of English vowel space. Thus, this uniform correction seems not perfect. A possible solution can be pursued to adjust the F_1 and F_2 dimensions separately, as was done in SRE within a language.

A third factor is the possibility of differences between scale factors relating male and female pharynx lengths on the one hand and scale factors relating male and female mouth cavity lengths on the other. Lengths of pharynges and mouth cavities were estimated from the vowel of English *heed* and Korean *hida* using equations **[2.]** and **[3.]**. Table 4.7 lists these estimates from the present English and Korean data as well as the Dutch, English, and Swedish data discussed in Chapter 2.

Table 4.7 Length of Back Tube (LB), Front Tube (LF) and Their Difference (LB - LF). The estimates are based on formant patterns of [i].

Language	English	Korean	Dutch	English*	Swedish	Average
Male						
LB	7.3	7.7	8.2	7.7	7.4	**7.7**
LF	5.6	5.6	5.7	6.2	5.7	**5.8**
LB-LF	1.7	2.1	2.5	1.5	1.7	**1.9**
Female						
LB	6	6.1	6.8	6.8	6.1	**6.3**
LF	5	4.9	5	5.6	5.1	**5.1**
LB-LF	1	1.2	1.8	1.2	1	**1.2**
Male-Female						
LBm-LBf	1.3	1.6	1.4	0.9	1.3	**1.4**
LFm-LFf	0.6	0.7	0.7	0.6	0.6	**0.7**

* Peterson and Barney (1952)

There are clear differences between speaker categories and languages. Generally, male speakers have a back tube that is longer than the front tube. The average difference in the front tube of male and female across the languages is small (0.7 cm), but the difference in the back tube is almost twice that of the front tube (1.3 cm). As argued in Fant (1975), this circumstance contributes to making scale factors vowel- and formant-number-specific.

To what extent are these anatomical factors captured by the SRE-equations? The average vocal tract length and differences in LB and LF for the normalized English and Korean data within each language were calculated. In English, the LB/LF difference for the male and female scaled was 0.07 cm for LB and 0.09 cm for LF while in Korean, the difference was 0.06 cm for LB and 0.07 cm for LF. The general vocal tract length of the female scaled also approached to that of male: In English, the difference was 0.3 cm while in Korean 0.6 cm. These numbers indicates that SRE removed almost all the non-linguistic factors within a language. However, the problem still remains for a cross-linguistic comparison. To what extent do these non-linguistic factors provide a basis for further improvements of the method for a cross-linguistic comparison? Simulation experiments along the lines of Nordstrom and Lindblom (1975) should shed light on these questions.

From these considerations, it seems that the present comparison of normalized English and Korean vowels is incomplete since various non-linguistic factors are still present to some extent. In other words, the SRE adjusted F_nf to F_nm within a language so that the non-linguistic difference between the two languages remained in the comparison. The average F_0 difference between English and Korean males was about 38 Hz; vocal tract length difference was 1 cm with a slight back tube difference. Further normalization will be necessary if future experimentation shows that those aspects are associated with significant changes in the perceptual qualities of vowels.

CHAPTER 5. CONCLUSIONS, IMPLICATIONS, AND RECOMMENDATIONS

5.1 Review

The acoustic correlates of vowel quality are the formant frequencies. However, vowels spoken by different native speakers show great variation in formant values. This complicates the acoustic comparison of vowels spoken by speakers of different dialect and language backgrounds and necessitates the use of normalization procedures to remove the effect of non-linguistic factors.

The goals of the present study were: (1) to develop linguistically relevant normalization procedures for specifying vowel quality, (2) to apply these procedures to sets of new formant frequency data collected from American and Korean male and female adults , and (3) to make a comparative study of normalized English and Korean vowels.

In a review of the literature this study examined various non-linguistic speaker-dependent sources of variation from the perspectives of talker and listener. The talker-oriented variation was discussed in terms of the vocal tract length, F_0, and the difference in pharynx and mouth cavity. The Quantal Theory and the Theory of Adaptive Dispersion were mentioned as possible sources of listener-oriented variation. Then, auditorily-based and articulatorily-based scaling methods were reviewed. On the basis of the review this study proposed SRE (Scaling by Regression Equation), a new scaling method made possible by the observation that for a given language, female formant frequencies can be predicted with high accuracy from male values using linear regression equations. This study evaluated two versions of the SRE method: one using formant values in Hz, the other using the values in Bark units and compared these versions with other procedures in terms of minimization of male and scaled female differences in the several data bases.

To test these proposals on the new sets of data, a total of forty adults were chosen to form homogeneous groups of ten American males, ten American females, ten Korean males, and ten Korean females. The selection was based on a questionnaire from each subject and peer judgment made after listening to randomly-chosen speech samples. Thirteen English and ten Korean vowels were studied from the speech samples of three repetitions chosen from sixty-seven English and fifty-two Korean words produced at normal speed. Then, formant values at four time points (22,080 data cells in grand total) were obtained. The two versions of SRE were applied to establish the linguistic qualities of English and Korean vowels before a comparative study of the normalized English and Korean vowels.

5.2 Principal Findings and Conclusions

The principal findings are as follows:

1. A strong positive correlation between male and female formant frequencies was observed in English, Dutch, Swedish, and Korean. Since these new databases were homogeneous with respect to linguistic factors, the speaker-dependent variation was attributed to non-linguistic factors such as vocal tract length, F_0, and difference in mouth cavity and pharynx.

2. An assumption was made that the normalized female formant frequencies should closely match those of the male speakers, if all the non-linguistic factors could be corrected, and if the vowel samples were linguistically homogeneous (i.e., if speakers use the same set of vowel qualities). From this assumption, two versions of a new normalization procedure were proposed. An application of these proposals to English, Swedish, and Dutch resulted in considerable improvement over the previous proposals both as regards simplicity and accuracy.

3. Using the SRE method based on Bark calibration of formants this study demonstrated a further reduction of male-female differences in the five language sets.

4. A comparative study of normalized English and Korean vowels was undertaken. From that investigation this paper concluded that the SRE method needs to consider F_0 dependence as well as estimates of length for overall vocal tract length and individual cavities for a cross-linguistic comparison. These topics identify areas where future research efforts are likely to be fruitful.

This study of normalized English and Korean vowels takes steps towards the development of new methods and approaches in phonetic research, foreign language teaching, and automatic speech recognition.

5.3 Pedagogical Implications

This study provides much insight into the English and Korean vowel systems. The normalized vowel space will be helpful in foreign language education. Because the acoustic values reflect physiological movement, English or Korean pronunciations can be taught more effectively from these vowel studies. For foreign language teachers, a comparative study of normalized vowel qualities of the target and native languages may help find persistent errors which are due to the different vowel systems of L_1 and L_2 before instruction. Instead of teaching the whole vowel system of a foreign language, the teacher may save time by basing curriculum and instruction on the different aspects on two vowel systems. By individual normalization, the pronunciation level can be evaluated. This time non-linguistic factors are removed so that linguistic judgment on the vowel qualities can be made. Although arguments continue on supplying "comprehensible Input" in second language acquisition instead of practice and interaction (Krashen, 1981, 1982, 1985; McLaughlin,1978, 1987), the teaching would be more productive and balanced by incorporating both comprehensible input and practice.

5.4 Recommendations

The sources of speaker variation are numerous. This study focused on a few of these non-linguistic factors, vocal tract length, F_0, and differences between mouth cavity and pharynx, which were observed in male and female speakers. Further studies on this relation between other non-linguistic factors and the formant values are desirable to find an independent source of normalization of any speaker of any language.

A study on the relation between the regression equation and non-linguistic factors may provide an independent source of normalization. Furthermore, a study on the relation between sociolinguistic or emotional state of the speaker and changing formants is recommended. All these experiments should be evaluated by an auditory judgment on the scaled values.

APPENDICES

Appendix A Dutch, English, and Swedish Data Scaled

A-1-1. Dutch Uniformly- and Non-Uniformly Scaled

Vowel	No	Male	Female	Fant's kn	Uniscld	Diff.(%)	NonUniscld	Diff(%).
u	F1	339	320	6	299	11.76	312	7.87
o	F1	487	505	7	472	3.06	491	0.80
o	F1	523	578	11	540	3.32	553	5.75
a	F1	679	762	17	712	4.91	712	4.91
a	F1	795	986	25	922	15.94	894	12.49
E	F1	583	669	19	625	7.27	621	6.46
e	F1	407	471	11	440	8.18	451	10.73
I	F1	388	465	11	435	12.04	445	14.67
i	F1	294	276	7	258	12.24	268	8.74
y	F1	305	288	0	269	11.73	288	5.57
oe	F1	438	490	7	458	4.58	476	8.75
ø	F1	443	476	5	445	0.45	466	5.29
u	F2	810	842	1	787	2.82	839	3.53
o	F2	911	961	5	898	1.39	942	3.37
o	F2	866	933	6	872	0.72	911	5.15
a	F2	1051	1117	12	1044	0.65	1065	1.30
a	F2	1301	1443	15	1349	3.69	1359	4.49
E	F2	1725	1905	18	1781	3.24	1774	2.85
e	F2	2017	2352	22	2199	9.01	2157	6.96
I	F2	2003	2262	22	2115	5.57	2075	3.59
i	F2	2208	2510	21	2346	6.27	2311	4.67
y	F2	1730	1832	19	1713	1.00	1700	1.76
oe	F2	1498	1688	18	1578	5.34	1572	4.94
ø	F2	1497	1690	16	1580	5.54	1586	5.94
u	F3	2323	2746	23	2567	10.51	2509	8.02
o	F3	2481	2608	17	2438	1.73	2438	1.73
o	F3	2692	2852	13	2666	0.96	2708	0.58
a	F3	2619	2752	15	2573	1.77	2593	1.01
a	F3	2565	2778	15	2597	1.25	2617	2.03
E	F3	2471	2788	20	2606	5.48	2577	4.28
e	F3	2553	2895	18	2706	6.01	2696	5.60
I	F3	2571	2840	18	2655	3.27	2645	2.87
i	F3	2766	3046	13	2848	2.95	2892	4.55
y	F3	2208	2520	17	2356	6.69	2356	6.69
oe	F3	2354	2568	17	2401	1.98	2401	1.98
ø	F3	2260	2512	16	2348	3.91	2357	4.31
				Average Diff.		**5.2**		**5.12**

A-1-2. Dutch Scaled by SRE Based on k_n vs. F_nf, log (F_nf) vs. log (F_nm)

Vowel	No	Male	kn/Fnf	Diff.(%)	log(Fnf/m)	Diff. (%)
u	F1	339	307	9.58	321	5.37
o	F1	487	459	5.84	465	4.52
o	F1	523	514	1.67	519	0.77
a	F1	679	645	4.97	650	4.29
a	F1	795	789	0.81	801	0.81
E	F1	583	581	0.40	585	0.27
e	F1	407	432	6.10	439	7.95
I	F1	388	427	10.06	435	12.06
i	F1	294	268	8.88	284	3.26
y	F1	305	279	8.68	294	3.46
oe	F1	438	447	2.01	454	3.59
ø	F1	443	436	1.63	443	0.03
u	F2	810	801	1.14	803	0.82
o	F2	911	903	0.92	908	0.33
o	F2	866	879	1.49	883	2.02
a	F2	1051	1033	1.76	1044	0.70
a	F2	1301	1291	0.76	1323	1.69
E	F2	1725	1630	5.49	1711	0.82
e	F2	2017	1932	4.23	2080	3.11
I	F2	2003	1873	6.49	2006	0.14
i	F2	2208	2032	7.96	2209	0.03
y	F2	1730	1579	8.75	1650	4.62
oe	F2	1498	1475	1.55	1530	2.12
ø	F2	1497	1476	1.39	1531	2.30
u	F3	2323	2351	1.19	2505	7.82
o	F3	2481	2223	10.42	2334	5.94
o	F3	2692	2450	9.00	2638	1.99
a	F3	2619	2356	10.03	2512	4.08
a	F3	2565	2381	7.19	2545	0.78
E	F3	2471	2390	3.28	2557	3.50
e	F3	2553	2490	2.46	2693	5.49
I	F3	2571	2439	5.15	2623	2.03
i	F3	2766	2633	4.80	2888	4.40
y	F3	2208	2142	3.01	2226	0.83
oe	F3	2354	2186	7.15	2285	2.94
ø	F3	2260	2134	5.57	2217	1.92
			Average Diff.	**4.77**		**2.97**

A-1-2. Dutch Scaled by SRE Based on F_nf vs. F_nm, B_nf vs. B_nm

Vowel	No	Fnfscld	Diff.(%)	Bnm	Bnf	Bnfscld	Diff.(%)
u	F1	321	5.30	3.29	3.11	3.10	5.73
o	F1	459	5.70	4.62	4.78	4.40	4.86
o	F1	514	1.80	4.94	5.40	4.88	1.08
a	F1	651	4.10	6.22	6.86	6.02	3.29
a	F1	818	2.90	7.10	8.42	7.23	1.78
E	F1	582	0.24	5.44	6.14	5.46	0.29
e	F1	434	6.60	3.91	4.48	4.17	6.57
I	F1	429	10.70	3.74	4.43	4.13	10.40
i	F1	288	1.90	2.86	2.69	2.77	3.11
y	F1	297	2.50	2.97	2.81	2.86	3.52
oe	F1	448	2.30	4.19	4.65	4.30	2.56
ø	F1	438	1.20	4.23	4.53	4.20	0.78
u	F2	807	0.31	7.21	7.44	7.12	1.27
o	F2	907	0.39	7.92	8.26	7.88	0.59
o	F2	884	2.10	7.61	8.07	7.70	1.20
a	F2	1039	1.20	8.83	9.23	8.78	0.60
a	F2	1312	0.88	10.24	10.94	10.36	1.19
E	F2	1701	1.40	12.13	12.78	12.07	0.47
e	F2	2076	2.90	13.15	14.11	13.31	1.23
I	F2	2001	0.11	13.10	13.87	13.08	0.14
i	F2	2209	0.05	13.72	14.51	13.68	0.33
y	F2	1639	5.20	12.15	12.52	11.84	2.57
oe	F2	1518	1.40	11.19	11.98	11.33	1.32
ø	F2	1520	1.50	11.18	11.99	11.34	1.42
u	F3	2494	7.30	14.04	15.04	14.46	3.03
o	F3	2323	6.40	14.44	14.74	14.03	2.82
o	F3	2625	2.50	14.93	15.26	14.77	1.03
a	F3	2501	4.50	14.76	15.06	14.48	1.92
a	F3	2533	1.20	14.64	15.11	14.56	0.56
E	F3	2546	3.00	14.41	15.13	14.59	1.20
e	F3	2678	4.90	14.61	15.35	14.89	1.95
I	F3	2610	1.50	14.65	15.24	14.74	0.58
i	F3	2864	3.50	15.09	15.64	15.31	1.46
y	F3	2215	0.30	13.72	14.53	13.74	0.15
oe	F3	2274	3.40	14.12	14.65	13.90	1.54
ø	F3	2205	2.40	13.87	14.51	13.71	1.10
	Average Diff.		**2.88**				**2.04**

A-2-1. English Uniformly- and Non-Uniformly Scaled

Vowel	No	Male	Female	Fant's kn	Uniscld	Diff.(%)	NonUniscld	Diff(%).
i	F1	270	310	7	262	3.04	288	6.73
I	F1	390	430	11	363	6.89	384	1.47
E	F1	530	610	19	515	2.80	506	4.54
æ	F1	660	860	27	726	10.04	666	0.84
a	F1	730	850	17	718	1.67	718	1.66
o	F1	570	590	11	498	12.59	527	7.50
U	F1	440	470	3	397	9.79	455	3.46
u	F1	300	370	6	312	4.16	347	15.81
/\	F1	640	760	18	642	0.28	636	0.61
3'	F1	490	500	2	422	13.83	489	0.12
i	F2	2290	2790	21	2356	2.89	2273	0.73
I	F2	1990	2480	22	2094	5.24	2003	0.66
E	F2	1840	2330	18	1968	6.94	1950	5.98
æ	F2	1720	2050	17	1731	0.65	1731	0.66
a	F2	1090	1220	12	1030	5.48	1080	0.94
o	F2	840	920	6	777	7.51	864	2.85
U	F2	1020	1160	12	980	3.96	1027	0.65
u	F2	870	950	1	802	7.78	940	8.03
/\	F2	1190	1400	18	1182	0.65	1172	1.54
3'	F2	1350	1640	21	1385	2.59	1336	1.02
i	F3	3010	3310	13	2795	7.13	2902	3.60
I	F3	2550	3070	18	2593	1.67	2569	0.76
E	F3	2480	2990	20	2525	1.82	2458	0.89
æ	F3	2410	2850	18	2407	0.13	2385	1.03
a	F3	2440	2810	15	2373	2.74	2418	0.92
o	F3	2410	2710	13	2289	5.04	2376	1.42
U	F3	2240	2680	18	2263	1.04	2243	0.13
u	F3	2240	2670	23	2255	0.66	2138	4.56
/\	F3	2390	2780	16	2348	1.77	2370	0.85
3'	F3	1690	1960	16	1655	2.06	1671	1.14
					Average Diff.	**4.43**		**2.7**

A-2-2. English Scaled by SRE Based on k_n vs. F_nf, log (F_nf) vs. log (F_nm)

Vowel	No	Male	kn/Fnf	Diff.(%)	log(Fnf/m)	Diff. (%)
i	F1	270	302	12.03	274	1.52
I	F1	390	401	2.77	378	3.04
E	F1	530	533	0.53	533	0.62
æ	F1	660	691	4.67	748	13.27
a	F1	730	685	6.17	739	1.24
o	F1	570	519	8.96	516	9.46
U	F1	440	432	1.90	413	6.21
u	F1	300	353	17.58	326	8.73
/\	F1	640	631	1.44	662	3.44
3'	F1	490	454	7.31	439	10.49
i	F2	2290	2254	1.57	2228	2.69
I	F2	1990	2044	2.72	2008	0.93
E	F2	1840	1939	5.41	1901	3.31
æ	F2	1720	1738	1.08	1698	1.28
a	F2	1090	1096	0.52	1074	1.43
o	F2	840	844	0.51	838	0.27
U	F2	1020	1046	2.57	1028	0.76
u	F2	870	870	0.01	862	0.95
/\	F2	1190	1241	4.32	1213	1.94
3'	F2	1350	1430	5.94	1395	3.31
i	F3	3010	2839	5.69	2869	4.70
I	F3	2550	2629	3.09	2647	3.81
E	F3	2480	2559	3.19	2574	3.77
æ	F3	2410	2437	1.12	2445	1.46
a	F3	2440	2402	1.55	2409	1.29
o	F3	2410	2315	3.94	2317	3.85
U	F3	2240	2289	2.19	2290	2.22
u	F3	2240	2280	1.80	2281	1.82
/\	F3	2390	2376	0.59	2381	0.37
3'	F3	1690	1666	1.40	1640	2.97
			Average Diff.	**3.75**		**3.02**

A-2-3. English Scaled by SRE Based on F_nf vs. F_nm and B_nf vs. B_nm.

Vowel	No	Fnfscld	Diff.(%)	Bnm	Bnf	Bnfscld	Diff.(%)
i	F1	287	6.20	2.64	3.01	2.75	4.5
I	F1	384	1.50	3.76	4.12	3.7	1.5
E	F1	530	0.05	5	5.67	5.03	0.6
æ	F1	733	11.10	6.07	7.57	6.66	9.64
a	F1	725	0.68	6.62	7.5	6.6	0.33
o	F1	514	9.80	5.33	5.5	4.88	8.45
U	F1	417	5.30	4.21	4.47	4	4.83
u	F1	335	11.80	2.92	3.57	3.23	10.7
/\	F1	652	1.90	5.91	6.84	6.03	2.09
3'	F1	441	10.00	4.65	4.74	4.23	9.04
i	F1	2889	4.00	13.95	15.14	13.71	1.74
I	F1	2660	4.30	13.06	14.44	13.08	0.17
E	F2	2583	4.20	12.55	14.05	12.74	1.53
æ	F2	2450	1.60	12.11	13.25	12.03	0.65
a	F2	2411	1.20	9.07	9.81	8.97	1.04
o	F2	2316	3.90	7.43	7.98	7.35	1.09
U	F2	2287	2.10	8.64	9.48	8.67	0.44
u	F2	2278	1.70	7.64	8.18	7.53	1.5
/\	F2	2383	0.30	9.64	10.73	9.79	1.52
3'	F2	1600	5.40	10.49	11.79	10.73	2.34
i	F2	2245	2.00	15.57	16.11	15.28	1.91
I	F2	2011	1.10	14.6	15.68	14.81	1.43
E	F2	1899	3.20	14.44	15.53	14.65	1.46
æ	F2	1688	1.90	14.26	15.26	14.34	0.57
a	F3	1063	2.40	14.34	15.18	14.25	0.59
o	F3	838	0.29	14.26	14.97	14.02	1.7
U	F3	1018	0.18	13.81	14.9	13.95	0.99
u	F3	860	1.10	13.81	14.88	13.92	0.82
/\	F3	1199	0.74	14.21	15.11	14.18	0.19
3'	F3	1379	2.20	11.99	12.96	11.82	1.46
		Average Diff.	**3.41**				**2.49**

A-3-1. Swedish Uniformly- and Non-Uniformly Normalized

Vowel	No	Male	Female	Fant's kn	Uniscld	Diff.(%)	NonUniscld	Diff(%).
i *il	F1	256	278	7	239	6.63	261	1.76
I*e1	F1	334	365	11	314	6.03	330	1.14
E*a"1	F1	438	545	19	469	6.99	461	5.26
æ*a"3	F1	606	785	27	675	11.39	624	2.90
a*a2	F1	680	860	17	739	8.75	739	8.75
o*a'2	F1	487	518	11	445	8.54	469	3.78
U*u2	F1	416	410	3	353	15.25	399	4.20
u*o1	F1	307	340	6	292	4.77	322	4.73
/*o"3	F1	524	565	18	486	7.29	482	8.04
i *il	F2	2066	2520	21	2167	4.88	2098	1.53
I*e1	F2	2050	2540	22	2184	6.54	2098	2.32
E*a"1	F2	1795	2140	18	1840	2.51	1825	1.68
æ*a"3	F2	1550	1820	17	1565	0.96	1565	0.96
a*a2	F2	1070	1195	12	1028	3.97	1072	0.16
o*a'2	F2	825	840	6	722	12.45	794	3.72
U*u2	F2	1070	1175	12	1010	5.58	1054	1.52
u*o1	F2	730	690	1	593	18.73	683	6.38
/*o"3	F2	1103	1290	18	1109	0.56	1100	0.26
i *il	F3	2960	3450	13	2967	0.22	3068	3.64
I*e1	F3	2510	2950	18	2537	1.06	2516	0.23
E*a"1	F3	2385	2860	20	2459	3.11	2400	0.62
æ*a"3	F3	2450	2950	18	2537	3.53	2516	2.69
a*a2	F3	2520	2830	15	2433	3.44	2474	1.82
o*a'2	F3	2560	2825	13	2429	5.11	2512	1.88
U*u2	F3	2315	2700	18	2322	0.29	2303	0.53
u*o1	F3	2230	2900	23	2494	11.82	2376	6.55
/*o"3	F3	2430	2730	16	2347	3.40	2367	2.60
					Average Diff.	**6.07**		**2.95**

*Fant's notation

A-3-2. Swedish Scaled by SRE Based on k_n vs. F_nf, log (F_nf) vs. log (F_nm)

Vowel	No	Male	kn/Fnf	Diff.(%)	log(Fnf/m)	Diff. (%)
i *il	F1	256	263	2.61	264	3.25
I*e1	F1	334	337	0.77	335	0.30
E*a"1	F1	438	479	9.30	475	8.42
æ*a"3	F1	606	649	7.02	652	7.66
a*a2	F1	680	698	2.58	706	3.87
o*a'2	F1	487	458	5.90	454	6.71
U*u2	F1	416	373	10.23	371	10.89
u*o1	F1	307	316	2.84	315	2.59
/*o"3	F1	524	494	5.78	490	6.49
i *il	F2	2066	2056	0.48	2025	1.98
I*e1	F2	2050	2069	0.95	2038	0.57
E*a"1	F2	1795	1796	0.06	1770	1.42
æ*a"3	F2	1550	1565	0.98	1548	0.12
a*a2	F2	1070	1080	0.92	1094	2.26
o*a'2	F2	825	782	5.27	818	0.84
U*u2	F2	1070	1063	0.61	1079	0.84
u*o1	F2	730	650	10.94	695	4.73
/*o"3	F2	1103	1157	4.88	1165	5.66
i *il	F3	2960	3011	1.73	3171	7.12
I*e1	F3	2510	2523	0.52	2545	1.39
E*a"1	F3	2385	2437	2.19	2436	2.16
æ*a"3	F3	2450	2523	2.98	2545	3.87
a*a2	F3	2520	2409	4.42	2401	4.74
o*a'2	F3	2560	2404	6.09	2395	6.46
U*u2	F3	2315	2286	1.24	2247	2.93
u*o1	F3	2230	2475	11.00	2484	11.41
/*o"3	F3	2430	2314	4.76	2282	6.08
			Average Diff.	**3.96**		**4.25**

A-3-3. Swedish Scaled by SRE Based on F_nf vs. F_nm and B_nf vs. B_nm

Vowel	No	Fnfscld	Diff.(%)	Bnm	Bnf	Bnfscld	Diff.(%)
i *il	F1	276	7.8	2.5	2.71	2.65	5.95
I*e1	F1	339	1.4	3.24	3.53	3.27	1.04
E*a"1	F1	469	7.1	4.19	5.12	4.49	7.19
æ*a"3	F1	643	6.1	5.63	7.03	5.95	5.54
a*a2	F1	697	2.5	6.23	7.57	6.36	2.06
o*a'2	F1	450	7.7	4.62	4.89	4.31	6.67
U*u2	F1	371	10.7	3.99	3.94	3.59	10.16
u*o1	F1	321	4.5	2.99	3.29	3.1	3.68
/*o"3	F1	484	7.7	4.94	5.29	4.62	6.56
i *il	F1	2055	0.52	13.3	14.53	13.17	1
I*e1	F1	2070	1	13.25	14.58	13.21	0.34
E*a"1	F1	1775	1.1	12.39	13.52	12.33	0.52
æ*a"3	F2	1540	0.66	11.42	12.48	11.46	0.34
a*a2	F2	1080	0.9	8.95	9.67	9.11	1.84
o*a'2	F2	818	0.83	7.32	7.43	7.24	1.15
U*u2	F2	1065	0.48	8.95	9.56	9.02	0.8
u*o1	F2	708	3.1	6.62	6.31	6.3	4.77
/*o"3	F2	1150	4.2	9.14	10.18	9.54	4.29
i *il	F2	3099	4.7	15.48	16.33	15.9	2.71
I*e1	F2	2530	0.8	14.51	15.46	14.57	0.45
E*a"1	F2	2428	1.8	14.2	15.28	14.31	0.75
æ*a"3	F2	2530	3.3	14.36	15.46	14.57	1.48
a*a2	F2	2394	5	14.53	15.22	14.21	2.2
o*a'2	F2	2388	6.7	14.63	15.21	14.2	2.94
U*u2	F3	2246	3	14.02	14.94	13.8	1.55
u*o1	F3	2473	10.9	13.78	15.36	14.43	4.67
/*o"3	F3	2280	6.2	14.31	15.01	13.9	2.91
	Average Diff.		**4.1**				**3.09**

Appendix B

Miller's APS and Syrdal and Gopal's Bark-Difference Dimensions for the Unnormalized and Normalized Peterson and Barney Data

B-1-1. Coordinates for Miller's Auditory-Perceptual Space (1989) for the Peterson and Barney Data Unnormalized

Vowel	SEX	SR	log SF1	log SF2	log SF3	x	y	z
i	male	2.19	2.43	3.36	3.48	0.12	0.24	0.93
I	male	2.19	2.59	3.30	3.41	0.11	0.40	0.71
E	male	2.19	2.72	3.26	3.39	0.13	0.54	0.54
æ	male	2.18	2.82	3.24	3.38	0.15	0.63	0.42
a	male	2.18	2.86	3.04	3.39	0.35	0.68	0.17
o	male	2.19	2.76	2.92	3.38	0.46	0.57	0.17
U	male	2.20	2.64	3.01	3.35	0.34	0.45	0.37
u	male	2.20	2.48	2.94	3.35	0.41	0.28	0.46
/\	male	2.19	2.81	3.08	3.38	0.30	0.62	0.27
3'	male	2.19	2.69	3.13	3.23	0.10	0.50	0.44
i	female	2.27	2.49	3.45	3.52	0.07	0.22	0.95
I	female	2.27	2.63	3.39	3.49	0.09	0.36	0.76
E	female	2.27	2.79	3.37	3.48	0.11	0.52	0.58
æ	female	2.26	2.93	3.31	3.45	0.14	0.68	0.38
a	female	2.26	2.93	3.09	3.45	0.36	0.67	0.16
o	female	2.26	2.77	2.96	3.43	0.47	0.51	0.19
U	female	2.27	2.67	3.06	3.43	0.36	0.40	0.39
u	female	2.27	2.57	2.98	3.43	0.45	0.30	0.41
/\	female	2.27	2.88	3.15	3.44	0.30	0.62	0.27
3'	female	2.26	2.70	3.21	3.29	0.08	0.44	0.52

Vowel	Diff.(%)	xm-xf	ym-yf	zm-zf
i		37.49	8.10	2.78
I		13.93	9.05	7.52
E		16.45	3.18	7.67
æ		2.32	6.64	9.31
a		3.54	1.69	9.86
o		2.50	10.49	14.57
U		6.45	10.64	7.45
u		9.27	7.08	11.44
/\		1.63	0.35	1.50
3'		20.65	12.58	17.21
Average Diff.		**11.42**	**6.98**	**8.93**
Grand Average Diff. **9.11**				

B-1-2. Coordinates for Miller's Auditory-Perceptual Space (1989) of the Peterson and Barney Data Normalized by SRE Based on log (F_nf) and log (F_nm)

Vowel	SEX	SR	log SF1	log SF2	log SF3	x	y	z
i	male	2.19	2.43	3.36	3.48	0.12	0.24	0.93
I	male	2.19	2.59	3.30	3.41	0.11	0.40	0.71
E	male	2.19	2.72	3.26	3.39	0.13	0.54	0.54
æ	male	2.18	2.82	3.24	3.38	0.15	0.63	0.42
a	male	2.18	2.86	3.04	3.39	0.35	0.68	0.17
o	male	2.19	2.76	2.92	3.38	0.46	0.57	0.17
U	male	2.20	2.64	3.01	3.35	0.34	0.45	0.37
u	male	2.20	2.48	2.94	3.35	0.41	0.28	0.46
/\	male	2.19	2.81	3.08	3.38	0.30	0.62	0.27
3'	male	2.19	2.69	3.13	3.23	0.10	0.50	0.44
i	female	2.20	2.44	3.35	3.46	0.11	0.24	0.91
I	female	2.20	2.58	3.30	3.42	0.12	0.38	0.73
E	female	2.19	2.73	3.28	3.41	0.13	0.54	0.55
æ	female	2.18	2.87	3.23	3.39	0.16	0.69	0.36
a	female	2.18	2.87	3.03	3.38	0.35	0.69	0.16
o	female	2.19	2.71	2.92	3.36	0.44	0.53	0.21
U	female	2.20	2.62	3.01	3.36	0.35	0.42	0.40
u	female	2.20	2.51	2.94	3.36	0.42	0.32	0.42
/\	female	2.19	2.82	3.08	3.38	0.29	0.63	0.26
3'	female	2.19	2.64	3.14	3.21	0.07	0.45	0.50

Vowel	Diff.(%)	xm-xf	ym-yf	zm-zf
i		7.62	0.68	1.98
I		11.35	4.38	2.46
E		1.49	0.09	2.12
æ		8.11	8.98	14.35
a		0.17	0.48	6.65
o		3.47	7.46	24.91
U		1.84	6.63	8.51
u		2.91	14.19	8.76
/\		3.29	2.09	2.35
3'		27.93	8.91	14.15
Average Diff.		**6.82**	**5.39**	**8.63**
Grand Average Diff. **6.94**				

B-2-1. Coordinates for Syrdal and Gopal's Bark-Difference Dimensions (1986) for the Peterson and Barney Data Unnormalized

Vowel	SEX	B0	B1	B2	B3	x	y	z
i	male	1.34	2.64	13.95	15.57	1.30	11.31	1.62
I	male	1.33	3.76	13.06	14.60	2.43	9.31	1.54
E	male	1.28	5.00	12.55	14.44	3.71	7.56	1.88
æ	male	1.25	6.07	12.11	14.26	4.82	6.04	2.15
a	male	1.22	6.62	9.07	14.34	5.40	2.45	5.27
o	male	1.27	5.33	7.43	14.26	4.06	2.10	6.83
U	male	1.35	4.21	8.64	13.81	2.86	4.43	5.17
u	male	1.39	2.92	7.64	13.81	1.53	4.72	6.17
/\	male	1.28	5.91	9.64	14.21	4.63	3.73	4.57
3'	male	1.31	4.65	10.49	11.99	3.34	5.84	1.50
i	female	2.30	3.01	15.14	16.11	0.71	12.12	0.97
I	female	2.27	4.12	14.44	15.68	1.85	10.32	1.25
E	female	2.19	5.67	14.05	15.53	3.48	8.39	1.48
æ	female	2.06	7.57	13.25	15.26	5.51	5.68	2.01
a	female	2.08	7.50	9.81	15.18	5.42	2.31	5.37
o	female	2.12	5.50	7.98	14.97	3.38	2.48	6.98
U	female	2.27	4.47	9.48	14.90	2.20	5.00	5.42
u	female	2.26	3.57	8.18	14.88	1.31	4.61	6.69
/\	female	2.17	6.84	10.73	15.11	4.68	3.89	4.38
3'	female	2.14	4.74	11.79	12.96	2.60	7.06	1.17

Vowel	Diff.(%)	xm-xf	ym-yf	zm-zf
i		44.97	7.15	40.25
I		23.90	10.88	19.04
E		6.28	11.00	21.43
æ		14.36	5.93	6.76
a		0.48	5.69	1.82
o		16.73	18.51	2.17
U		22.95	12.93	4.82
u		14.45	2.30	8.48
/\		1.07	4.10	4.03
3'		22.15	20.85	22.18
Average Diff.		**16.74**	**9.94**	**13.1**
Grand Average Diff. **13.26**				

B-2-2. Coordinates for Syrdal and Gopal's Bark-Difference Dimensions (1986) for the Peterson and Barney Data Normalized by SRE Based on $B_n f$ and $B_n m$

Vowel	SEX	B0	B1	B2	B3	x	y	z
i	male	1.34	2.64	13.95	15.57	1.30	11.31	1.62
I	male	1.33	3.76	13.06	14.60	2.43	9.31	1.54
E	male	1.28	5.00	12.55	14.44	3.71	7.56	1.88
æ	male	1.25	6.07	12.11	14.26	4.82	6.04	2.15
a	male	1.22	6.62	9.07	14.34	5.40	2.45	5.27
o	male	1.27	5.33	7.43	14.26	4.06	2.10	6.83
U	male	1.35	4.21	8.64	13.81	2.86	4.43	5.17
u	male	1.39	2.92	7.64	13.81	1.53	4.72	6.17
/\	male	1.28	5.91	9.64	14.21	4.63	3.73	4.57
3'	male	1.31	4.65	10.49	11.99	3.34	5.84	1.50
i	female	1.38	2.75	13.70	15.29	1.37	10.95	1.59
I	female	1.36	3.70	13.08	14.83	2.34	9.38	1.74
E	female	1.30	5.03	12.74	14.66	3.72	7.72	1.92
æ	female	1.22	6.66	12.03	14.36	5.44	5.37	2.33
a	female	1.23	6.60	8.97	14.27	5.36	2.37	5.30
o	female	1.26	4.88	7.35	14.03	3.63	2.46	6.69
U	female	1.36	4.00	8.67	13.96	2.64	4.67	5.29
u	female	1.35	3.23	7.52	13.94	1.88	4.29	6.41
/\	female	1.29	6.03	9.79	14.20	4.74	3.75	4.41
3'	female	1.27	4.23	10.73	11.82	2.96	6.50	1.09

Vowel	Diff.(%)	xm-xf	ym-yf	zm-zf
i		6.11	3.22	2.29
I		3.56	0.82	13.11
E		0.22	2.11	1.84
æ		12.80	11.03	8.13
a		0.60	3.08	0.49
o		10.77	17.52	2.14
U		7.48	5.38	2.20
u		22.69	9.09	3.92
/\		2.48	0.55	3.47
3'		11.40	11.36	27.29
Average Diff.		**7.81**	**6.42**	**6.49**
Grand Average Diff. **6.91**				

Appendix C
Background Questionnaire

C-1. Questionnaire for English Subjects.

*Please fill in the blank or check yes or no.

Name: ________________ (First) ______________ (Last)

Sex: Male __________ Female ___________

Height: __________ feet _________inches (__________ cm)

Age: _____________

Native Language(s): 1. _______________

2.________________

Other languages you speak fluently: 1. ________________

2.________________ 3. ______________

Area where you have spent most of your life:

England________ Canada_________ Mexico__________

U.S.A.: Eastern New England_______ New York City________

Southern________ Middle Atlantic_____ Northwest______

Western Pennsilvania______Southwest_______

Southern Mountain________ Central Midland_______

North Central__________ Other Countries_______________

Health: Missing teeth __________ Cold ________

Laryngotomy ___________ Tonsilectomy __________

C-2. Questionnaire for Korean Subjects.

*Please fill in the blank or check yes or no.

Name: __________________ (First) ________________ (Last)

Sex: Male ___________ Female ____________

Height:___________ cm

Age: ______________

Native Language: Korean

Other languages you speak fluently: 1. _________________

2.__________________ 3. _______________

I was born in : Seoul________

Other place___________ (If yes, when did you move into

Seoul____________________ U.S._________________)

Education in Seoul: Public school________ Middle school_________

High school_________ College____________

Period of stay in the U.S. ___________year(s) _________month(s)

Parents' dialect: Father_____________ Mother ______________

Health: Missing teeth ___________ Cold _________

Laryngotomy ____________ Tonsilectomy ___________

Appendix D

Characteristics of Subjects

D-1. English Subjects

SUBJECT	SEX	DIALECT	AGE	HEIGHT(cm)
S1	male	Southwest	21	183
S2	male	Southwest	21	180
S3	male	Southwest	20	178
S4	male	Southwest	19	170
S5	male	Southwest	24	193
S6	male	Southern	18	180
S7	male	Southwest	18	178
S8	male	Southwest	23	165
S9	male	Southwest	25	183
S10	male	Southwest	20	198
S11	female	Southwest	19	165
S12	female	Southern	22	157
S13	female	Southern	20	165
S14	female	Southern	26	168
S15	female	Southern	30	173
S16	female	Southern	37	168
S17	female	Southwest	25	163
S18	female	Southern	37	163
S19	female	Southwest	37	157
S20	female	Southwest	31	157

D-2. Korean Subjects

SUBJECT	SEX	DIALECT	AGE	HEIGHT(cm)
s1	male	Seoul	32	161
s2	male	Seoul	31	180
s3	male	Seoul	34	160
s4	male	Seoul	27	174
s5	male	Seoul	29	175
s6	male	Seoul	24	175
s7	male	Seoul	29	170
s8	male	Seoul	30	164
s9	male	Seoul	30	173
s10	male	Seoul	26	175
s11	female	Seoul	28	163
s12	female	Seoul	29	158
s13	female	Seoul	25	162
s14	female	Seoul	22	155
s15	female	Seoul	33	153
s16	female	Seoul	21	157
s17	female	Seoul	27	165
s18	female	Seoul	32	167
s19	female	Seoul	35	156
s20	female	Seoul	29	156

Appendix E

Speech Samples

E-1. English Speech Samples

1.head	22.had	43.hid
2.heed	23.hood	44.Hudd
3.hard	24.Hudd	45.hawed
4.hoed	25.hid	46.herd
5.who'd	26.hod	47.head
6.hid	27.head	48.hard
7.had	28.hard	49.had
8.herd	29.hawed	50.herd
9.hayed	30.who'd	51.hood
10.Hudd	31.hoed	52.Hudd
11.heed	32.heed	53.hod
12.hard	33.hood	54.who'd
13.hod	34.had	55.hid
14.head	35.herd	56.hoed
15.who'd	36.hawed	57.heed
16.hid	37.head	58.had
17.hayed	38.heed	59.hod
18.hawed	39.who'd	60.head
19.Hudd	40.hod	61.hood
20.hoed	41.hard	62.hawed
21.heed	42.hoed	

E-1. Korean Speech Samples

1. hada
2. hida
3. huda
4. hɛda
5. huuda
6. hwida
7. hada
8. hoda
9. hʌda
10. hida
11. heda
12. hweda
13. huuda
14. hida
15. hɛda
16. hoda
17. huda
18. hada
19. heda
20. hʌda
21. hweda
22. hɛda
23. hida
24. huuda
25. hoda
26. hida
27. hada
28. hʌda
29. hweda
30. hida
31. huuda
32. hwida
33. huda
34. hʌda
35. hoda
36. hwida
37. hada
38. huda
39. hɛda
40. hweda
41. heda
42. hʌda
43. hwida
44. huuda
45. hoda
46. hada
47. huda
48. heda
49. hweda
50. hɛda
51. hwida
52. heda

Appendix F

Answer Sheet for Homogeneous Dialect Screening and Analyses of English and Korean Subjects

F-1-1. Answer Sheet for English Subjects

Name ____________________

Directions: You will hear a set of ten different male (Part I) and female (Part II) subjects saying the same word. Just listen. This will be repeated. Then, you will hear four sets of five sounds randomly drawn from the set. From the five sounds, please check one or more that deviate from your own dialect (assuming the sounds are in the order of 1, 2, 3, 4, 5). If you think all the five sounds are spoken by speakers of a dialect similar to yours, please check the column, *all homogeneous.*

Part I. English Male Subjects:

A. Just listen to two sets of ten heed's. Then, check the appropriate column(s) when you hear the following five sounds.

	1	2	3	4	5	All homogeneous
1.	||	||	||	||	||	||
2.	||	||	||	||	||	||
3.	||	||	||	||	||	||
4.	||	||	||	||	||	||

B. Just listen to two sets of ten had's. Then, check the appropriate column(s) when you hear the following five sounds.

1 2 3 4 5 All homogeneous

1. || || || || || ||

2. || || || || || ||

3. || || || || || ||

4. || || || || || ||

C. Just listen to two sets of ten hard's. Then, check the appropriate column(s) when you hear the following five sounds.

1 2 3 4 5 All homogeneous

1. || || || || || ||

2. || || || || || ||

3. || || || || || ||

4. || || || || || ||

D. Just listen to two sets of ten who'd's. Then, check the appropriate column(s) when you hear the following five sounds.

1 2 3 4 5 All homogeneous

1. || || || || || ||

2. || || || || || ||

3. || || || || || ||

4. || || || || || ||

Part II. English Female Subjects:

*Part II consists of the same format as in Part I.

F-1-2. Answer Sheet for Korean Subjects

Name ____________________

Directions: You will hear a set of ten different male (Part I) and female (Part II) subjects saying the same word. Just listen. This will be repeated. Then, you will hear four sets of five sounds randomly drawn from the set. From the five sounds, please check one or more that deviate from your own dialect (assuming the sounds are in the order of 1, 2, 3, 4, 5). If you think all the five sounds are spoken by speakers of a dialect similar to yours, please check the column, *all homogeneous*.

Part I. Korean Male Subjects:

A. Just listen to two sets of ten hida's. Then, check the appropriate column(s) when you hear the following five sounds.

	1	2	3	4	5	All homogeneous
1.	| |	| |	| |	| |	| |	| |
2.	| |	| |	| |	| |	| |	| |
3.	| |	| |	| |	| |	| |	| |
4.	| |	| |	| |	| |	| |	| |

B. Just listen to two sets of ten hɛda's. Then, check the appropriate column(s) when you hear the following five sounds.

1 2 3 4 5 All homogeneous

1. || || || || || ||

2. || || || || || ||

3. || || || || || ||

4. || || || || || ||

C. Just listen to two sets of ten hada's. Then, check the appropriate column(s) when you hear the following five sounds.

1 2 3 4 5 All homogeneous

1. || || || || || ||

2. || || || || || ||

3. || || || || || ||

4. || || || || || ||

D. Just listen to two sets of ten huda's. Then, check the appropriate column(s) when you hear the following five sounds.

1 2 3 4 5 All homogeneous

1. || || || || || ||

2. || || || || || ||

3. || || || || || ||

4. || || || || || ||

Part II. Korean Female Subjects:

*Part II consists of the same format as in Part I.

F-2-1. Analysis of Deviant Marks for English Subjects

Subject	S2*	s8*		s13*	s16*	Sum	(Sum/32)*100
s1	0	2	2	1	5	16%	
s2	0	0	0	0	0	0%	
s3	0	3	1	3	7	22%	
s4	4	0	1	0	5	16%	
s5	1	0	3	0	4	13%	
s6	0	1	1	0	2	6%	
s7	0	0	2	0	2	6%	
s8	0	0	0	0	0	0%	
s9	8	1	0	2	11	34%	
s10	1	1	0	0	2	6%	
s11	2	2	0	0	4	13%	
s12	1	0	1	0	2	6%	
s13	0	4	0	1	5	16%	
s14	2	6	3	0	11	34%	
s15	0	2	3	0	5	16%	
s16	0	0	1	0	1	3%	
s17	3	0	5	0	8	25%	
s18	0	0	3	3	6	19%	
s19	2	0	0	0	2	6%	
s20	0	0	0	0	0	0%	
Sum:	2	4	22	26	10	82	
(Sum/160)*100	15%	14%	16%	6%			
			Average			**13%**	

* judges (two males and two females)

F-2-2. Analysis of Korean Subjects

Subject	S9*	s10*	s12*	s13*	Sum	(Sum/32)*100
s1	1	0	0	0	1	3%
s2	0	0	0	3	3	9%
s3	0	0	6	1	7	22%
s4	4	0	2	2	8	25%
s5	3	7	0	0	10	31%
s6	0	3	2	6	11	34%
s7	0	6	4	1	11	34%
s8	4	4	3	0	11	34%
s9	0	0	0	2	2	6%
s10	0	0	0	1	1	3%
s11	5	0	0	0	5	16%
s12	0	0	0	0	0	0%
s13	0	0	0	0	0	0%
s14	2	1	0	1	4	13%
s15	0	0	7	0	7	22%
s16	0	0	0	1	1	3%
s17	3	0	2	6	8	25%
s18	0	0	2	6	8	25%
s19	4	2	1	2	9	28%
s20	2	2	6	1	11	34%
Sum:	28	25	33	30	116	
(Sum/160)*100	18%	16%	21%	19%		
		Average		**18%**		

* judges (two males and two females)

Appendix G

Vowel Formants for English and Korean Subjects

G-1-1. English Male

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
had	s1	113	113	111	106	716	712	712	734
had	s10	138	139	139	140	730	712	700	681
had	s2	118	120	122	125	686	665	639	655
had	s3	109	111	111	112	574	577	589	595
had	s4	127	124	124	125	679	673	670	628
had	s5	117	120	123	123	629	630	625	626
had	s6	127	129	130	128	852	860	864	843
had	s7	142	147	144	143	732	744	763	829
had	s8	122	119	114	107	708	711	691	664
had	s9	144	143	143	144	586	586	597	599

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
had	s1	1910	1923	1891	1820	2774	2777	2784	2749
had	s10	1646	1623	1624	1615	2369	2360	2370	2366
had	s2	1791	1784	1723	1700	2497	2473	2521	2568
had	s3	1817	1815	1798	1772	2489	2478	2468	2482
had	s4	1681	1732	1744	1763	2371	2325	2350	2377
had	s5	1580	1542	1492	1439	2355	2338	2364	2408
had	s6	1679	1674	1682	1695	2627	2615	2601	2603
had	s7	1853	1840	1799	1720	2532	2539	2553	2554
had	s8	1833	1823	1822	1828	2540	2534	2522	2536
had	s9	1608	1673	1653	1657	2505	2531	2564	2633

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hard	s1	105	100	95	93	702	702	671	618
hard	s10	140	140	141	141	657	659	644	591
hard	s2	115	118	122	128	661	655	619	565
hard	s3	109	111	110	112	557	559	556	541
hard	s4	123	122	121	122	606	612	609	605
hard	s5	116	118	119	120	651	656	619	587
hard	s6	132	136	137	132	673	663	653	632
hard	s7	133	134	139	143	637	640	626	606
hard	s8	122	120	112	105	661	672	663	647
hard	s9	148	147	145	147	567	566	560	531

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hard	s1	1151	1212	1263	1416	2769	2716	2418	2120
hard	s10	1033	1048	1134	1255	2289	2216	2091	1863
hard	s2	981	998	1134	1258	2436	2290	2049	1804
hard	s3	998	1009	1077	1208	2125	2002	1874	1712
hard	s4	983	1007	1051	1180	2297	2234	2084	1998
hard	s5	1057	1079	1139	1237	2444	2366	2176	1836
hard	s6	1096	1100	1177	1268	2522	2449	2323	2039

hard	s7	1002	992	1101	1348	2455	2420	2297	2078
hard	s8	1012	1007	1029	1205	2586	2246	2053	1656
hard	s9	1039	1053	1175	1314	2308	2241	2095	2023

G-1-1. English Male

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hawed	s1	104	102	100	102	724	720	720	707
hawed	s10	138	139	139	140	684	700	701	691
hawed	s2	114	117	122	127	666	675	653	641
hawed	s3	109	110	111	113	576	579	574	577
hawed	s4	124	123	123	124	635	641	626	604
hawed	s5	117	118	120	124	627	640	638	612
hawed	s6	131	136	134	129	737	775	769	729
hawed	s7	159	168	164	152	635	641	657	680
hawed	s8	125	123	118	110	654	677	685	666
hawed	s9	150	149	146	149	577	581	585	579

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hawed	s1	1137	1128	1155	1166	2762	2767	2788	2803
hawed	s10	1046	1046	1042	1075	2371	2367	2378	2399
hawed	s2	950	946	987	1054	2613	2610	2615	2582
hawed	s3	1028	1014	1015	1044	2299	2290	2296	2288
hawed	s4	974	961	968	970	2343	2357	2367	2380
hawed	s5	1090	1089	1093	1128	2787	2787	2810	2804
hawed	s6	1059	1060	1077	1145	2611	2636	2638	2612
hawed	s7	1012	995	1014	1050	2554	2569	2578	2551
hawed	s8	1010	997	1002	1001	2419	2429	2414	2426
hawed	s9	1022	1024	1036	1059	2462	2462	2427	2423

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hayed	s1	100	100	100	102	544	497	449	438
hayed	s10	135	137	139	141	543	519	455	409
hayed	s2	117	122	126	129	471	441	328	306
hayed	s3	109	112	113	114	510	469	420	371
hayed	s4	126	125	126	126	522	472	441	370
hayed	s5	126	122	122	123	471	437	372	337
hayed	s6	140	145	145	135	517	481	457	405
hayed	s7	144	152	155	153	495	487	447	419
hayed	s8	130	126	119	112	493	470	438	391
hayed	s9	142	140	141	143	429	421	410	407

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hayed	s1	2089	2148	2236	2289	2715	2833	2876	2888
hayed	s10	1826	1897	1964	1968	2453	2474	2500	2567
hayed	s2	2016	2095	2201	2251	2561	2559	2639	2673

hayed	s3	2049	2131	2221	2247	2671	2687	2745	2814
hayed	s4	1765	1905	1995	2055	2383	2406	2401	2382
hayed	s5	1924	1923	1969	1995	2464	2473	2486	2474
hayed	s6	1961	2212	2302	2311	2762	2771	2787	2784
hayed	s7	2111	2231	2228	2255	2881	2914	2915	2909
hayed	s8	2075	2150	2184	2218	2627	2625	2658	2692
hayed	s9	2105	2123	2135	2129	2640	2618	2739	2748

G-1-1. English Male

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
head	s1	114	110	109	111	547	562	564	549
head	s10	138	138	140	141	605	596	584	572
head	s2	121	122	123	124	471	480	498	501
head	s3	113	113	113	113	525	527	530	533
head	s4	123	122	124	125	473	470	472	468
head	s5	124	123	124	125	491	491	503	504
head	s6	140	139	136	134	580	591	585	582
head	s7	170	183	188	181	575	592	592	591
head	s8	129	125	119	112	523	509	503	511
head	s9	145	145	145	148	498	490	489	462

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
head	s1	1929	1949	1929	1947	2841	2804	2889	2873
head	s10	1693	1695	1673	1688	2412	2412	2423	2465
head	s2	1989	1962	1793	1720	2464	2493	2536	2574
head	s3	1948	1940	1895	1845	2614	2618	2618	2622
head	s4	1889	1908	1937	1881	2423	2421	2427	2403
head	s5	1900	1908	1894	1812	2400	2393	2427	2417
head	s6	1839	1851	1830	1835	2695	2677	2685	2689
head	s7	1934	1894	1819	1818	2517	2516	2523	2511
head	s8	1928	1920	1930	1907	2540	2523	2538	2516
head	s9	1979	1973	1996	1971	2752	2752	2755	2811

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
heed	s1	110	110	110	109	274	267	247	246
heed	s10	143	142	142	143	263	264	266	269
heed	s2	129	128	131	136	255	255	257	260
heed	s3	121	124	122	121	334	309	301	301
heed	s4	129	127	128	130	291	293	292	289
heed	s5	122	123	124	126	261	262	259	258
heed	s6	152	154	152	142	306	316	303	300
heed	s7	177	176	167	166	338	339	337	330
heed	s8	126	122	116	109	269	268	274	282
heed	s9	153	151	149	147	287	287	277	281

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
heed	s1	2484	2515	2509	2561	3150	3247	3183	3144
heed	s10	2191	2183	2156	2144	2871	2881	2871	2866
heed	s2	2315	2309	2306	2347	2750	2757	2743	2760
heed	s3	2399	2415	2413	2413	3219	3231	3270	3238
heed	s4	2207	2224	2229	2242	2774	2768	2743	2606
heed	s5	2216	2221	2210	2209	2962	2968	2977	2976
heed	s6	2296	2330	2346	2350	3144	3158	3138	3157
heed	s7	2369	2354	2351	2333	3286	3223	3213	3214
heed	s8	2300	2328	2339	2340	3057	3066	3063	3056
heed	s9	2280	2293	2323	2286	3052	3033	3029	3001

G-1-1. English Male

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
herd	s1	105	100	96	95	502	487	469	438
herd	s10	137	138	138	139	554	543	540	534
herd	s2	116	119	122	126	481	467	456	448
herd	s3	110	112	114	115	503	487	453	436
herd	s4	123	122	122	125	516	480	465	459
herd	s5	122	121	122	125	471	474	467	453
herd	s6	137	139	137	132	506	506	504	504
herd	s7	162	168	164	161	556	529	493	480
herd	s8	129	125	121	116	495	486	475	457
herd	s9	155	151	151	151	441	441	439	433

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
herd	s1	1538	1603	1609	1577	2155	2108	2071	2025
herd	s10	1237	1282	1324	1372	1803	1783	1784	1782
herd	s2	1288	1308	1324	1338	1613	1584	1566	1606
herd	s3	1376	1384	1363	1368	1648	1635	1596	1610
herd	s4	1408	1420	1445	1500	1874	1886	1887	1872
herd	s5	1270	1272	1276	1297	1879	1819	1731	1560
herd	s6	1361	1342	1353	1372	1816	1814	1817	1827
herd	s7	1359	1393	1427	1461	1978	1904	1905	1862
herd	s8	1282	1265	1252	1252	1581	1545	1505	1504
herd	s9	1375	1362	1377	1382	1839	1790	1819	1813

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hid	s1	108	104	100	101	387	395	420	421
hid	s10	140	141	142	142	461	461	466	468
hid	s2	127	128	129	129	369	384	417	438
hid	s3	110	114	115	116	393	406	433	448
hid	s4	127	125	125	125	367	371	379	405
hid	s5	124	123	122	124	375	398	418	448
hid	s6	138	139	137	133	400	397	440	461

hid	s7	144	148	152	156	432	463	474	480
hid	s8	131	124	115	108	379	396	420	431
hid	s9	151	150	150	150	418	417	430	434

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hid	s1	2140	2126	2074	2014	2877	2881	2893	2877
hid	s10	1831	1822	1782	1763	2635	2622	2524	2499
hid	s2	2042	2044	1885	1754	2533	2534	2552	2518
hid	s3	2253	2135	2022	1951	2771	2733	2689	2674
hid	s4	2035	2029	1996	1925	2485	2443	2457	2413
hid	s5	1912	1896	1838	1808	2498	2487	2501	2512
hid	s6	1940	1933	1915	1893	2769	2755	2717	2702
hid	s7	2003	1941	1902	1887	2898	2858	2877	2872
hid	s8	2120	2111	2090	2069	2671	2672	2655	2646
hid	s9	2071	2085	2097	2071	2768	2726	2675	2690

G-1-1. English Male

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hod	s1	105	103	105	106	794	810	816	795
hod	s10	139	139	140	140	718	731	730	714
hod	s2	120	122	128	133	683	691	698	689
hod	s3	109	110	111	112	574	579	581	579
hod	s4	125	123	122	123	674	671	672	649
hod	s5	121	120	123	122	663	642	660	653
hod	s6	135	138	135	130	825	833	844	842
hod	s7	137	142	146	155	684	725	765	786
hod	s8	126	122	114	105	680	691	684	691
hod	s9	150	150	148	146	553	571	576	573

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hod	s1	1209	1242	1303	1419	2720	2731	2717	2745
hod	s10	1067	1070	1087	1128	2434	2433	2439	2450
hod	s2	1215	1188	1217	1247	2624	2656	2646	2619
hod	s3	1034	1029	1037	1076	2323	2338	2319	2301
hod	s4	1096	1102	1114	1218	2356	2374	2378	2368
hod	s5	1107	1106	1122	1134	2617	2613	2620	2616
hod	s6	1290	1274	1310	1353	2636	2654	2634	2562
hod	s7	1043	1044	1073	1273	2601	2614	2599	2578
hod	s8	1090	1088	1106	1110	2620	2610	2583	2602
hod	s9	1059	1072	1086	1106	2427	2462	2461	2468

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hoed	s1	110	108	107	109	534	517	478	452
hoed	s10	141	140	140	140	568	560	549	520
hoed	s2	115	119	125	130	502	461	407	370

hoed	s3	107	111	110	111	535	526	476	418
hoed	s4	124	123	125	127	501	484	459	415
hoed	s5	121	121	122	125	498	478	470	445
hoed	s6	137	142	142	133	531	512	493	474
hoed	s7	158	159	152	153	545	534	494	441
hoed	s8	126	124	119	111	500	489	461	443
hoed	s9	148	148	148	148	412	422	414	414

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hoed	s1	1284	1245	1204	1164	2585	2597	2599	2572
hoed	s10	1153	1142	1128	1123	2295	2287	2270	2266
hoed	s2	1004	962	928	915	2465	2487	2484	2480
hoed	s3	1242	1214	1172	1146	2266	2286	2300	2294
hoed	s4	1108	1065	1026	994	2191	2188	2200	2179
hoed	s5	1230	1207	1165	1152	2338	2266	2222	2182
hoed	s6	1091	1086	1050	1035	2339	2338	2353	2307
hoed	s7	1266	1212	1159	1142	2531	2514	2507	2491
hoed	s8	1111	1106	1081	1073	2381	2388	2396	2377
hoed	s9	1055	1036	999	979	2399	2399	2397	2394

G-1-1. English Male

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hood	s1	113	111	110	111	455	443	471	473
hood	s10	143	141	141	142	506	534	538	534
hood	s2	126	127	131	135	386	392	410	400
hood	s3	111	111	112	115	450	451	456	458
hood	s4	129	129	130	131	403	399	408	429
hood	s5	128	128	128	129	439	460	479	481
hood	s6	147	147	142	133	446	459	480	488
hood	s7	171	176	174	169	479	489	506	505
hood	s8	134	128	122	113	377	397	406	417
hood	s9	155	154	150	150	436	437	438	444

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hood	s1	1497	1533	1577	1678	2625	2651	2640	2693
hood	s10	1352	1357	1375	1416	2286	2301	2305	2301
hood	s2	1244	1253	1324	1429	2411	2405	2436	2458
hood	s3	1426	1423	1447	1511	2420	2407	2429	2436
hood	s4	1185	1220	1293	1381	2194	2244	2265	2280
hood	s5	1314	1319	1335	1362	2308	2319	2335	2345
hood	s6	1336	1337	1349	1428	2245	2257	2260	2247
hood	s7	1325	1336	1368	1473	2512	2503	2530	2544
hood	s8	1208	1204	1208	1253	2401	2408	2407	2410
hood	s9	1323	1331	1382	1462	2255	2305	2269	2234

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
Hudd	s1	107	103	97	98	624	632	628	639
Hudd	s10	139	138	140	140	641	648	632	598
Hudd	s2	124	123	125	128	562	570	556	540
Hudd	s3	109	109	111	110	551	553	554	552
Hudd	s4	125	123	123	123	559	560	542	532
Hudd	s5	125	121	123	124	553	554	545	535
Hudd	s6	142	143	140	132	608	607	603	600
Hudd	s7	136	139	143	148	676	651	654	612
Hudd	s8	131	125	120	113	601	586	591	587
Hudd	s9	149	148	147	151	561	557	564	552

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
Hudd	s1	1426	1477	1515	1605	2799	2859	2807	2756
Hudd	s10	1244	1265	1315	1379	2358	2363	2374	2378
Hudd	s2	1314	1296	1327	1365	2572	2571	2585	2575
Hudd	s3	1320	1344	1384	1484	2402	2391	2390	2392
Hudd	s4	1341	1366	1355	1422	2312	2323	2358	2361
Hudd	s5	1309	1310	1302	1331	2357	2376	2392	2423
Hudd	s6	1293	1298	1336	1426	2524	2521	2507	2430
Hudd	s7	1376	1373	1408	1484	2660	2650	2665	2702
Hudd	s8	1234	1244	1247	1270	2519	2517	2485	2487
Hudd	s9	1325	1334	1378	1459	2341	2371	2390	2318

G-1-1. English Male

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
who'd	s1	115	111	109	107	301	282	245	240
who'd	s10	141	144	145	146	322	317	313	301
who'd	s2	127	126	130	134	345	327	301	298
who'd	s3	117	121	121	122	379	361	353	346
who'd	s4	127	127	127	128	359	351	343	321
who'd	s5	128	128	131	133	334	336	311	283
who'd	s6	149	155	150	138	370	373	377	379
who'd	s7	149	148	153	161	380	353	328	333
who'd	s8	135	131	125	115	282	284	283	297
who'd	s9	153	155	152	150	354	350	323	305

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
who'd	s1	1693	1707	1672	1681	2475	2449	2473	2423
who'd	s10	1370	1380	1358	1325	2104	2095	2120	2110
who'd	s2	1316	1278	1242	1242	2302	2301	2340	2355
who'd	s3	1804	1806	1791	1797	2410	2404	2353	2335
who'd	s4	1193	1176	1145	1153	2150	2123	2148	2161
who'd	s5	1419	1388	1372	1377	2244	2211	2145	2142
who'd	s6	1447	1437	1412	1380	2296	2303	2295	2272

who'd	s7	1441	1392	1374	1397	2343	2376	2343	2358
who'd	s8	1245	1227	1218	1195	2258	2275	2281	2257
who'd	s9	1185	1134	1093	1118	2243	2281	2309	2304

G-1-2. English Female

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
had	s11	209	206	199	196	832	825	797	784
had	s12	219	213	208	212	804	813	797	793
had	s13	218	217	218	220	871	868	873	880
had	s14	222	215	205	193	739	739	737	719
had	s15	275	260	222	193	777	751	756	738
had	s16	178	172	168	164	757	794	792	835
had	s17	220	209	198	185	1048	1022	992	979
had	s18	210	203	197	191	827	822	841	904
had	s19	206	206	206	209	829	820	838	834
had	s20	196	192	185	177	815	798	784	751

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
had	s11	1777	1713	1650	1669	2920	2874	2858	2901
had	s12	1928	1906	1919	1957	2885	2805	2807	2743
had	s13	2117	2090	1991	1966	2957	2959	2957	2947
had	s14	2039	2034	2026	1997	2886	2903	2831	2901
had	s15	2396	2354	2349	1984	2971	2963	2926	2875
had	s16	1979	1901	1804	1697	2858	2806	2782	2810
had	s17	1988	1975	1980	1967	3014	3045	3014	3043
had	s18	2476	2427	2358	2324	2910	2891	2901	2893
had	s19	2093	2090	2091	1995	2956	3001	2991	2993
had	s20	2166	2103	2008	2027	3070	3031	3092	2988

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hard	s11	205	202	198	197	825	805	748	627
hard	s12	219	212	206	206	859	830	793	749
hard	s13	219	218	217	215	771	748	717	698
hard	s14	223	218	205	195	730	720	582	486
hard	s15	267	239	206	188	721	741	685	631
hard	s16	168	168	168	168	686	690	651	595
hard	s17	206	196	186	178	947	922	896	847
hard	s18	209	200	190	184	885	821	750	684
hard	s19	211	208	205	208	950	938	780	631
hard	s20	201	194	182	171	591	604	621	513

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hard	s11	1367	1386	1406	1473	2509	2438	2349	2186
hard	s12	1329	1309	1466	1626	2686	2528	2379	2179
hard	s13	1273	1297	1382	1591	2567	2516	2214	2161

hard	s14	1122	1372	1501	1561	2661	2314	1951	1863
hard	s15	1296	1282	1264	1385	2563	2496	2120	1879
hard	s16	1267	1301	1447	1558	2557	2474	2191	2086
hard	s17	1283	1359	1391	1505	2649	2651	2646	2559
hard	s18	1147	1186	1244	1414	2951	2894	2228	1928
hard	s19	1282	1283	1453	1651	2958	2795	2197	2093
hard	s20	1086	1095	1395	1496	2585	2522	2134	1957

G-1-2. English Female

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hawed	s11	215	205	198	198	764	752	718	806
hawed	s12	221	214	207	205	813	805	795	819
hawed	s13	224	223	223	226	858	853	872	809
hawed	s14	223	214	203	192	818	784	778	829
hawed	s15	259	239	209	190	818	817	760	720
hawed	s16	179	176	179	181	703	693	701	723
hawed	s17	203	194	185	173	915	857	892	900
hawed	s18	193	188	185	184	819	765	739	738
hawed	s19	213	211	209	211	851	849	833	822
hawed	s20	197	192	181	182	629	600	628	667

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hawed	s11	1066	1039	1086	1260	2920	2924	2859	2867
hawed	s12	1243	1216	1280	1457	2735	2731	2686	2673
hawed	s13	1119	1270	1353	1508	2812	2855	2825	2786
hawed	s14	1135	1146	1202	1341	2950	2910	2906	2887
hawed	s15	1252	1234	1243	1243	2585	2625	2570	2532
hawed	s16	1016	1014	1028	1243	2865	2883	2875	2815
hawed	s17	1211	1158	1185	1254	2967	2989	2996	2973
hawed	s18	1125	1110	1116	1131	2956	2918	2903	2946
hawed	s19	1144	1149	1249	1463	3180	3101	3072	3001
hawed	s20	1056	1065	1084	1170	3102	3014	3008	2997

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hayed	s11	225	213	207	204	639	606	497	477
hayed	s12	222	216	212	211	552	461	394	375
hayed	s13	219	219	221	221	639	609	487	440
hayed	s14	232	225	213	198	477	440	410	383
hayed	s15	255	227	192	181	580	560	520	458
hayed	s16	174	173	176	178	500	491	432	386
hayed	s17	212	204	197	180	434	422	400	378
hayed	s18	204	199	194	192	596	545	449	394
hayed	s19	219	218	217	221	609	503	445	441
hayed	s20	201	194	186	176	592	570	512	417

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hayed	s11	2248	2317	2382	2457	2980	2968	2955	2963
hayed	s12	2558	2624	2663	2756	2762	3008	3089	3172
hayed	s13	2460	2716	2765	2799	2724	2977	3044	3046
hayed	s14	2352	2379	2419	2440	2916	2973	2964	2925
hayed	s15	2485	2498	2554	2555	2982	2982	2944	2923
hayed	s16	2356	2423	2485	2542	2962	2988	3020	2986
hayed	s17	2676	2737	2756	2779	3027	3045	2997	3006
hayed	s18	2486	2639	2648	2648	2908	2881	2861	2868
hayed	s19	2425	2516	2544	2715	2990	2993	2991	2967
hayed	s20	2546	2517	2523	2579	3053	3096	3119	3127

G-1-2. English Female

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
head	s11	221	212	208	210	658	634	620	626
head	s12	225	220	215	213	653	651	644	629
head	s13	218	218	218	219	634	637	644	646
head	s14	235	227	216	202	643	638	607	584
head	s15	277	249	221	192	580	628	665	701
head	s16	180	175	176	177	534	534	541	543
head	s17	216	206	192	182	754	747	719	680
head	s18	206	201	192	189	618	663	737	745
head	s19	221	214	212	216	611	615	614	622
head	s20	200	191	181	172	583	567	582	611

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
head	s11	2075	1978	1961	1940	2989	2944	2976	3043
head	s12	2341	2358	2346	2282	2844	2852	2861	2823
head	s13	2378	2369	2300	2272	3002	2995	3059	3078
head	s14	2122	2076	2098	2053	2909	2963	2958	2944
head	s15	2454	2410	2345	2127	2963	3034	2995	2978
head	s16	2056	1944	1870	1839	2857	2855	2848	2846
head	s17	2448	2470	2448	2448	3053	3097	3079	3059
head	s18	2433	2422	2337	2368	2919	2912	2917	2919
head	s19	2297	2279	2157	2081	3023	2958	2996	3018
head	s20	2074	2133	2035	1978	3004	3068	3080	3094

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
heed	s11	226	220	222	221	364	397	411	412
heed	s12	228	221	217	217	332	340	356	356
heed	s13	231	231	231	231	429	413	413	396
heed	s14	248	234	217	200	372	378	369	370
heed	s15	280	260	239	200	399	434	428	405
heed	s16	180	178	180	182	360	356	361	364
heed	s17	222	212	205	207	391	386	392	380

heed	s18	236	220	206	194	369	378	388	387
heed	s19	233	232	233	243	439	433	439	454
heed	s20	213	205	193	181	397	389	387	364

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
heed	s11	2669	2712	2649	2602	3107	3088	3078	2986
heed	s12	2800	2790	2793	2816	3410	3441	3408	3436
heed	s13	2866	2872	2868	2882	3481	3529	3517	3463
heed	s14	2713	2691	2682	2723	3451	3408	3381	3346
heed	s15	2951	2934	2998	2979	3416	3407	3400	3409
heed	s16	2796	2800	2807	2828	3408	3413	3405	3366
heed	s17	2979	2988	2968	2947	3521	3572	3549	3523
heed	s18	2911	2969	2925	2970	3535	3584	3651	3568
heed	s19	2890	2936	2927	2893	3550	3532	3481	3546
heed	s20	2560	2565	2598	2607	3221	3184	3179	3182

G-1-2. English Female

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
herd	s11	255	244	223	204	543	557	561	603
herd	s12	231	227	223	225	443	434	433	443
herd	s13	219	216	215	215	610	590	570	542
herd	s14	234	229	217	203	477	424	384	359
herd	s15	269	241	205	186	594	586	586	559
herd	s16	181	181	181	182	523	515	499	483
herd	s17	239	226	207	184	483	470	508	514
herd	s18	218	203	197	195	549	538	513	477
herd	s19	213	210	210	216	597	574	541	476
herd	s20	202	199	192	183	555	540	528	504

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
herd	s11	1545	1511	1525	1524	2054	2031	2077	2008
herd	s12	1796	1783	1798	1786	2081	2110	2140	2077
herd	s13	1566	1638	1676	1687	2184	2180	2140	2120
herd	s14	1486	1543	1520	1564	1861	1845	1814	1779
herd	s15	1488	1521	1476	1528	1802	1782	1742	1783
herd	s16	1444	1463	1481	1508	1899	1908	1890	1897
herd	s17	1589	1560	1578	1567	1998	2035	1983	1986
herd	s18	1474	1511	1548	1653	1958	1865	1910	1922
herd	s19	1534	1591	1623	1699	2148	2139	2122	2159
herd	s20	1382	1383	1379	1408	1863	1845	1821	1843

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hid	s11	225	216	212	206	433	432	474	489
hid	s12	230	223	219	219	446	442	431	450
hid	s13	225	223	224	225	467	489	518	545

hid	s14	237	228	213	199	463	448	409	389
hid	s15	280	264	236	207	510	529	512	583
hid	s16	176	179	180	183	407	427	475	490
hid	s17	225	217	207	194	424	420	416	423
hid	s18	215	198	194	189	435	461	566	567
hid	s19	223	221	222	226	448	447	461	469
hid	s20	208	196	180	164	451	570	545	517

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hid	s11	2293	2247	2166	2096	2998	3024	3017	3023
hid	s12	2537	2573	2483	2414	3035	2998	2968	2957
hid	s13	2464	2444	2465	2407	3098	3074	3106	3098
hid	s14	2282	2241	2152	2161	3012	2988	2956	2948
hid	s15	2444	2434	2242	2190	3020	3013	3029	2982
hid	s16	2385	2227	2122	1983	2909	2877	2852	2849
hid	s17	2546	2571	2550	2527	3182	3192	3186	3173
hid	s18	2453	2487	2406	2324	3018	3028	3068	2992
hid	s19	2454	2428	2280	2096	3007	2986	2953	2976
hid	s20	2089	2082	2003	1996	3014	2957	2952	3002

G-1-2. English Female

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hod	s11	217	210	207	208	911	886	874	788
hod	s12	220	214	208	210	793	788	780	753
hod	s13	220	219	220	224	884	890	885	905
hod	s14	217	211	201	190	868	844	802	798
hod	s15	256	234	199	183	870	839	726	664
hod	s16	172	172	172	172	746	715	720	734
hod	s17	200	192	186	180	996	997	998	1005
hod	s18	206	201	198	195	909	911	890	904
hod	s19	213	207	207	211	957	932	930	916
hod	s20	200	193	184	172	800	770	778	779

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hod	s11	1374	1358	1366	1467	2936	2962	2950	2946
hod	s12	1279	1250	1247	1260	2752	2714	2702	2699
hod	s13	1319	1342	1379	1446	2778	2760	2791	2800
hod	s14	1222	1233	1336	1481	2923	2894	2852	2833
hod	s15	1246	1255	1225	1278	2661	2619	2582	2563
hod	s16	1062	1074	1213	1383	2833	2839	2843	2803
hod	s17	1332	1323	1346	1341	2698	2750	2823	2831
hod	s18	1236	1234	1264	1300	3098	3091	3070	3038
hod	s19	1302	1268	1325	1396	3092	3118	3054	3062
hod	s20	1162	1215	1261	1388	3004	3024	2990	2979

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hoed	s11	210	203	198	194	616	599	573	533
hoed	s12	223	219	218	222	612	518	453	426
hoed	s13	215	213	212	212	633	622	586	504
hoed	s14	234	227	209	195	467	428	383	376
hoed	s15	256	222	196	186	603	567	577	535
hoed	s16	178	174	176	176	522	500	484	437
hoed	s17	213	202	191	179	446	412	413	419
hoed	s18	208	200	194	192	616	582	503	419
hoed	s19	215	216	218	225	550	499	486	457
hoed	s20	201	196	190	180	590	558	493	456

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hoed	s11	1411	1369	1333	1318	2894	2912	2870	2893
hoed	s12	1322	1153	1121	1098	2724	2783	2777	2763
hoed	s13	1636	1558	1482	1376	2811	2803	2832	2840
hoed	s14	1363	1254	1251	1183	2601	2556	2456	2383
hoed	s15	1239	1136	1112	1029	2925	2909	2886	2923
hoed	s16	1325	1188	1123	1103	2688	2682	2649	2577
hoed	s17	882	815	859	812	3006	3005	3094	3004
hoed	s18	1234	1203	1173	1163	2958	2991	2989	3003
hoed	s19	1240	1210	1135	1108	2878	2875	2882	2849
hoed	s20	1201	1177	1143	1088	2626	2726	2667	2670

G-1-2. English Female

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hood	s11	221	219	218	219	500	511	505	508
hood	s12	228	223	221	220	443	462	468	464
hood	s13	215	214	213	212	596	597	602	598
hood	s14	234	225	206	193	455	441	424	432
hood	s15	278	245	217	188	555	534	539	542
hood	s16	185	183	183	184	441	449	471	467
hood	s17	222	212	204	194	416	447	425	442
hood	s18	211	199	194	193	469	508	530	537
hood	s19	223	221	219	223	473	476	492	494
hood	s20	210	201	187	175	445	483	527	508

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hood	s11	1496	1482	1593	1623	2843	2916	2953	2969
hood	s12	1393	1418	1534	1707	2665	2677	2672	2677
hood	s13	1657	1629	1684	1804	2811	2873	2874	2864
hood	s14	1778	1812	1832	1802	2857	2809	2790	2796
hood	s15	1344	1315	1343	1484	3018	3002	2958	2926
hood	s16	1406	1378	1485	1506	2575	2573	2579	2577
hood	s17	1218	1235	1402	1546	2994	3004	2958	2968

hood	s18	1554	1586	1678	1776	2974	2979	2950	2972
hood	s19	1394	1406	1569	1832	2882	2864	2901	2881
hood	s20	1647	1600	1662	1731	2664	2660	2684	2653

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
Hudd	s11	208	204	199	198	633	638	659	617
Hudd	s12	232	227	221	218	753	698	689	681
Hudd	s13	213	213	215	217	736	711	707	689
Hudd	s14	225	215	203	192	665	634	606	585
Hudd	s15	258	231	202	185	698	727	678	668
Hudd	s16	178	176	176	178	691	672	621	549
Hudd	s17	203	193	183	175	868	832	814	783
Hudd	s18	212	201	195	191	791	787	764	715
Hudd	s19	212	212	214	218	717	705	675	643
Hudd	s20	199	189	187	179	608	603	565	512

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
Hudd	s11	1617	1653	1685	1749	2987	3024	3023	3034
Hudd	s12	1734	1735	1741	1766	2791	2807	2817	2810
Hudd	s13	1678	1661	1664	1775	2783	2833	2891	2883
Hudd	s14	1581	1675	1722	1749	2792	2822	2879	2903
Hudd	s15	1620	1647	1646	1668	2994	2984	2939	2945
Hudd	s16	1470	1468	1546	1636	2779	2832	2804	2774
Hudd	s17	1484	1644	1571	1585	2973	2987	3022	3013
Hudd	s18	1741	1766	1797	1896	3029	2998	3037	3007
Hudd	s19	1518	1530	1601	1575	2984	2973	2960	2952
Hudd	s20	1611	1636	1777	1817	2700	2745	2733	2551

G-1-2. English Female

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
who'd	s11	220	215	213	212	424	426	416	412
who'd	s12	238	233	229	230	429	401	395	383
who'd	s13	235	233	234	234	463	456	455	454
who'd	s14	244	237	220	204	428	408	409	393
who'd	s15	307	280	244	215	423	446	474	413
who'd	s16	185	185	185	186	372	372	374	374
who'd	s17	262	251	231	213	372	399	417	402
who'd	s18	226	210	203	201	442	415	402	395
who'd	s19	226	224	225	232	444	441	443	459
who'd	s20	216	208	192	176	411	402	384	351

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
who'd	s11	1484	1486	1443	1437	2838	2847	2826	2821
who'd	s12	1421	1422	1408	1423	2716	2735	2732	2707
who'd	s13	2146	2129	2038	2050	2882	2885	2877	2878

who'd	s14	1249	1371	1371	1407	2690	2761	2682	2603
who'd	s15	1290	1272	1241	1180	3067	3020	3067	3003
who'd	s16	1467	1485	1481	1472	2504	2511	2491	2520
who'd	s17	915	890	877	903	3030	3016	3006	3056
who'd	s18	1890	1868	1812	1620	2863	2848	2846	2820
who'd	s19	1562	1520	1545	1601	2790	2785	2764	2781
who'd	s20	1676	1664	1624	1566	2560	2553	2584	2542

G-2-1. Korean Male

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hada	s1	152	150	148	147	763	783	779	735
hada	s10	149	151	150	149	661	656	641	634
hada	s2	143	144	144	148	654	643	639	609
hada	s3	203	207	206	208	713	722	709	685
hada	s4	184	184	183	183	810	777	729	662
hada	s5	134	131	131	131	739	721	711	685
hada	s6	165	162	161	159	647	610	580	538
hada	s7	137	136	137	137	852	826	815	811
hada	s8	196	194	193	192	837	801	771	702
hada	s9	160	160	161	159	854	846	831	797

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hada	s1	1268	1299	1343	1440	2456	2456	2473	2416
hada	s10	1254	1253	1256	1255	2707	2762	2759	2739
hada	s2	1425	1354	1361	1396	2582	2579	2573	2556
hada	s3	1244	1225	1228	1251	2530	2531	2582	2465
hada	s4	1267	1266	1329	1368	2717	2682	2635	2656
hada	s5	1366	1324	1338	1355	2520	2491	2434	2417
hada	s6	1454	1447	1458	1454	2352	2384	2383	2401
hada	s7	1439	1465	1454	1525	2716	2681	2596	2588
hada	s8	1490	1616	1671	1672	2737	2700	2773	2773
hada	s9	1475	1466	1463	1496	2475	2464	2423	2415

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hEda	s1	153	151	151	151	589	570	570	542
hEda	s10	162	161	159	156	511	499	498	492
hEda	s2	163	154	149	146	587	574	577	567
hEda	s3	205	206	206	204	601	608	612	609
hEda	s4	182	182	181	180	576	564	561	548
hEda	s5	135	136	135	134	586	581	566	549
hEda	s6	167	165	164	161	518	491	483	450
hEda	s7	142	141	140	140	644	612	617	575
hEda	s8	199	192	191	190	756	715	682	643
hEda	s9	161	163	163	159	755	700	686	631

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hEda	s1	1859	1800	1778	1772	2649	2688	2706	2739
hEda	s10	1759	1753	1692	1651	2520	2558	2566	2561
hEda	s2	1800	1770	1772	1698	2543	2567	2586	2593
hEda	s3	2113	2042	1985	1942	2635	2615	2636	2669
hEda	s4	1730	1733	1708	1660	2567	2546	2567	2627
hEda	s5	1880	1890	1881	1900	2525	2503	2478	2513
hEda	s6	1740	1770	1779	1756	2587	2575	2552	2545

hEda	s7	1916	1886	1888	1877	2685	2677	2691	2718
hEda	s8	2134	1999	2008	2079	2729	2800	2829	2844
hEda	s9	1862	1853	1774	1755	2425	2448	2454	2438

G-2-1. Korean Male

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
heda	s1	144	145	146	147	421	418	420	421
heda	s10	164	164	161	158	505	505	501	493
heda	s2	151	149	149	148	496	496	491	466
heda	s3	219	219	218	215	447	450	447	449
heda	s4	189	191	190	189	572	573	572	562
heda	s5	136	137	136	135	514	518	518	511
heda	s6	169	166	165	162	409	419	425	416
heda	s7	149	145	144	143	419	439	446	441
heda	s8	199	197	194	192	743	733	709	665
heda	s9	159	160	157	155	319	347	367	361

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
heda	s1	2144	2140	2150	2117	2738	2687	2715	2745
heda	s10	1862	1830	1789	1752	2594	2606	2619	2619
heda	s2	1824	1773	1773	1778	2583	2588	2588	2599
heda	s3	2176	2192	2192	2135	2593	2560	2613	2536
heda	s4	1650	1749	1739	1690	2618	2582	2616	2648
heda	s5	1956	2044	2017	1960	2779	2789	2745	2766
heda	s6	1957	1972	1943	1887	2609	2639	2575	2547
heda	s7	2037	2004	1951	1909	2739	2728	2774	2789
heda	s8	2055	2047	2046	2104	2747	2733	2747	2774
heda	s9	2025	1932	1909	1899	2535	2535	2475	2490

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hida	s1	157	156	155	154	329	324	336	342
hida	s10	167	167	165	164	352	355	360	366
hida	s2	164	156	152	150	322	328	335	326
hida	s3	212	213	213	213	367	378	390	409
hida	s4	197	196	193	191	368	368	365	367
hida	s5	140	141	139	138	299	319	323	317
hida	s6	169	168	167	163	349	346	341	334
hida	s7	148	149	150	151	307	300	293	298
hida	s8	207	204	203	206	363	368	377	371
hida	s9	162	169	169	165	311	325	329	324

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hida	s1	2230	2240	2246	2205	3190	3281	3238	3245
hida	s10	2112	2129	2118	2058	2994	2954	2920	2878
hida	s2	1855	1860	1870	1863	3040	2937	2908	2902

hida	s3	2421	2424	2421	2399	3144	3077	3060	3025
hida	s4	2209	2188	2156	2118	3006	2931	2902	2910
hida	s5	2368	2324	2360	2369	2942	2979	2977	2871
hida	s6	2002	2003	1990	1958	2892	2869	2878	2929
hida	s7	2438	2407	2434	2405	3075	3151	3161	3113
hida	s8	2376	2345	2338	2314	3322	3278	3227	3172
hida	s9	2284	2269	2275	2305	3058	3011	3060	3076

G-2-1. Korean Male

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hoda	s1	153	152	152	151	448	450	457	455
hoda	s10	168	167	164	162	487	488	483	475
hoda	s2	156	155	153	150	474	472	473	456
hoda	s3	207	208	207	206	496	500	495	488
hoda	s4	195	193	191	191	409	415	428	417
hoda	s5	136	137	136	136	484	495	500	491
hoda	s6	169	168	166	164	410	424	421	400
hoda	s7	142	143	143	144	388	385	383	376
hoda	s8	204	204	204	201	504	496	495	492
hoda	s9	172	171	172	170	388	402	417	397

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hoda	s1	932	999	1034	1154	2718	2771	2806	2903
hoda	s10	898	937	1001	1047	2575	2608	2608	2603
hoda	s2	892	928	1030	1099	2497	2515	2478	2497
hoda	s3	735	751	810	919	2667	2682	2736	2681
hoda	s4	746	824	925	1053	2724	2713	2604	2543
hoda	s5	1025	1056	1102	1135	2584	2551	2522	2456
hoda	s6	1141	1189	1220	1265	2393	2399	2447	2475
hoda	s7	837	835	863	927	2809	2818	2764	2675
hoda	s8	939	991	1155	1241	2786	2784	2869	2877
hoda	s9	887	943	1046	1056	2900	2904	2869	2894

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hweda	s1	148	150	151	151	430	435	436	433
hweda	s10	166	163	161	158	490	487	483	482
hweda	s2	153	149	148	146	472	482	460	448
hweda	s3	209	209	209	209	439	457	471	483
hweda	s4	188	190	190	190	562	565	567	560
hweda	s5	136	136	136	136	492	497	497	487
hweda	s6	166	164	163	161	405	414	420	409
hweda	s7	146	145	144	143	371	407	416	398
hweda	s8	200	194	191	188	500	519	527	512
hweda	s9	160	160	156	152	314	326	324	314

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hweda	s1	1993	2020	2044	2045	2531	2582	2750	2855
hweda	s10	1747	1746	1730	1676	2416	2475	2567	2585
hweda	s2	1812	1811	1774	1739	2468	2492	2538	2575
hweda	s3	1852	1938	2026	2036	2408	2373	2500	2529
hweda	s4	1608	1637	1640	1617	2442	2491	2517	2526
hweda	s5	1874	1919	1867	1853	2338	2352	2361	2467
hweda	s6	1841	1837	1837	1813	2315	2343	2407	2491
hweda	s7	1520	1557	1662	1716	2504	2463	2493	2501
hweda	s8	2029	2012	2004	2030	2755	2771	2765	2735
hweda	s9	1695	1699	1713	1734	2328	2339	2351	2397

G-2-1. Korean Male

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
huda	s1	153	153	153	152	395	402	414	415
huda	s10	170	166	162	158	411	425	430	422
huda	s2	173	167	165	161	332	352	385	384
huda	s3	212	212	213	211	414	420	419	417
huda	s4	205	203	201	201	366	380	383	379
huda	s5	140	139	138	138	371	369	360	372
huda	s6	168	170	167	167	348	353	353	351
huda	s7	147	148	147	147	300	292	297	309
huda	s8	219	214	208	205	368	379	380	371
huda	s9	161	164	164	163	312	324	328	327

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
huda	s1	891	953	1086	1159	2703	2739	2710	2661
huda	s10	1016	1090	1228	1244	2591	2579	2592	2598
huda	s2	916	875	992	1065	2587	2569	2444	2507
huda	s3	727	724	763	900	2515	2483	2516	2550
huda	s4	822	894	999	1038	2464	2457	2437	2448
huda	s5	1073	1117	1079	1157	2375	2353	2413	2453
huda	s6	1134	1192	1239	1334	2296	2305	2353	2401
huda	s7	952	913	943	1067	2662	2661	2641	2613
huda	s8	983	1011	1122	1193	2636	2606	2554	2644
huda	s9	963	1039	1074	1090	2913	2898	2890	2888

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hwida	s1	162	162	162	160	327	324	328	329
hwida	s10	159	165	163	157	332	337	339	343
hwida	s2	172	164	162	159	286	301	317	318
hwida	s3	216	218	218	217	388	400	406	413
hwida	s4	204	203	199	194	344	340	345	346
hwida	s5	138	138	137	136	346	357	357	355
hwida	s6	173	170	168	166	348	344	341	335

hwida	s7	155	153	153	152	313	318	315	315
hwida	s8	211	206	203	200	338	347	361	365
hwida	s9	163	162	159	156	314	317	317	311

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hwida	s1	2198	2206	2214	2191	2671	2757	2888	2973
hwida	s10	2115	2091	2085	2070	2583	2626	2671	2639
hwida	s2	1912	1907	1918	1900	2907	3023	2990	2853
hwida	s3	2202	2265	2307	2315	2438	2572	2707	2792
hwida	s4	2108	2106	2090	2087	2681	2789	2866	2863
hwida	s5	2027	2180	2151	2073	2734	2768	2802	2783
hwida	s6	2024	2027	2029	1977	2909	2938	2967	2952
hwida	s7	2027	2173	2256	2254	2435	2484	2537	2603
hwida	s8	2275	2280	2283	2299	2947	2936	2990	3001
hwida	s9	1912	1904	1916	1968	2349	2395	2411	2527

G-2-1. Korean Male

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hΛda	s1	145	146	147	147	582	587	584	565
hΛda	s10	159	163	160	156	554	543	541	537
hΛda	s2	148	147	146	143	581	579	567	553
hΛda	s3	205	208	210	210	616	617	617	615
hΛda	s4	187	188	188	187	591	582	571	552
hΛda	s5	131	133	133	132	683	675	663	629
hΛda	s6	171	169	166	164	480	475	452	429
hΛda	s7	144	144	145	146	634	607	585	563
hΛda	s8	201	199	198	196	707	677	625	598
hΛda	s9	156	156	159	158	754	734	711	673

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hΛda	s1	1054	1106	1123	1184	2603	2605	2581	2542
hΛda	s10	1024	1022	1036	1047	2716	2703	2696	2675
hΛda	s2	1093	1112	1176	1229	2506	2507	2466	2462
hΛda	s3	1026	1035	1034	1075	2750	2780	2780	2808
hΛda	s4	1070	1079	1125	1140	2876	2818	2755	2739
hΛda	s5	1144	1133	1162	1229	2556	2528	2503	2461
hΛda	s6	1387	1382	1403	1408	2902	2854	2819	2818
hΛda	s7	1050	1046	1065	1160	2841	2840	2831	2786
hΛda	s8	1189	1212	1229	1289	2683	2727	2798	2784
hΛda	s9	1039	1079	1084	1093	2487	2468	2471	2440

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
huuda	s1	160	158	158	158	411	429	423	438
huuda	s10	166	165	162	161	418	437	448	449
huuda	s2	167	166	162	158	400	441	438	426

huuda	s3	218	219	218	216	421	428	429	433
huuda	s4	189	189	189	189	397	398	398	392
huuda	s5	139	139	140	139	393	405	411	398
huuda	s6	173	171	170	168	386	397	398	385
huuda	s7	154	153	153	152	358	353	345	336
huuda	s8	221	218	215	211	414	424	420	420
huuda	s9	165	166	164	160	340	340	338	330

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
huuda	s1	1370	1381	1423	1510	2540	2558	2566	2494
huuda	s10	1450	1448	1440	1468	2450	2478	2509	2536
huuda	s2	1396	1392	1399	1410	2522	2515	2492	2483
huuda	s3	1192	1191	1259	1319	2484	2540	2585	2647
huuda	s4	1327	1334	1347	1354	2393	2401	2423	2421
huuda	s5	1476	1490	1538	1594	2362	2371	2424	2455
huuda	s6	1662	1676	1710	1742	2456	2445	2458	2453
huuda	s7	1649	1634	1638	1664	2584	2593	2590	2659
huuda	s8	1785	1788	1782	1859	2535	2571	2608	2611
huuda	s9	1569	1549	1547	1605	2494	2499	2544	2554

G-2-2. Korean Female

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hada	s11	255	256	255	253	1013	986	963	929
hada	s12	250	248	248	246	952	923	906	832
hada	s13	279	268	264	263	909	880	803	777
hada	s14	259	240	231	228	1010	992	901	874
hada	s15	266	264	261	258	1152	1126	1130	1057
hada	s16	286	285	283	281	914	900	851	828
hada	s17	245	238	236	233	956	930	913	894
hada	s18	300	298	291	288	1211	1182	1175	1140
hada	s19	244	237	233	232	976	949	934	928
hada	s20	313	308	307	306	1070	994	947	930

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hada	s11	1765	1752	1798	1838	2810	2813	2878	2809
hada	s12	1833	1818	1786	1773	3230	3192	3192	3179
hada	s13	1678	1709	1769	1820	2648	2638	2566	2347
hada	s14	1801	1820	1852	1852	2812	2832	2894	2903
hada	s15	1722	1687	1734	1775	2937	2901	2889	2906
hada	s16	1951	1980	1988	1982	3483	3448	3495	3526
hada	s17	1662	1665	1668	1686	2986	2996	2966	2983
hada	s18	1754	1761	1749	1744	3066	3071	3084	3065
hada	s19	1894	1836	1855	1830	2787	2838	2836	2827
hada	s20	1901	1916	2039	2038	2848	2844	2872	2841

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hEda	s11	253	253	250	249	669	664	646	600
hEda	s12	234	232	230	229	718	711	704	684
hEda	s13	281	272	267	266	578	579	576	557
hEda	s14	255	243	240	237	730	689	663	647
hEda	s15	257	256	252	248	776	773	764	750
hEda	s16	286	285	284	283	870	843	781	724
hEda	s17	245	237	233	230	521	506	486	463
hEda	s18	299	295	287	287	558	558	546	552
hEda	s19	253	241	236	234	667	675	603	582
hEda	s20	324	320	319	319	781	772	769	744

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hEda	s11	2316	2310	2288	2263	3258	3257	3250	3249
hEda	s12	2401	2402	2369	2319	3058	3133	3132	3135
hEda	s13	2040	2155	2118	2072	3034	3090	3073	3083
hEda	s14	2274	2245	2226	2201	2952	2943	2973	3068
hEda	s15	2346	2366	2305	2279	2960	2966	2990	3028
hEda	s16	2434	2427	2383	2359	3161	3289	3310	3423
hEda	s17	2232	2168	2119	2124	3017	2975	2981	2986
hEda	s18	2325	2354	2312	2283	3004	2958	2906	2926
hEda	s19	1949	1921	1910	1906	2987	2894	2959	2868
hEda	s20	2490	2506	2561	2486	3144	3126	3114	3116

G-2-2. Korean Female

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
heda	s11	244	250	250	247	542	556	586	547
heda	s12	246	239	236	233	701	688	654	646
heda	s13	280	274	271	272	556	552	551	543
heda	s14	248	237	235	234	644	626	588	508
heda	s15	256	253	249	245	760	754	743	728
heda	s16	292	290	287	283	883	878	856	823
heda	s17	249	241	238	236	496	485	464	451
heda	s18	301	297	290	291	584	588	577	571
heda	s19	250	243	240	239	707	667	642	585
heda	s20	312	304	300	299	728	709	700	696

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
heda	s11	2284	2325	2304	2242	3211	3209	3242	3252
heda	s12	2391	2412	2283	2160	3138	3119	3083	3032
heda	s13	2406	2408	2405	2387	3022	3023	2995	3013
heda	s14	2302	2293	2280	2238	2889	2946	2972	3004
heda	s15	2352	2436	2458	2409	2978	3042	3093	3051
heda	s16	2343	2330	2322	2298	3229	3272	3266	3294
heda	s17	2257	2265	2305	2292	3002	2982	3065	2948

heda	s18	2413	2364	2322	2304	2983	3001	2953	2994
heda	s19	2517	2516	2452	2417	2969	2970	2971	2905
heda	s20	2452	2420	2486	2490	3048	3121	3152	3136

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hida	s11	267	264	261	260	334	331	354	361
hida	s12	251	248	247	243	393	399	404	391
hida	s13	290	269	264	261	366	356	369	379
hida	s14	247	236	230	228	373	375	375	351
hida	s15	279	278	275	271	280	281	281	281
hida	s16	308	296	289	288	321	304	300	299
hida	s17	248	244	243	241	423	426	428	428
hida	s18	307	307	304	300	312	313	312	310
hida	s19	249	248	249	247	311	333	334	333
hida	s20	328	323	321	319	326	324	324	323

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hida	s11	3115	2968	2910	2880	3583	3532	3541	3472
hida	s12	2808	2773	2769	2710	3106	3083	3108	3091
hida	s13	2583	2614	2607	2570	3640	3622	3597	3574
hida	s14	2777	2802	2823	2749	3517	3528	3547	3539
hida	s15	3157	3101	3055	2992	3605	3595	3574	3557
hida	s16	2859	2759	2746	2734	3586	3594	3608	3592
hida	s17	2619	2609	2589	2613	3410	3380	3286	3196
hida	s18	2767	2749	2728	2714	3275	3312	3307	3310
hida	s19	2735	2731	2723	2735	3405	3417	3383	3454
hida	s20	2983	3033	3142	3096	3563	3652	3640	3581

G-2-2. Korean Female

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hoda	s11	257	257	257	254	511	510	508	504
hoda	s12	253	247	245	243	481	482	494	484
hoda	s13	263	254	253	255	534	517	513	508
hoda	s14	241	239	236	235	486	465	455	453
hoda	s15	278	277	275	271	512	523	522	528
hoda	s16	295	295	294	292	548	547	549	530
hoda	s17	239	236	236	232	476	467	464	460
hoda	s18	307	307	305	304	614	597	585	569
hoda	s19	254	252	244	240	507	503	489	472
hoda	s20	331	327	324	321	367	381	377	398

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hoda	s11	955	971	1035	1120	3233	3187	3129	3076
hoda	s12	1053	1183	1218	1246	3299	3227	3145	3177
hoda	s13	898	963	1250	1352	2831	2798	2803	2808

hoda	s14	1130	1219	1299	1440	3043	3066	3063	3053
hoda	s15	814	838	836	925	3055	3029	3077	3065
hoda	s16	1000	1136	1215	1440	3252	3227	3168	3280
hoda	s17	990	1122	1200	1358	2954	2953	2952	2951
hoda	s18	1044	1039	1166	1235	3241	3273	3165	3073
hoda	s19	768	808	876	1083	2977	2980	2958	2893
hoda	s20	952	1010	1154	1298	2945	2938	2907	2880

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hweda	s11	255	252	250	248	496	497	491	499
hweda	s12	245	245	241	239	682	655	635	631
hweda	s13	284	275	271	270	577	570	575	566
hweda	s14	248	231	232	233	515	493	477	458
hweda	s15	263	262	259	255	728	730	714	698
hweda	s16	289	286	285	284	768	764	713	711
hweda	s17	243	238	235	230	472	464	472	453
hweda	s18	304	300	293	289	573	585	565	559
hweda	s19	247	239	236	235	546	553	552	558
hweda	s20	317	318	315	314	704	707	639	642

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hweda	s11	2309	2283	2276	2256	3102	3167	3144	3173
hweda	s12	2034	2165	2188	2170	3159	3096	3169	3128
hweda	s13	2366	2323	2278	2264	2892	2965	3007	2995
hweda	s14	2133	2246	2267	2337	2863	2918	2961	2985
hweda	s15	2394	2369	2353	2311	2943	2950	2930	2912
hweda	s16	2370	2315	2339	2325	3224	3208	3312	3341
hweda	s17	2145	2196	2248	2280	2814	2812	2832	2843
hweda	s18	1852	1890	1962	2182	2968	2984	2934	3078
hweda	s19	2055	1986	1958	1969	2845	2905	2931	2986
hweda	s20	2162	2179	2169	2161	3128	3122	3132	3106

G-2-2. Korean Female

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
huda	s11	265	264	261	257	504	512	510	504
huda	s12	264	260	256	256	484	484	477	478
huda	s13	283	277	279	278	479	515	520	508
huda	s14	256	246	236	236	383	443	436	431
huda	s15	286	288	286	281	314	320	323	328
huda	s16	304	302	299	297	331	338	340	338
huda	s17	263	242	241	236	436	475	472	464
huda	s18	311	313	312	305	315	318	319	323
huda	s19	263	263	261	251	413	484	492	481
huda	s20	327	324	323	321	331	330	327	330

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
huda	s11	1055	1063	1086	1213	3227	3217	3201	3155
huda	s12	1047	1057	1177	1213	3162	3150	3144	3125
huda	s13	825	980	1127	1325	2743	2776	2744	2727
huda	s14	1075	1131	1282	1380	2996	2982	2918	2956
huda	s15	850	862	958	1020	2925	3010	3015	3062
huda	s16	1105	1107	1209	1235	3200	3175	3199	3187
huda	s17	1208	1260	1399	1560	2903	2924	2910	2847
huda	s18	900	911	875	1255	3067	3075	3063	3016
huda	s19	760	859	1013	1070	2901	2922	2933	2965
huda	s20	987	983	1032	1151	2999	3010	2994	2973

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hwida	s11	267	265	267	261	419	421	398	389
hwida	s12	248	243	243	242	389	400	387	383
hwida	s13	287	275	264	262	444	454	461	458
hwida	s14	247	241	237	234	385	382	374	364
hwida	s15	276	273	268	263	286	290	291	285
hwida	s16	297	291	285	281	306	302	304	302
hwida	s17	248	245	243	241	423	432	435	435
hwida	s18	309	307	307	303	311	314	314	314
hwida	s19	256	253	250	247	389	403	415	414
hwida	s20	326	328	323	323	335	332	329	326

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hwida	s11	2764	2730	2713	2743	3270	3256	3245	3262
hwida	s12	2682	2739	2771	2780	3076	3134	3167	3109
hwida	s13	2510	2530	2566	2528	3296	3315	3339	3384
hwida	s14	2672	2726	2679	2677	3303	3255	3351	3284
hwida	s15	2877	2856	2851	2840	3274	3257	3307	3231
hwida	s16	2704	2727	2748	2732	3193	3322	3323	3236
hwida	s17	2542	2587	2555	2533	3238	3261	3258	3223

hwida	s18	2709	2735	2743	2686	3007	3066	3039	3087
hwida	s19	2669	2667	2650	2690	3192	3263	3251	3212
hwida	s20	2751	2746	2736	2727	3100	3089	3092	3099

G-2-2. Korean Female

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
hʌda	s11	251	250	250	249	865	812	750	707
hʌda	s12	249	242	238	238	824	807	753	714
hʌda	s13	274	263	255	254	789	759	759	740
hʌda	s14	241	230	226	227	746	693	659	575
hʌda	s15	265	267	268	267	843	836	817	789
hʌda	s16	294	292	293	292	883	878	875	875
hʌda	s17	239	233	232	231	690	665	635	624
hʌda	s18	299	296	291	287	567	566	563	556
hʌda	s19	251	249	246	244	729	677	625	592
hʌda	s20	308	311	307	303	957	954	933	921

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
hʌda	s11	1376	1434	1513	1707	3142	3106	3092	3137
hʌda	s12	1208	1286	1426	1526	3119	3089	3138	3220
hʌda	s13	1468	1426	1495	1591	2640	2583	2576	2584
hʌda	s14	1256	1287	1400	1635	2916	2926	2928	2905
hʌda	s15	1293	1308	1334	1352	2940	2961	3006	2974
hʌda	s16	1499	1587	1733	1731	3203	3243	3314	3290
hʌda	s17	1394	1422	1506	1599	3069	3064	2995	3073
hʌda	s18	1452	1393	1358	1430	3222	3186	3190	3184
hʌda	s19	1247	1221	1229	1243	3002	2966	3125	3062
hʌda	s20	1299	1342	1411	1530	3030	2961	2926	2981

Word	Sn	F0A	F0B	F0C	F0D	F1A	F1B	F1C	F1D
huuda	s11	268	267	266	263	518	526	528	526
huuda	s12	253	250	248	246	502	489	486	481
huuda	s13	288	278	275	274	470	521	522	519
huuda	s14	265	250	243	241	452	468	457	463
huuda	s15	282	283	281	278	369	363	392	397
huuda	s16	302	305	305	303	370	374	379	373
huuda	s17	251	248	247	246	479	493	496	490
huuda	s18	306	309	307	303	383	415	467	492
huuda	s19	260	260	256	253	436	473	492	493
huuda	s20	347	341	337	333	352	347	343	338

Word	Sn	F2A	F2B	F2C	F2D	F3A	F3B	F3C	F3D
huuda	s11	1621	1609	1622	1647	3231	3207	3189	3207
huuda	s12	1587	1571	1587	1623	3174	3144	3158	3107
huuda	s13	1752	1801	1979	1958	2885	2855	2823	2818

huuda	s14	1755	1761	1779	1909	2789	2776	2848	2831
huuda	s15	1686	1676	1699	1700	2997	3006	3047	3011
huuda	s16	1799	1850	1875	1882	3281	3246	3265	3256
huuda	s17	1692	1740	1787	1846	2960	2814	2841	2837
huuda	s18	1583	1610	1684	1812	3041	3060	3050	3033
huuda	s19	1812	1797	1820	1846	2855	2848	2881	2948
huuda	s20	1369	1611	1742	1803	3088	3020	2968	2973

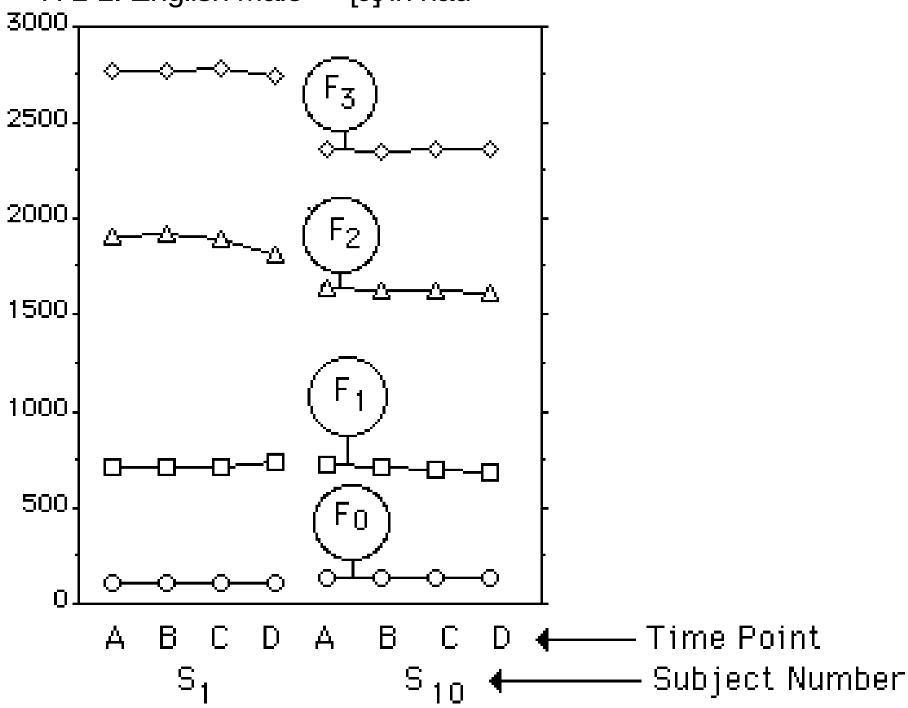
Appendix H

Line Chart of Vowel Formants for Individual

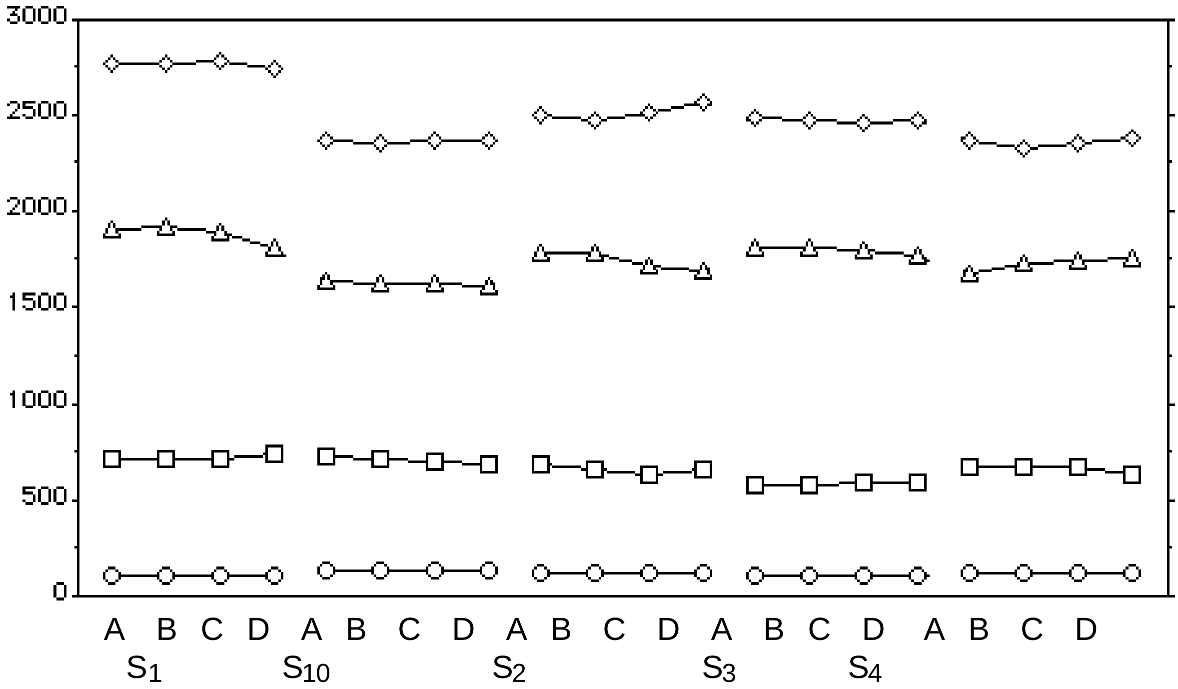
Subject and Average of Each Group

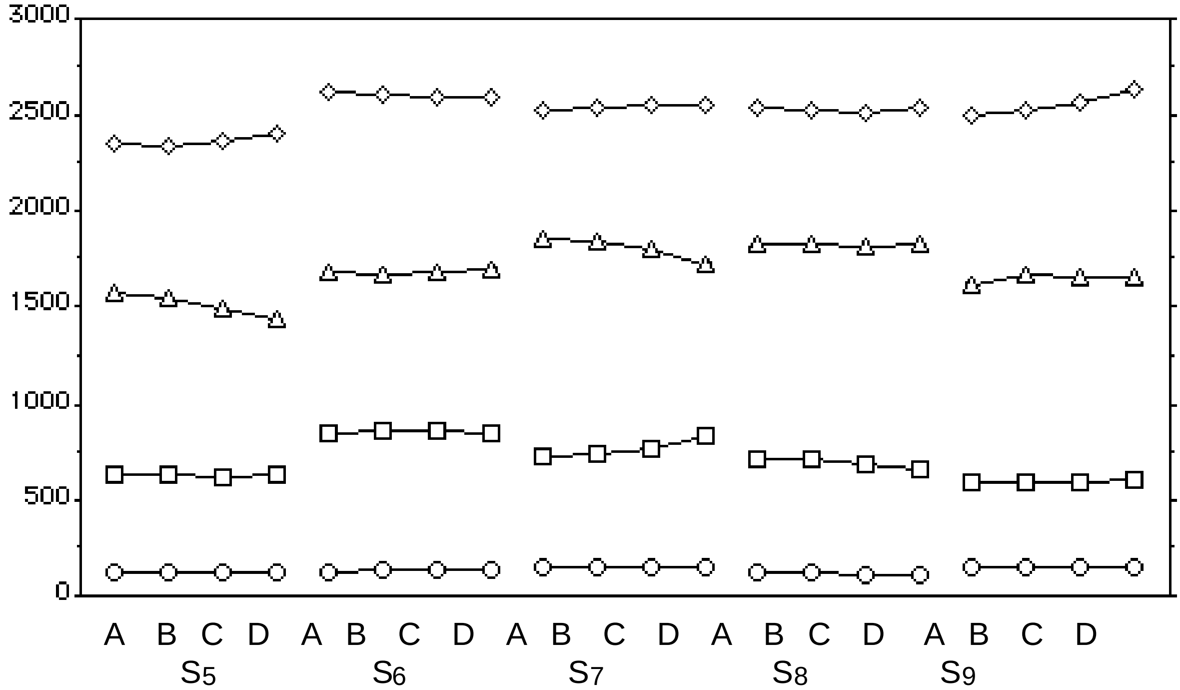
The abscissa indicates four time points and subject number. The ordinate shows formant frequencies. The circles indicate F_0 values. The squares are used for F_1. The triangles show F_2. The diamonds represent F_3.

H-1-1. English Male [æ] in had

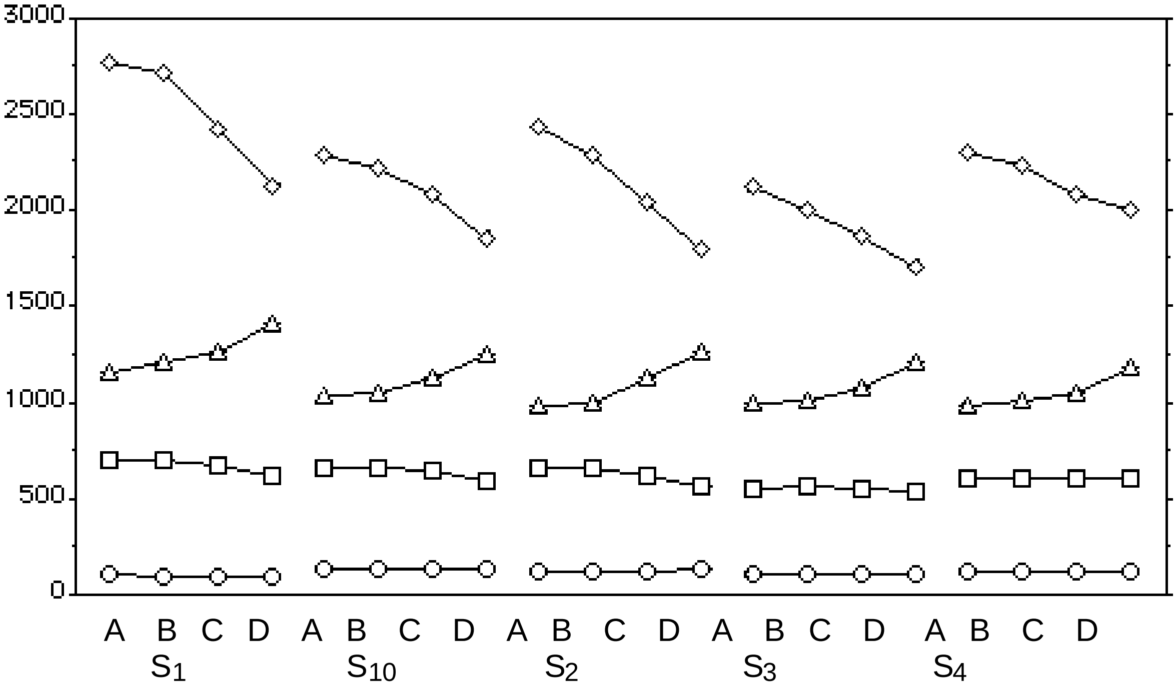


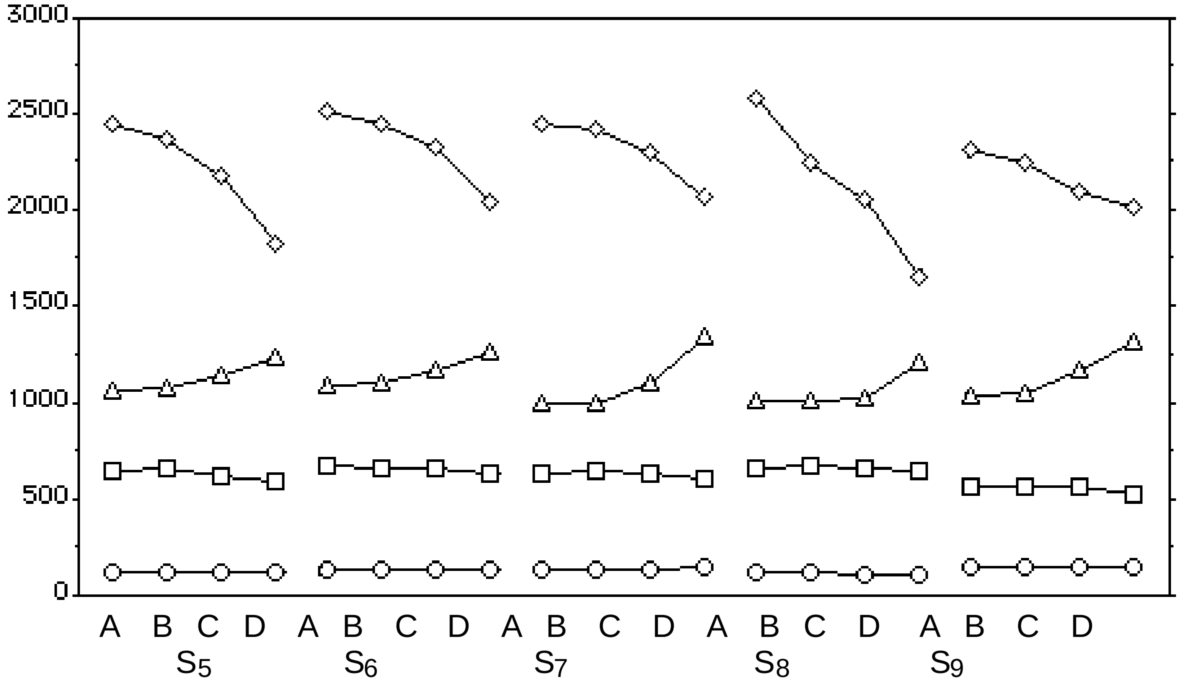
H-1-1. English Male [æ] in had



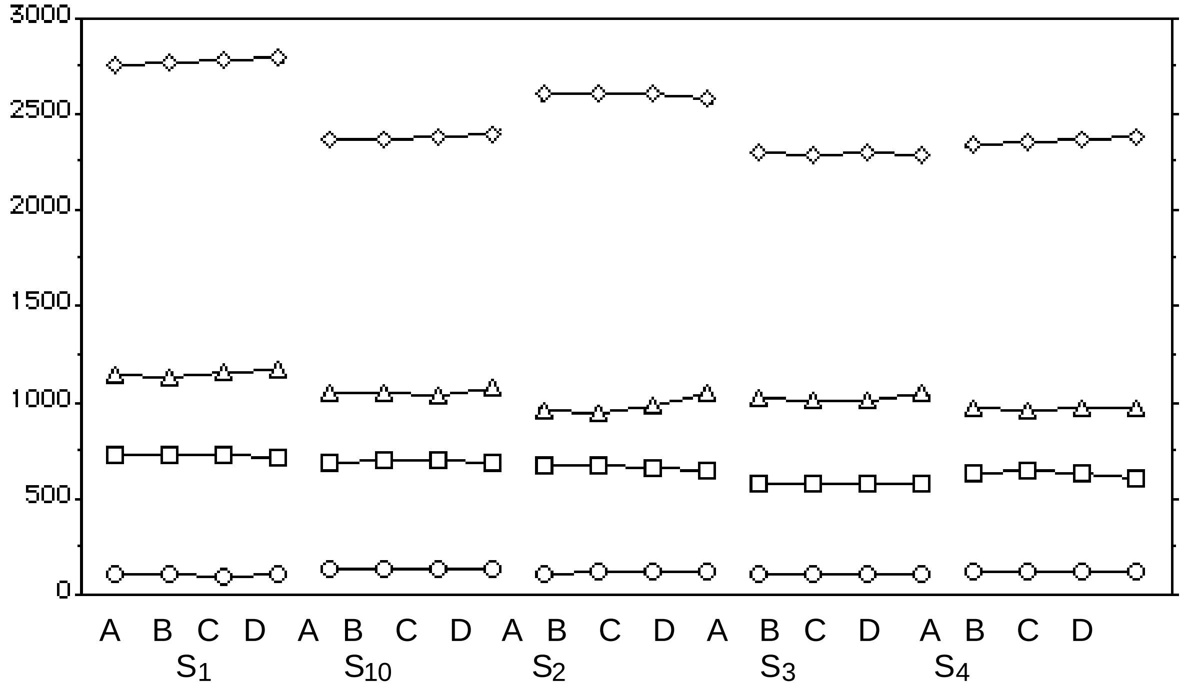


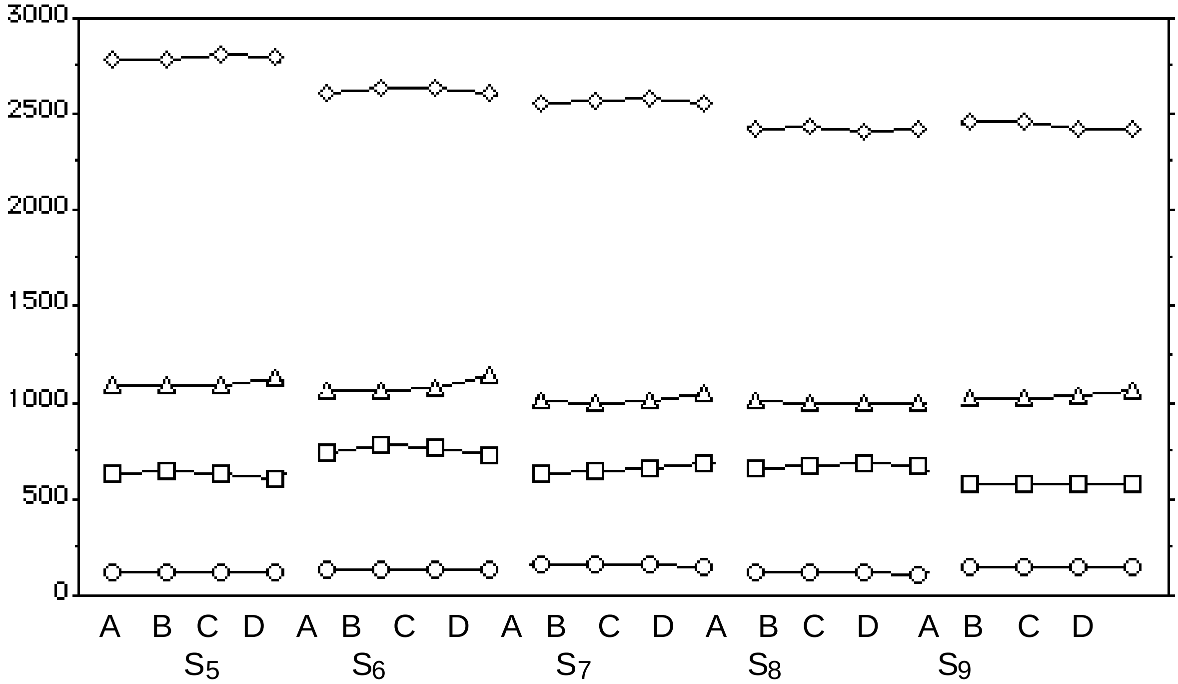
H-1-1. English Male [a] in hard



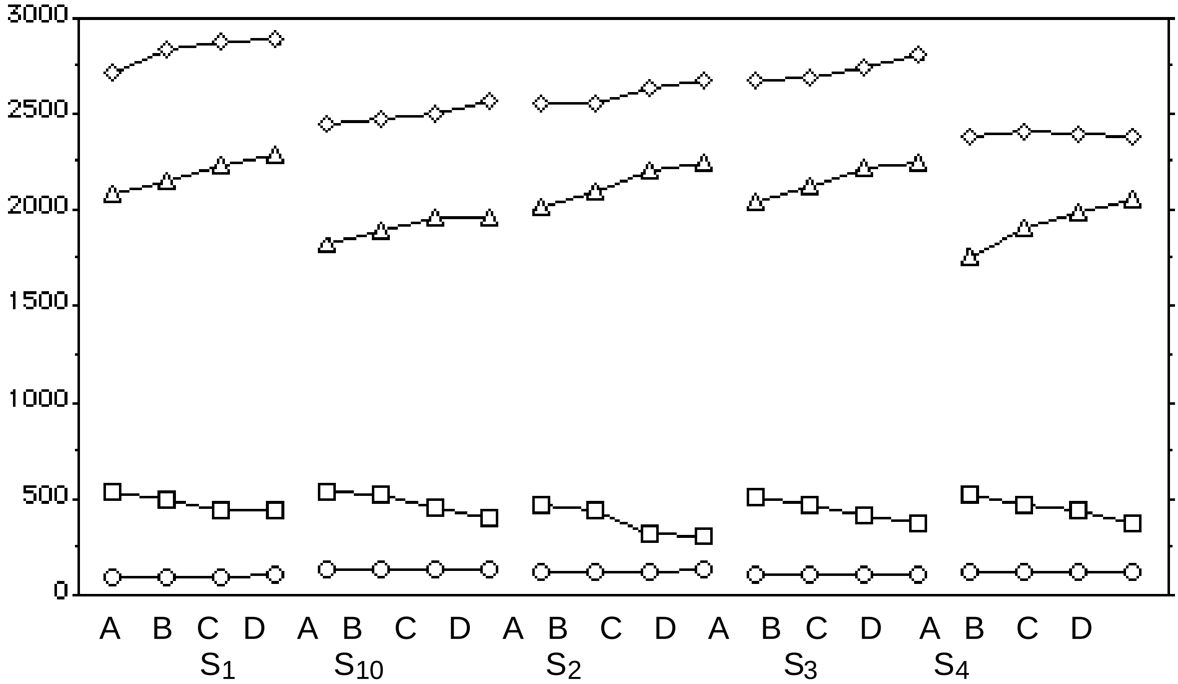


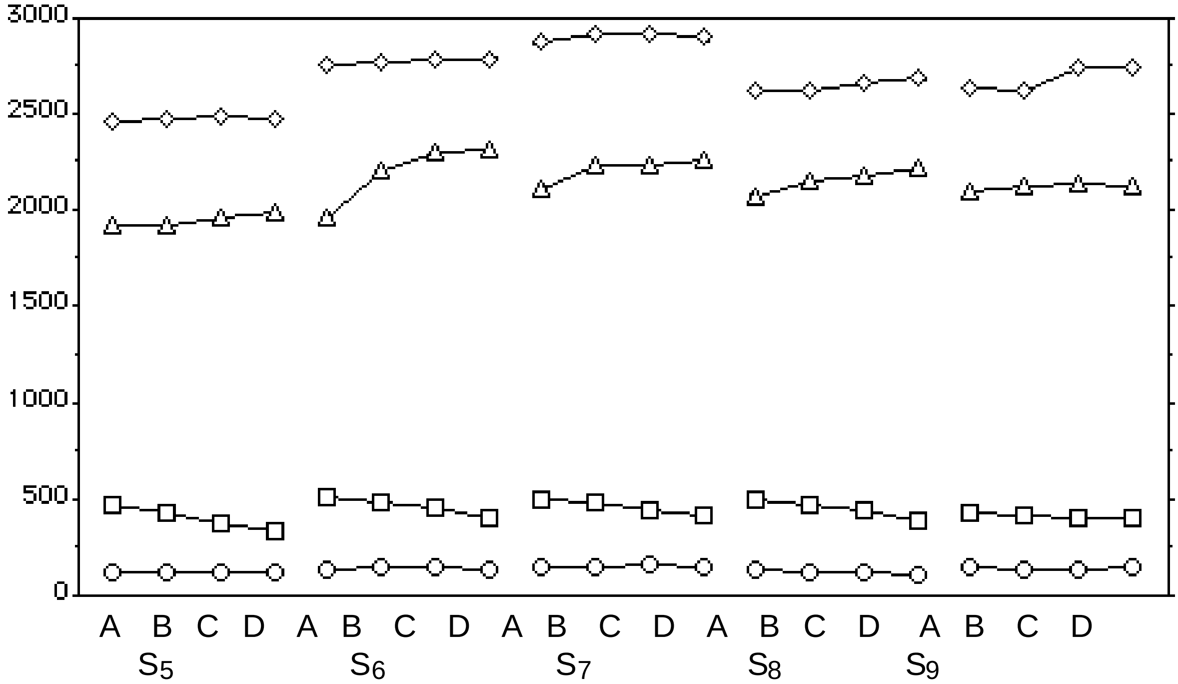
H-1-1. English Male [o] in hawed



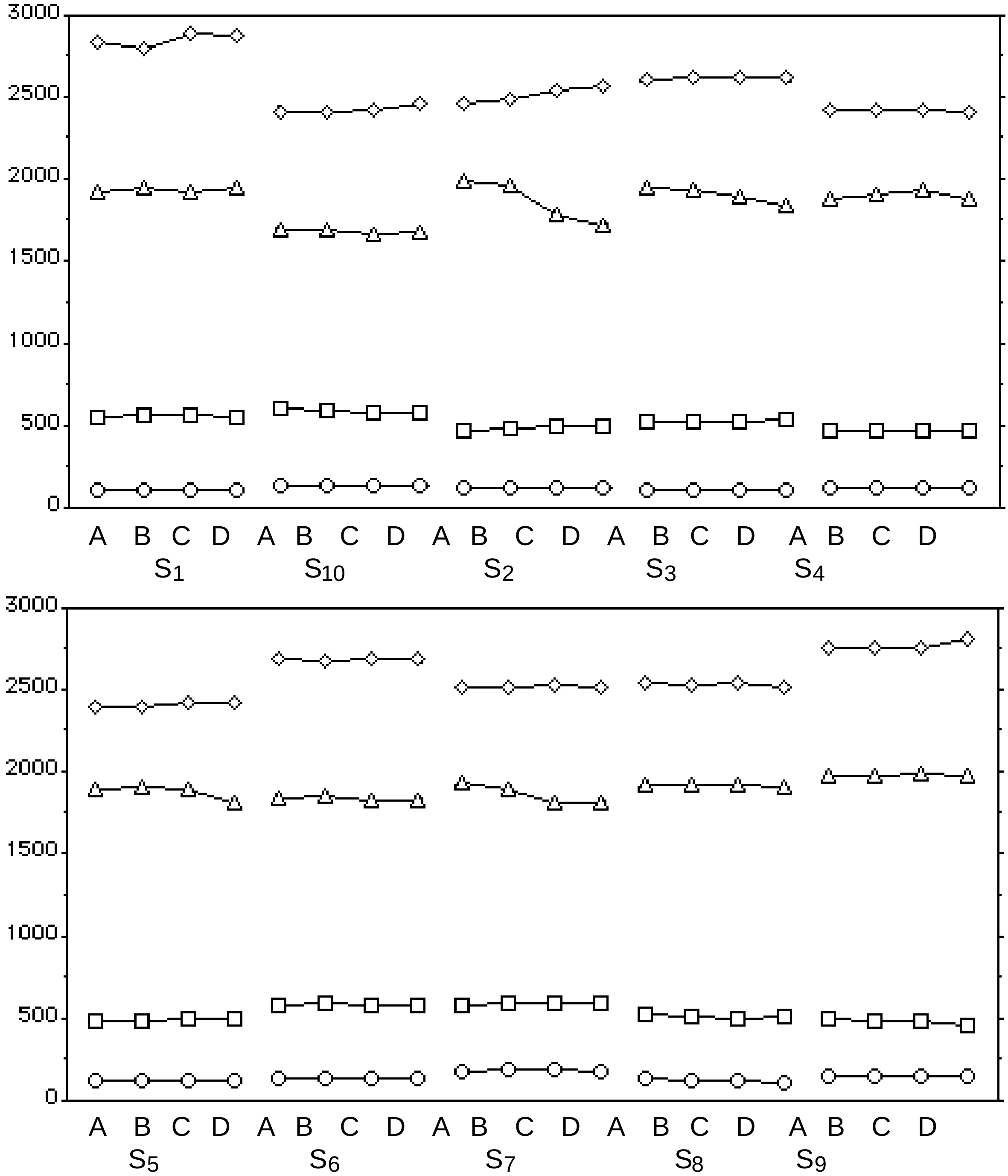


H-1-1. English Male [ei] in hayed

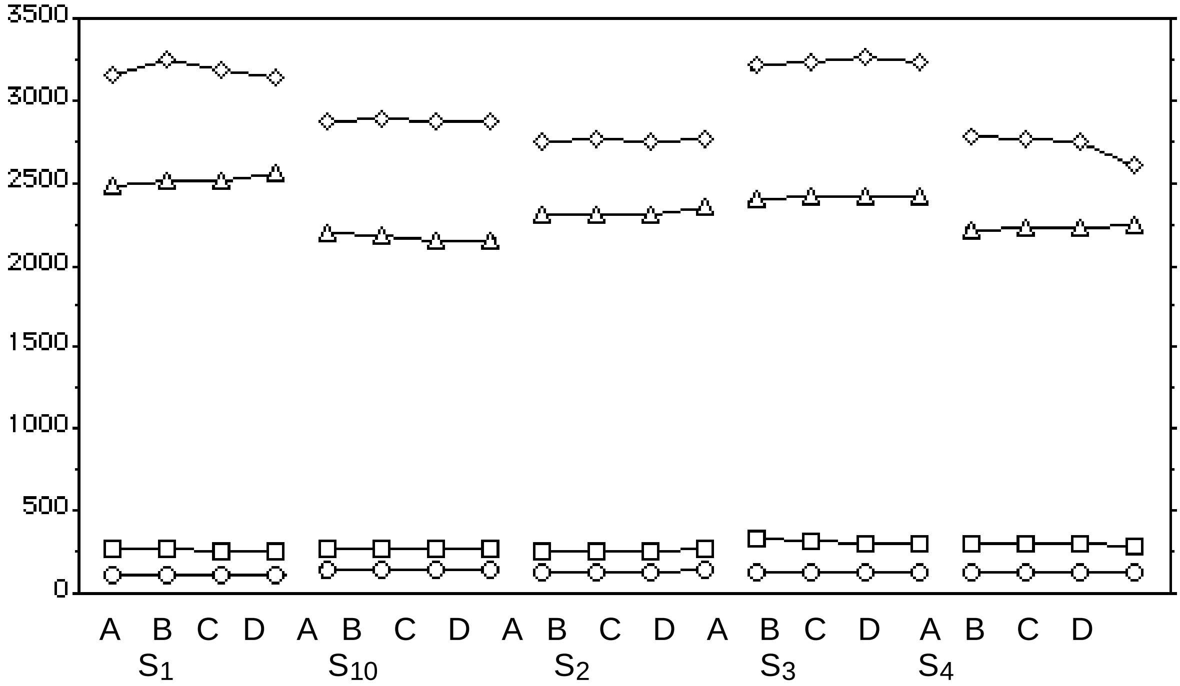


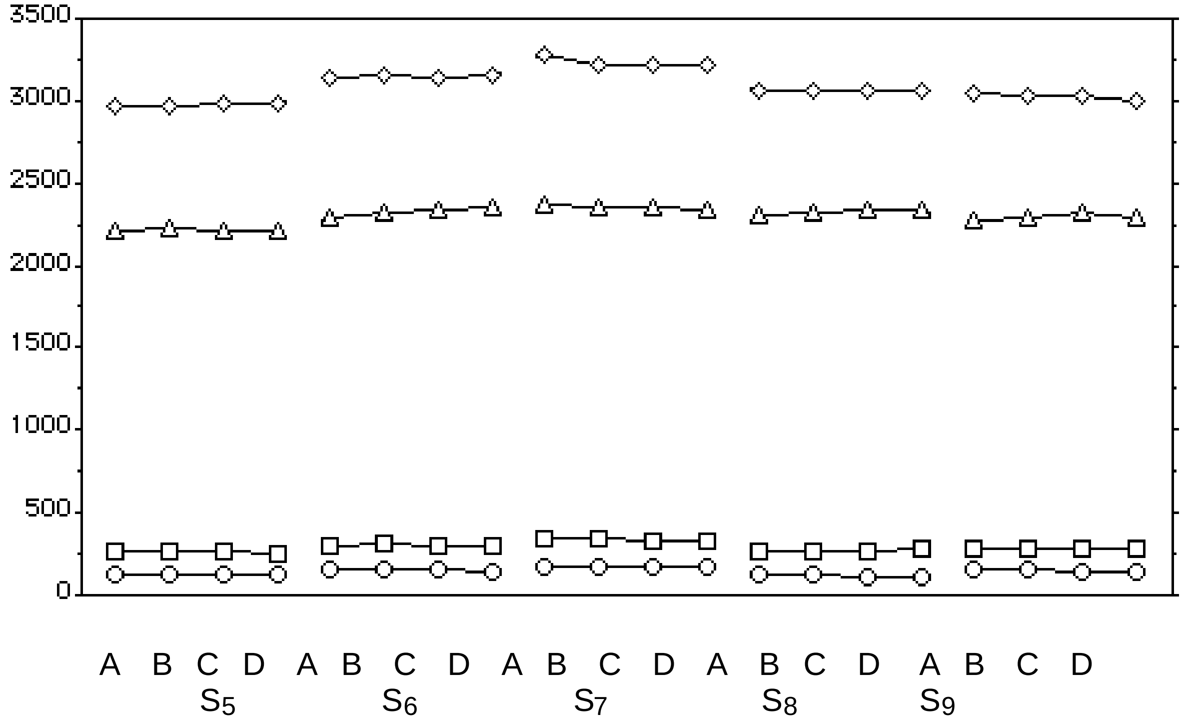


H-1-1. English Male [E] in head

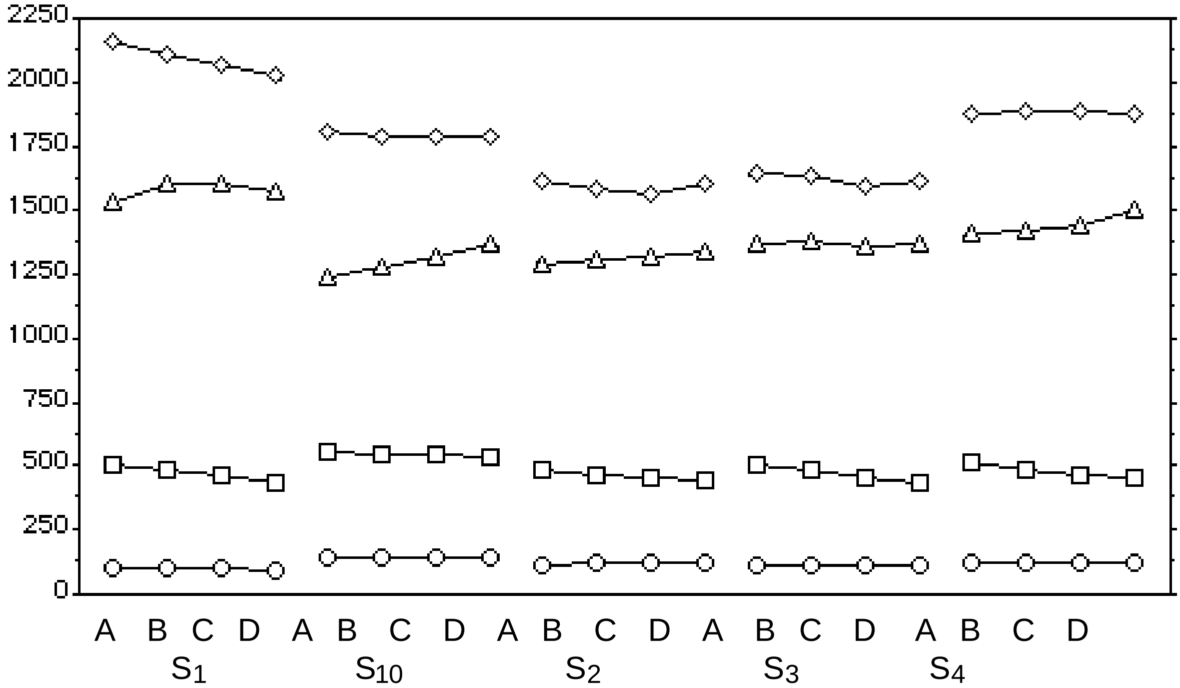


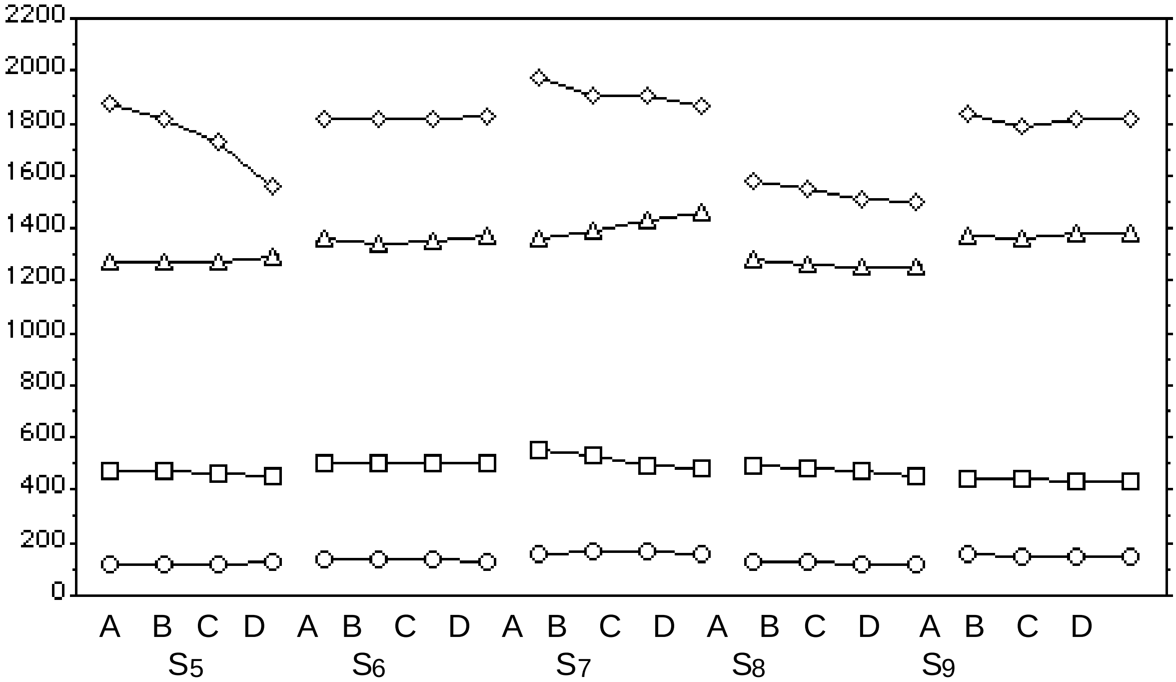
H-1-1. English Male [i] in heed



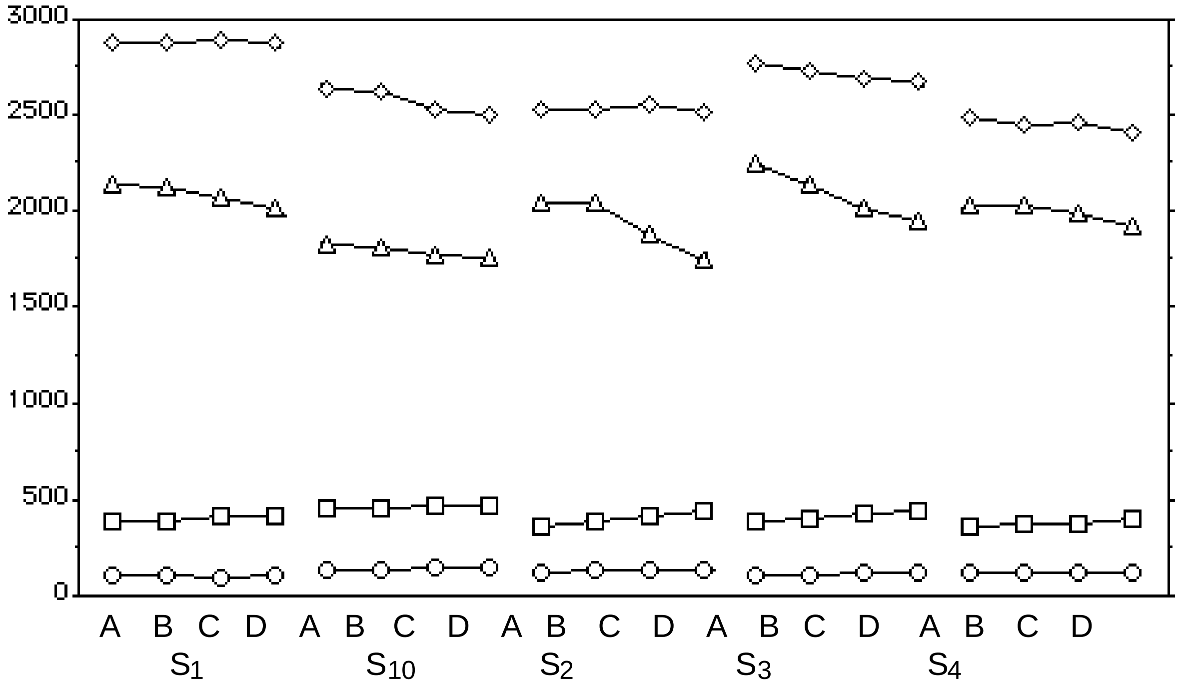


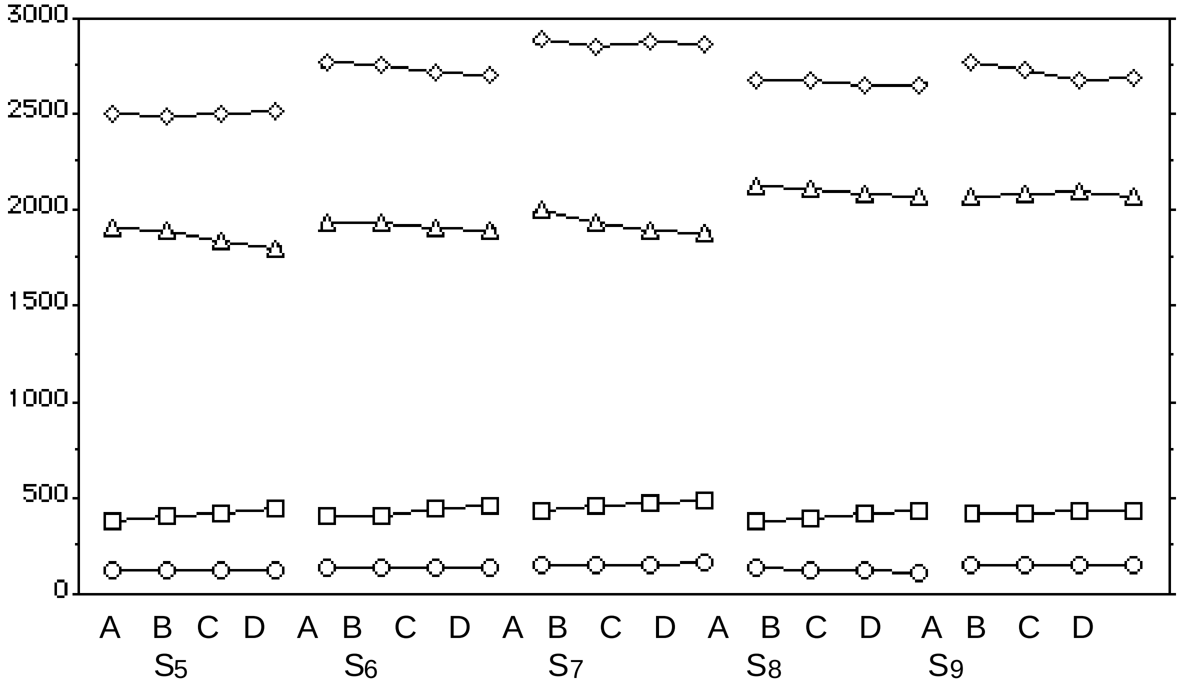
H-1-1. English Male [ɜ'] in herd



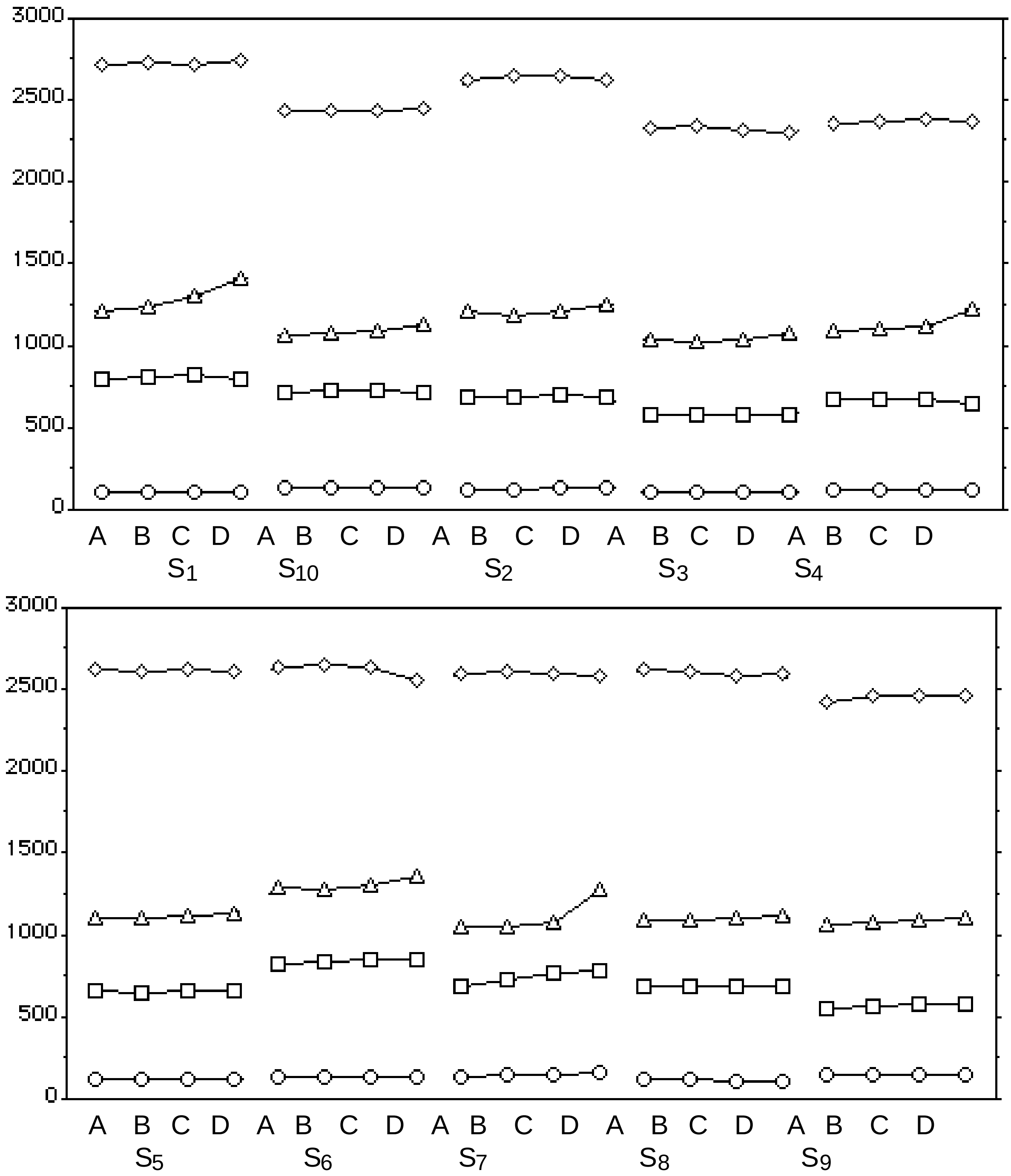


H-1-1. English Male [I] in hid

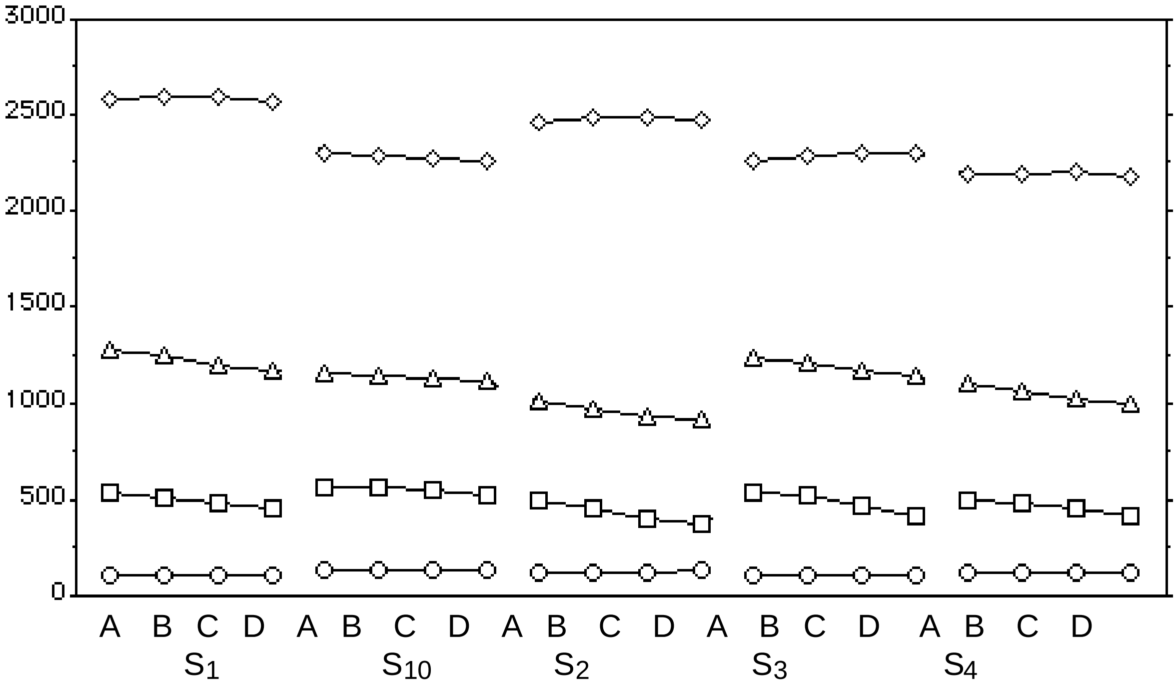


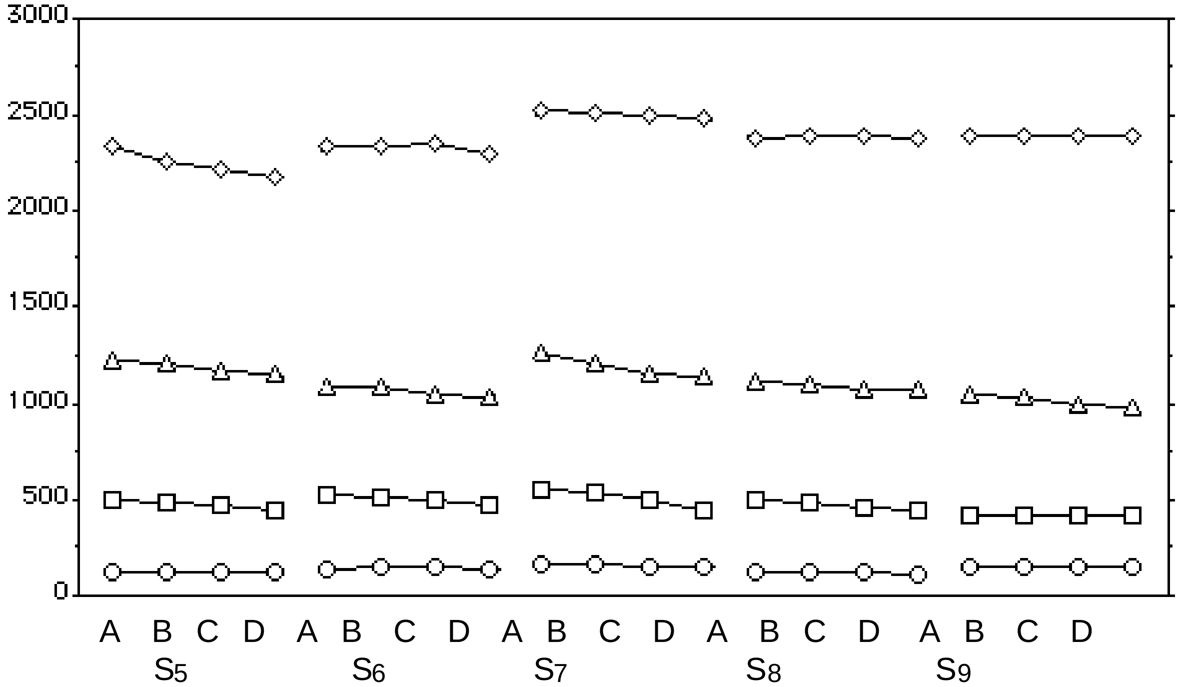


H-1-1. English Male [a] in hod

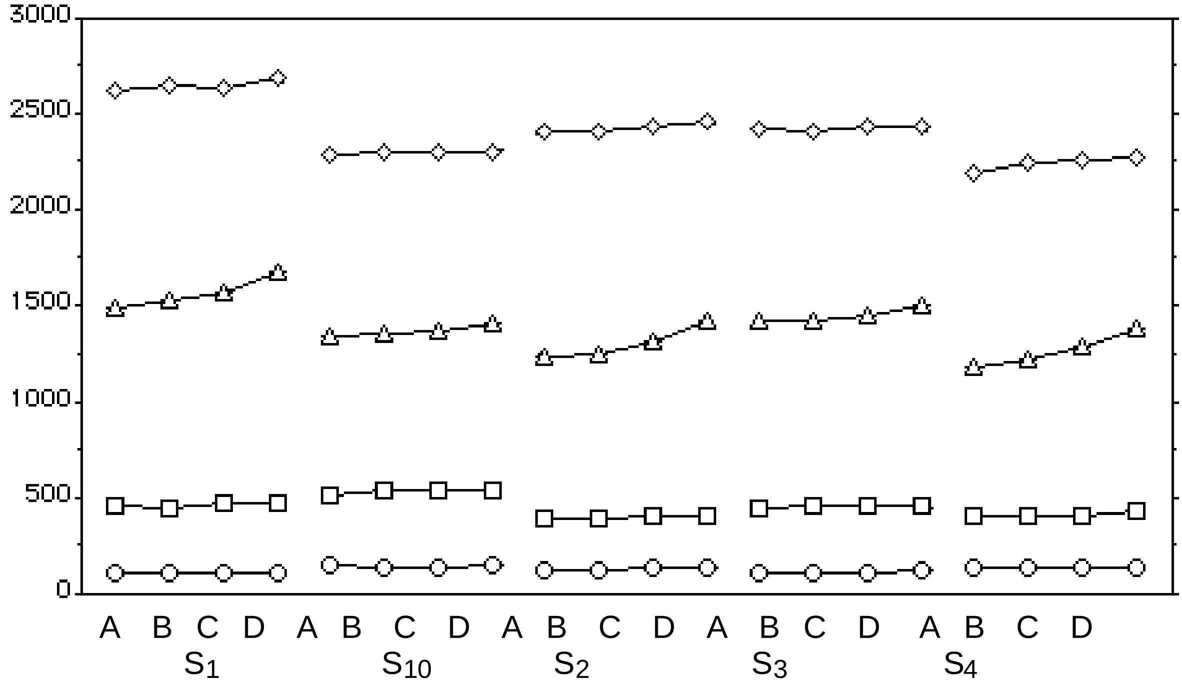


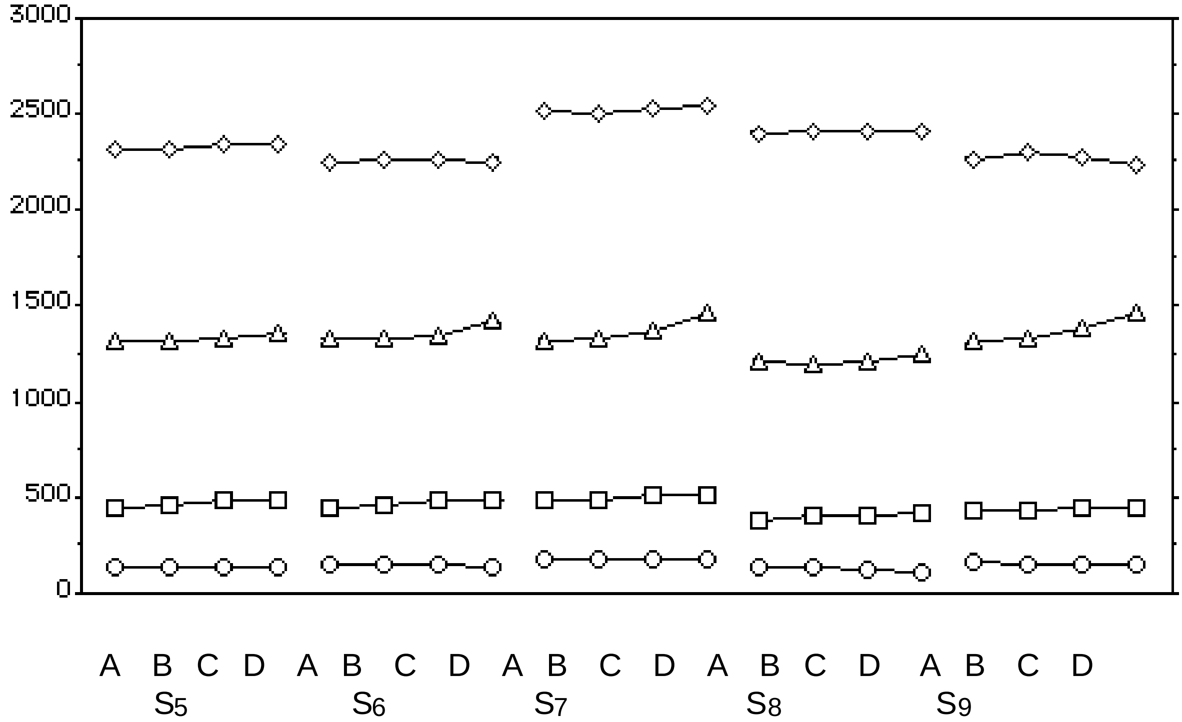
H-1-1. English Male [ou] in hoed



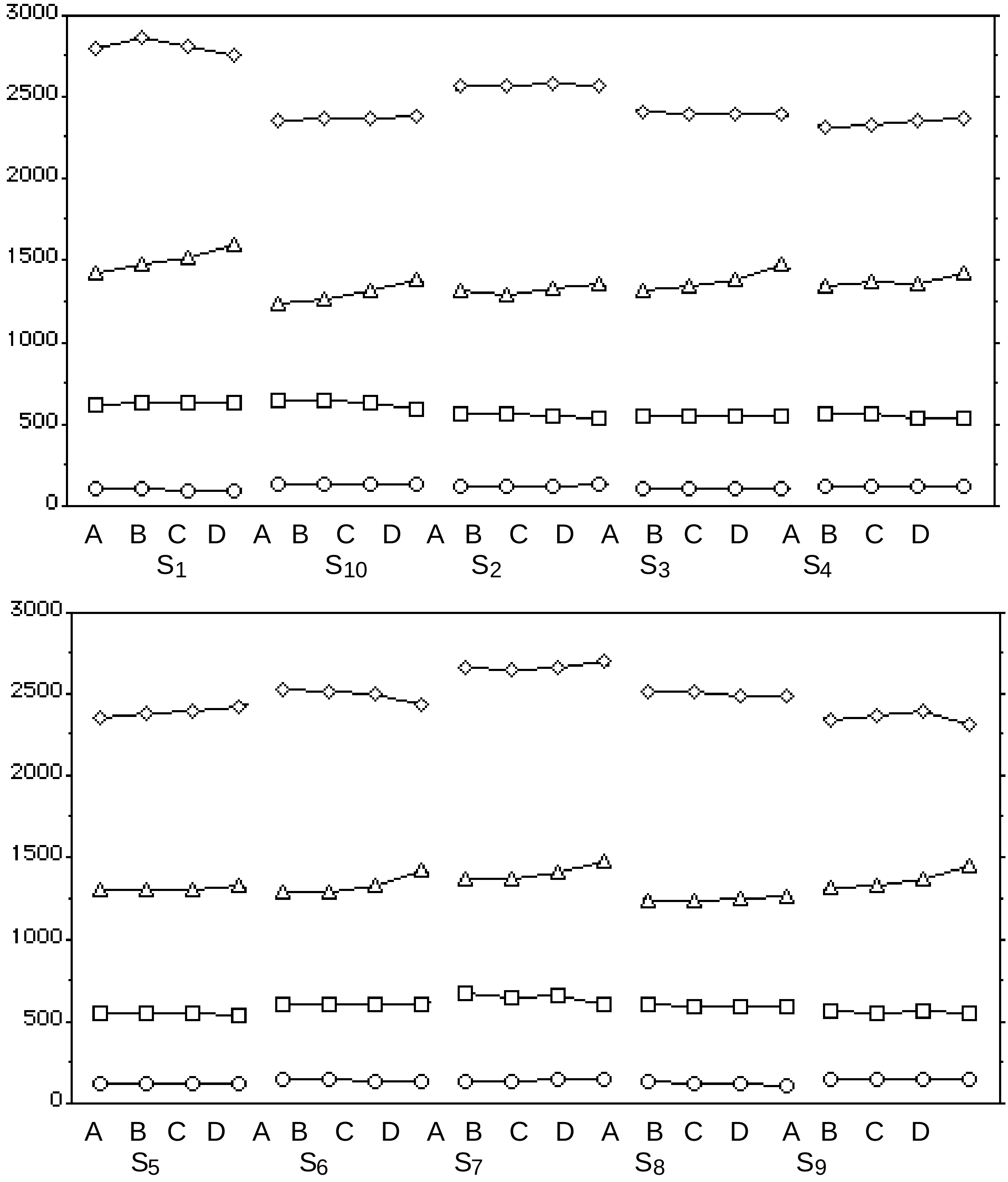


H-1-1. English Male [ʊ] in hood

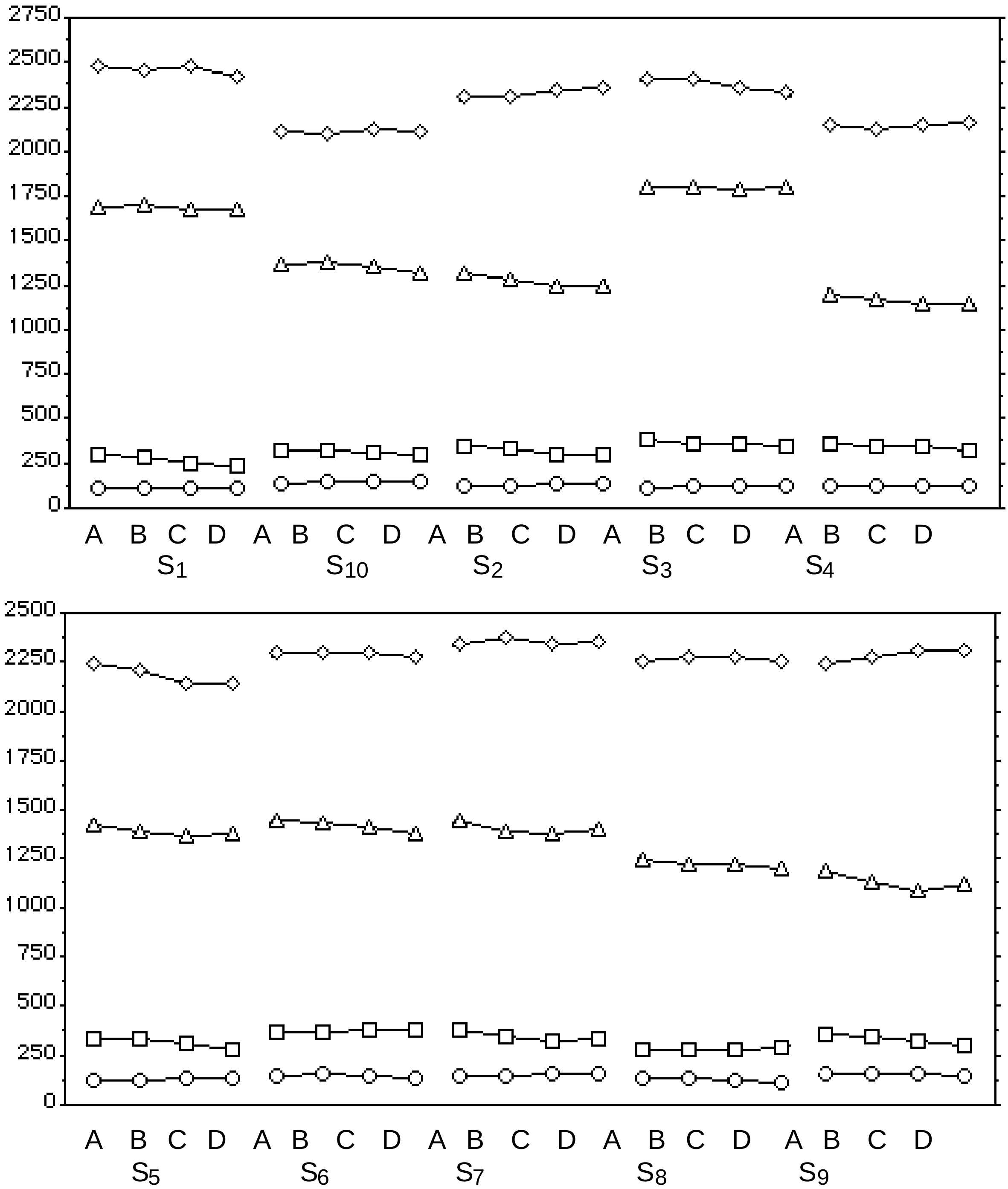




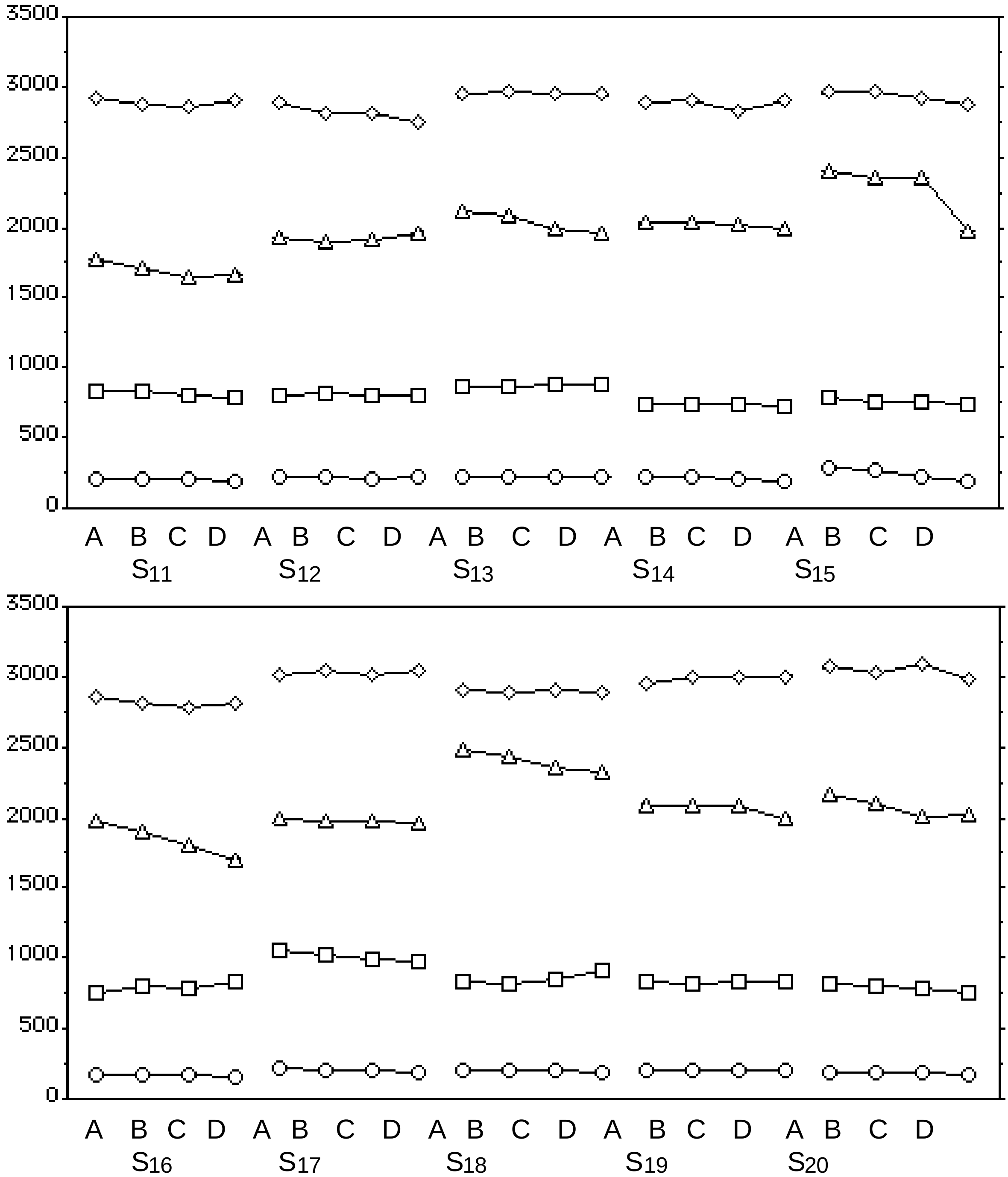
H-1-1. English Male [ʌ] in Hudd



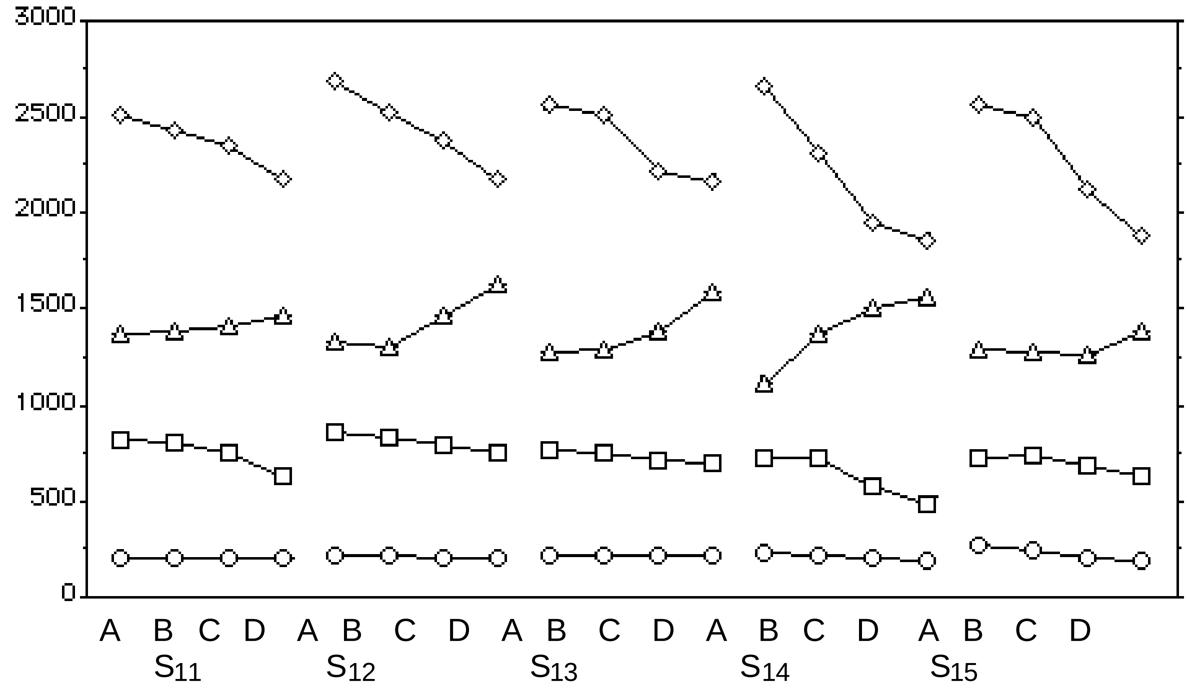
H-1-1. English Male [u] in who'd

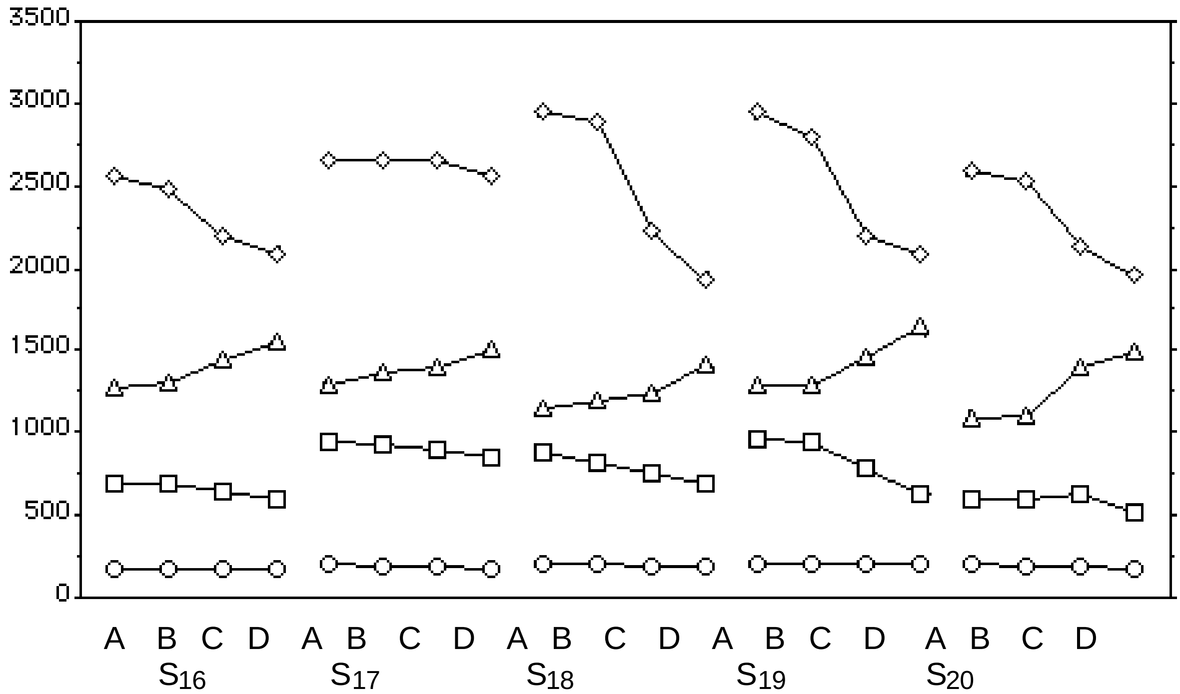


H-1-2. English Female [æ] in had

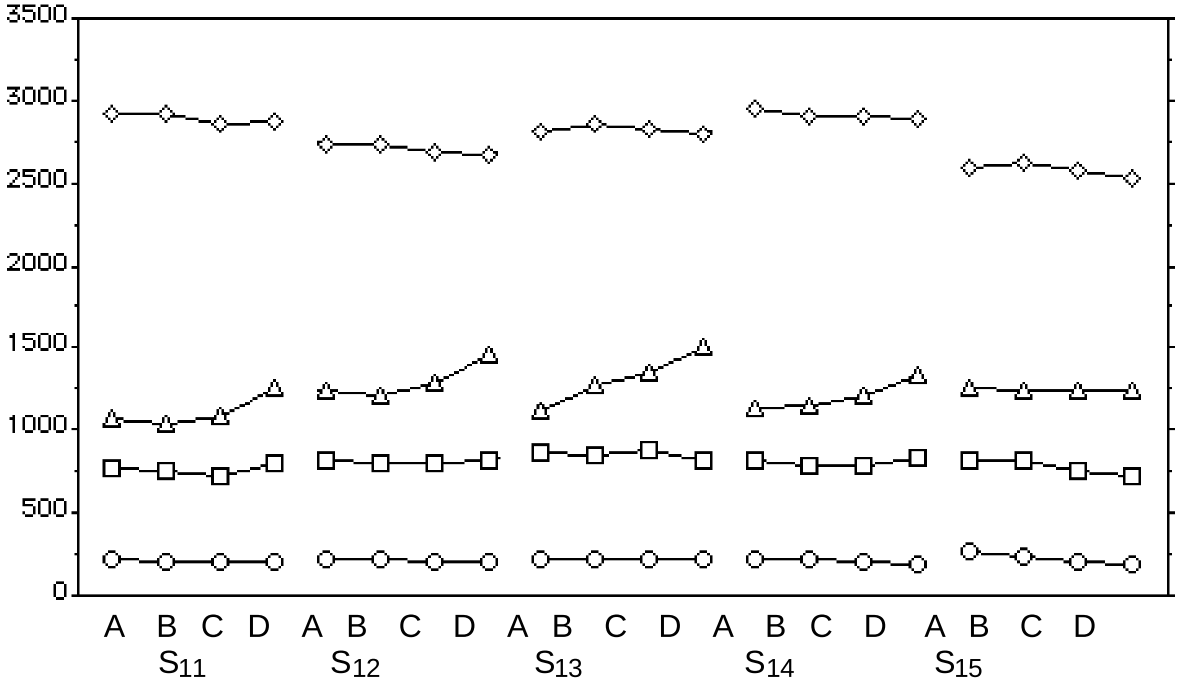


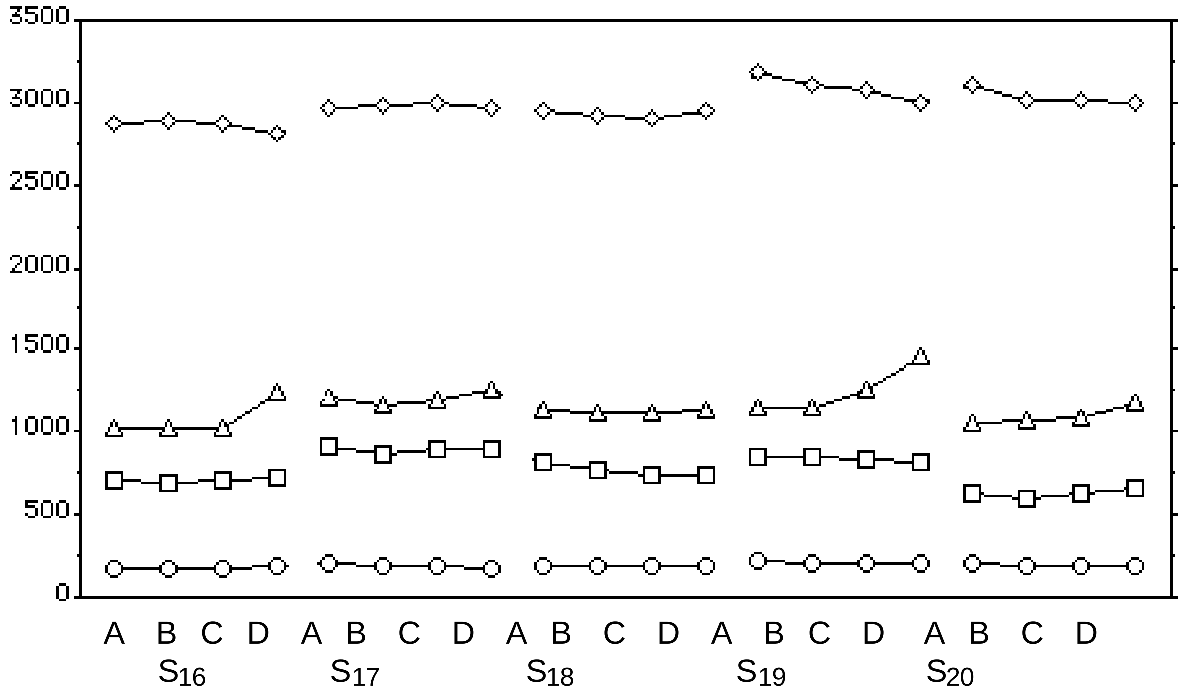
H-1-2. English Female [a] in hard



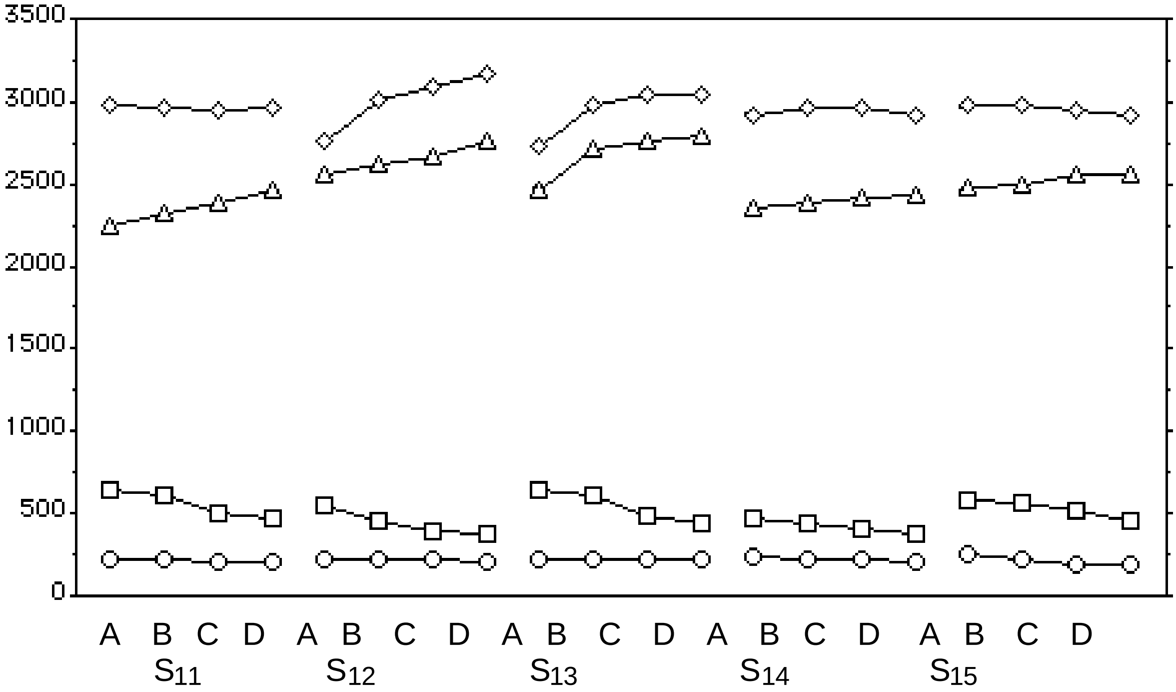


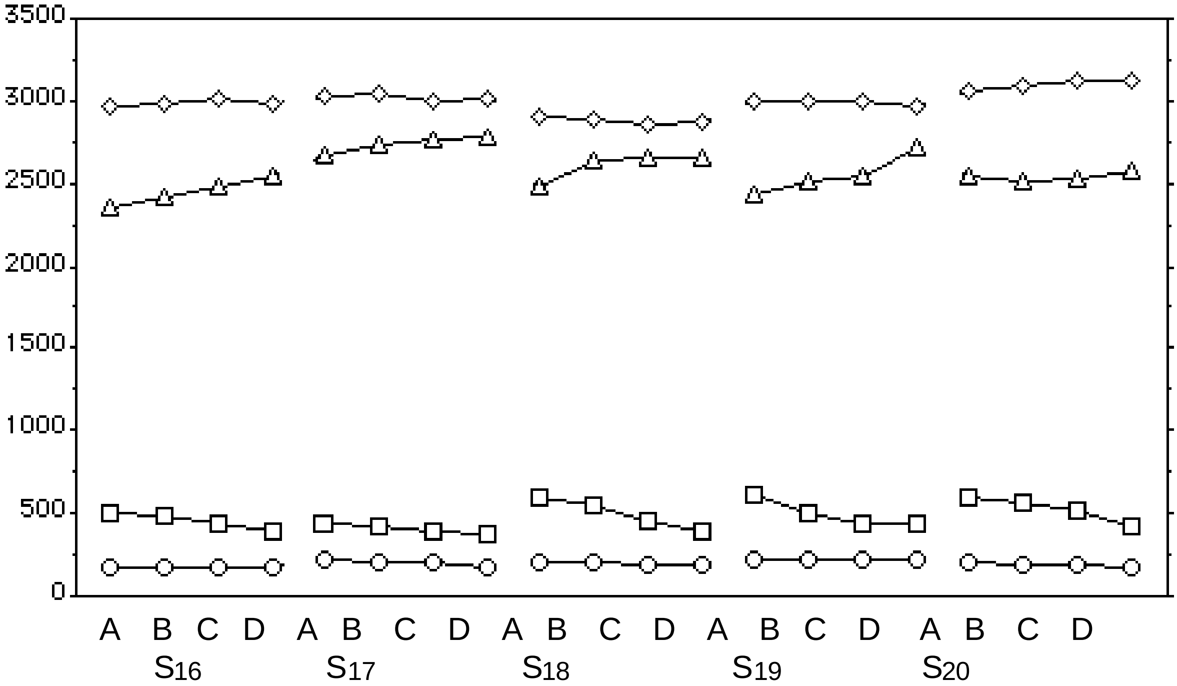
H-1-2. English Female [o] in hawed



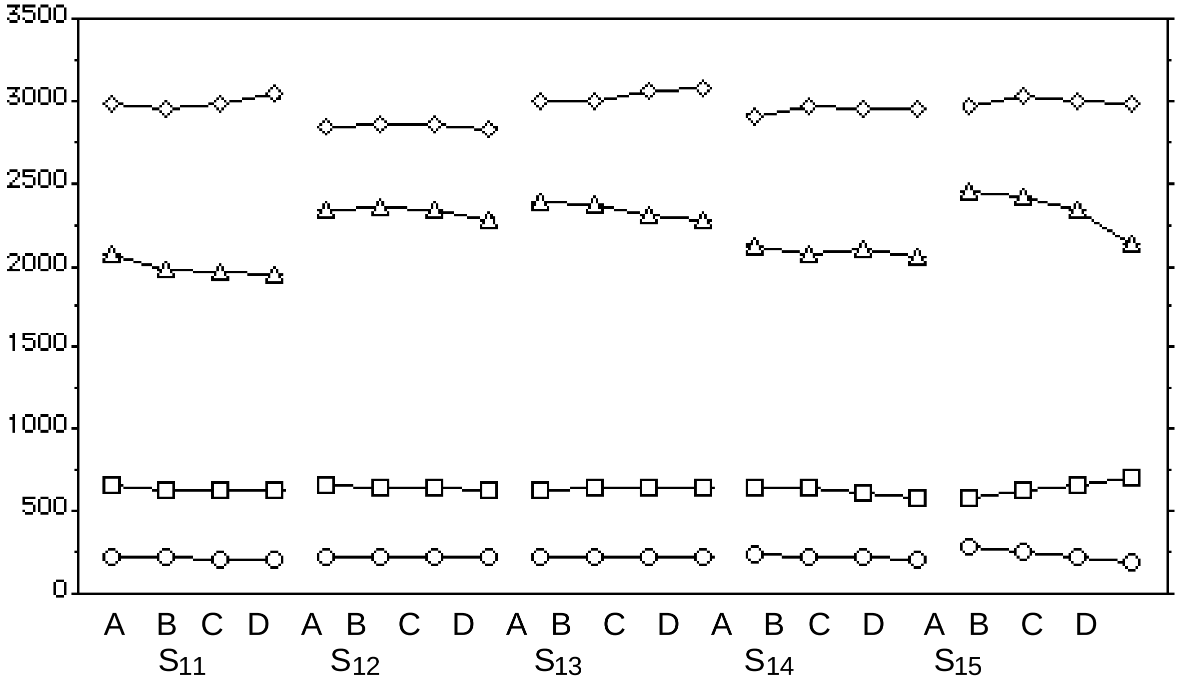


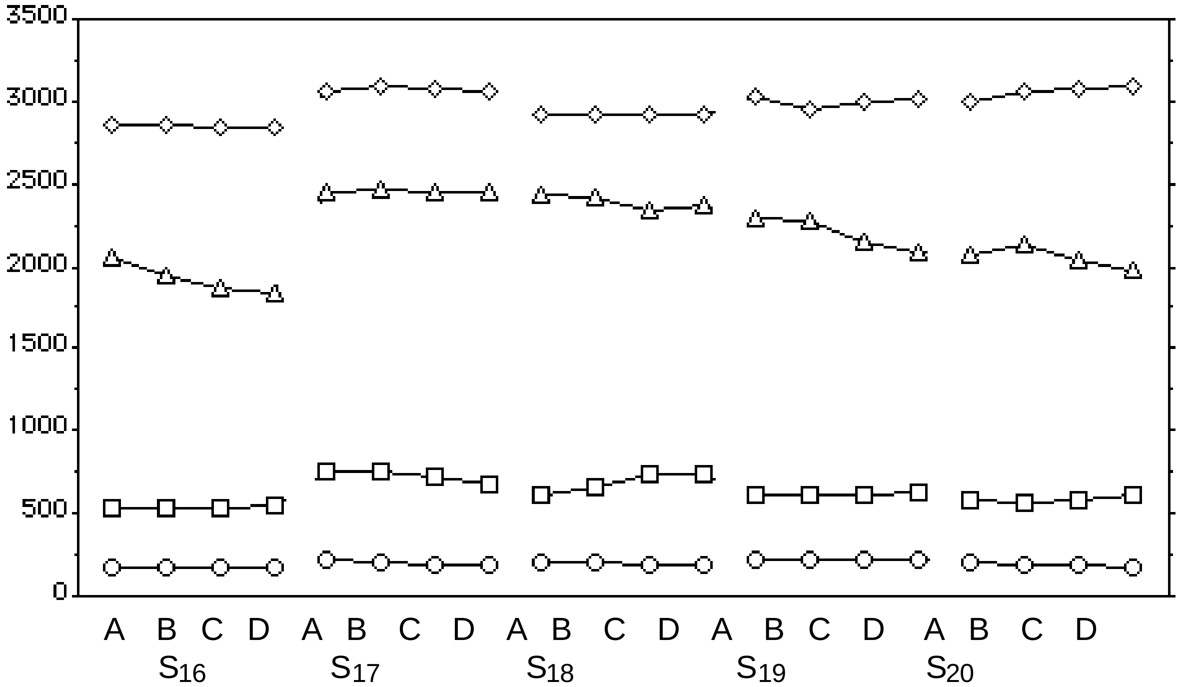
H-1-2. English Female [ei] in hayed



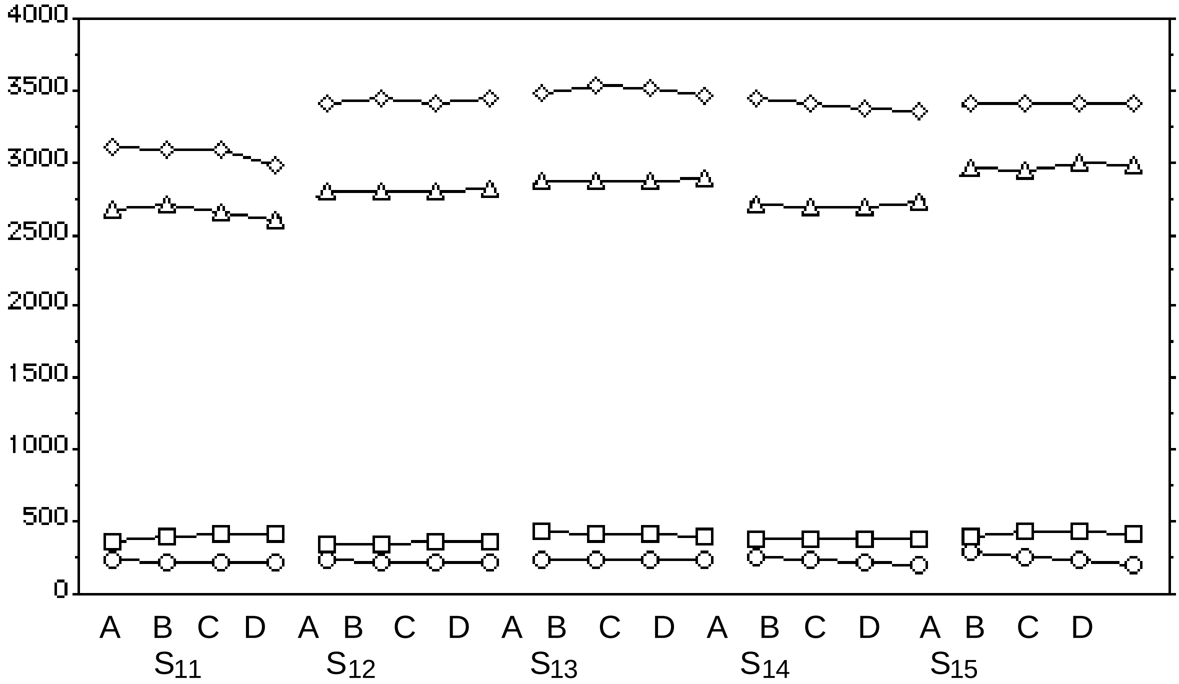


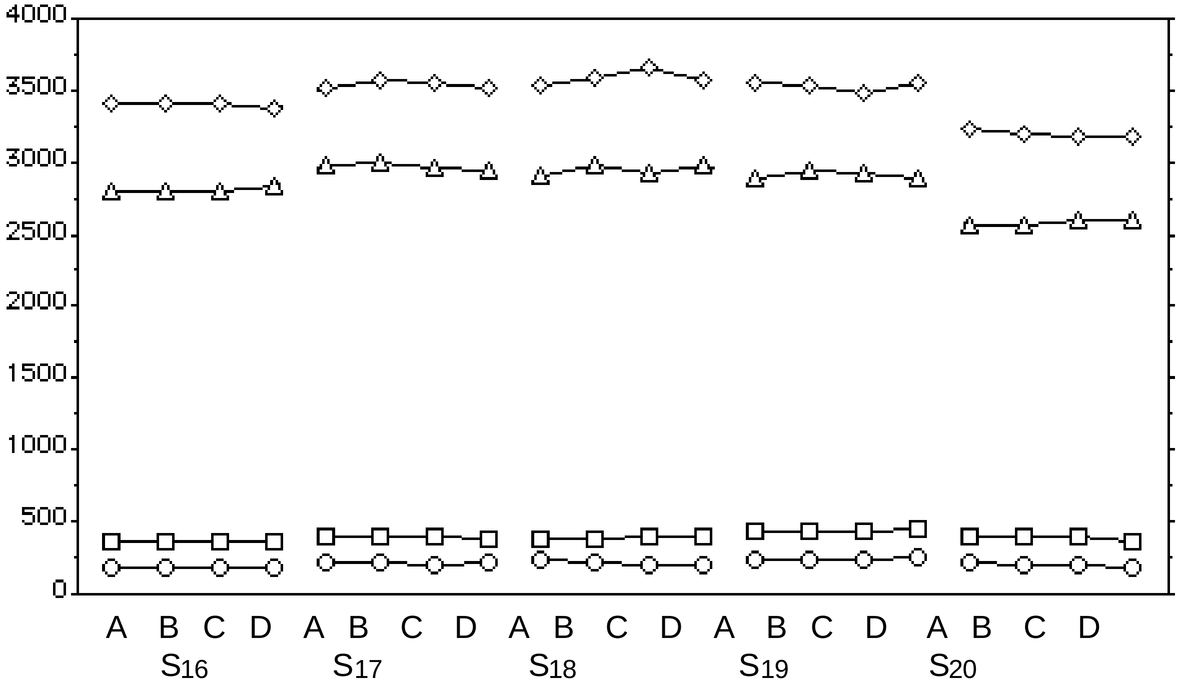
H-1-2. English Female [ᴇ] in head



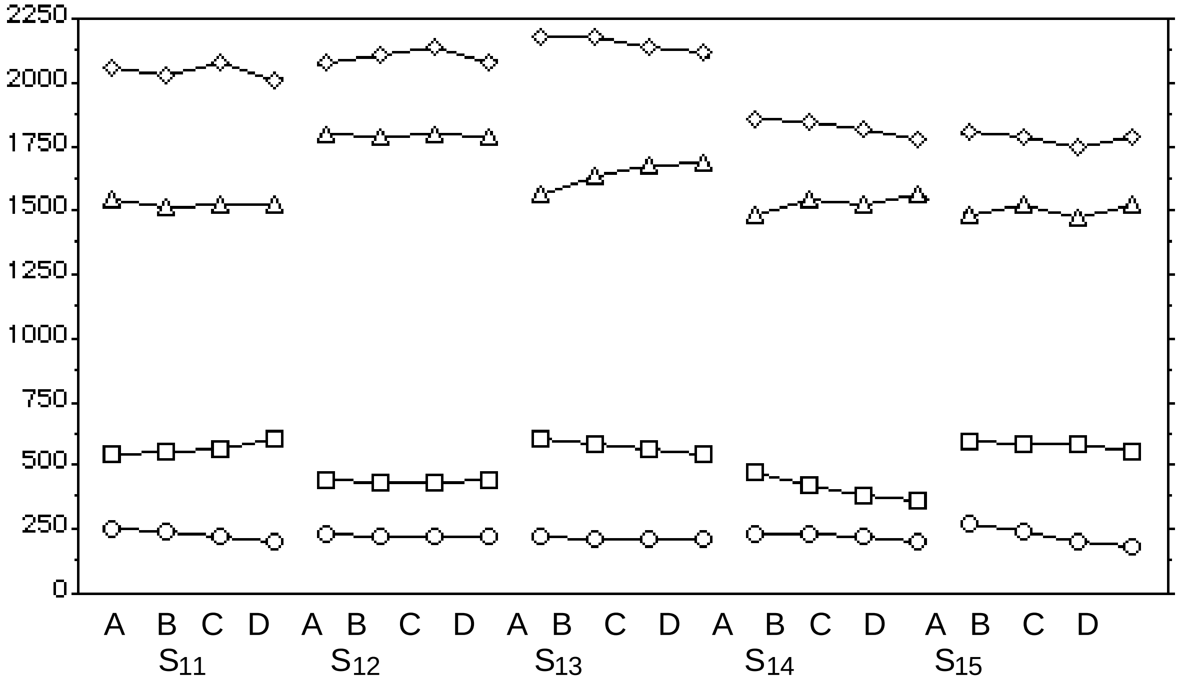


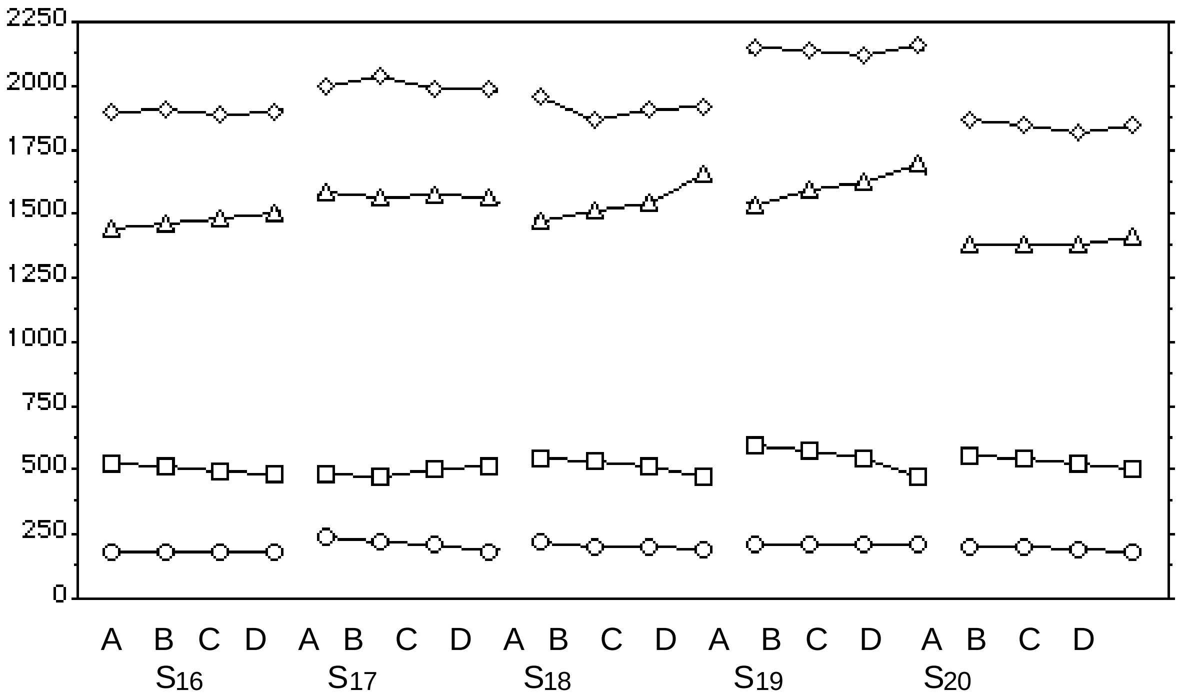
H-1-2. English Female [i] in heed



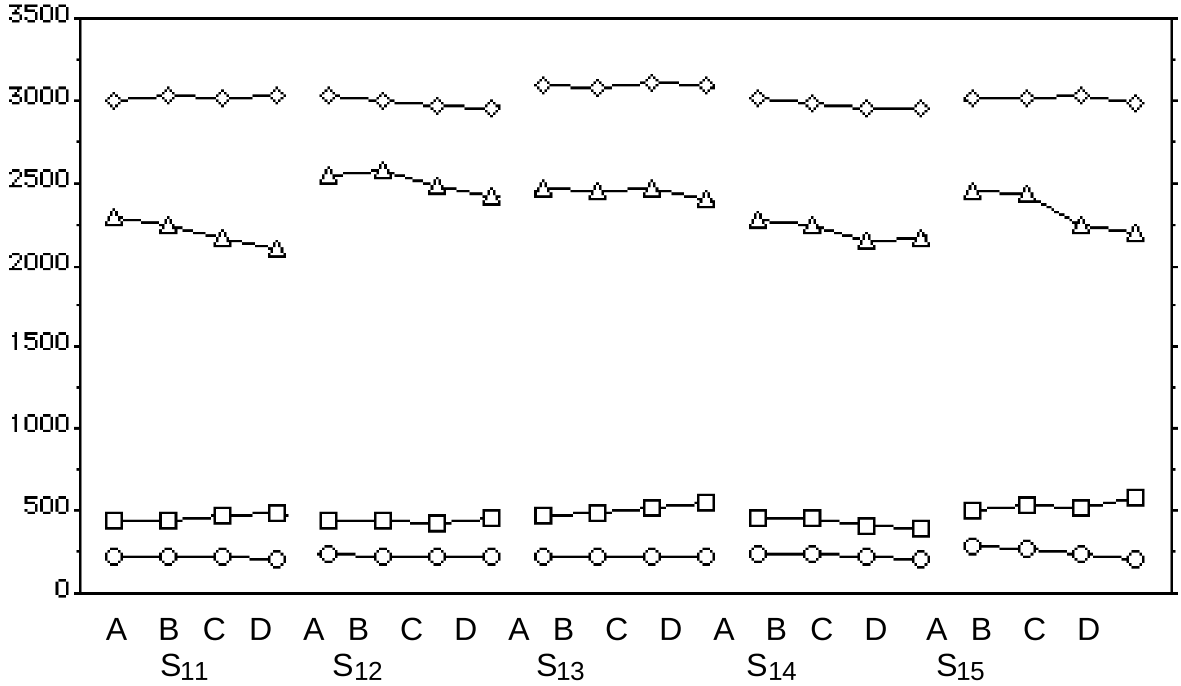


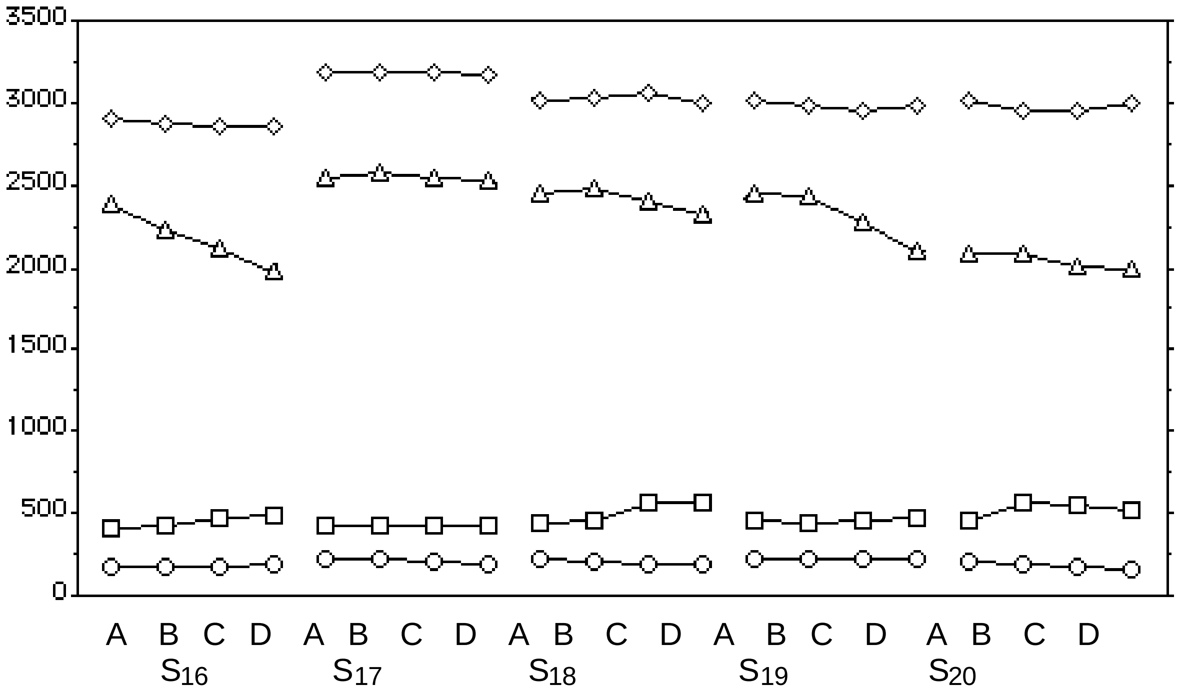
H-1-2. English Female [ɜ˞] in herd



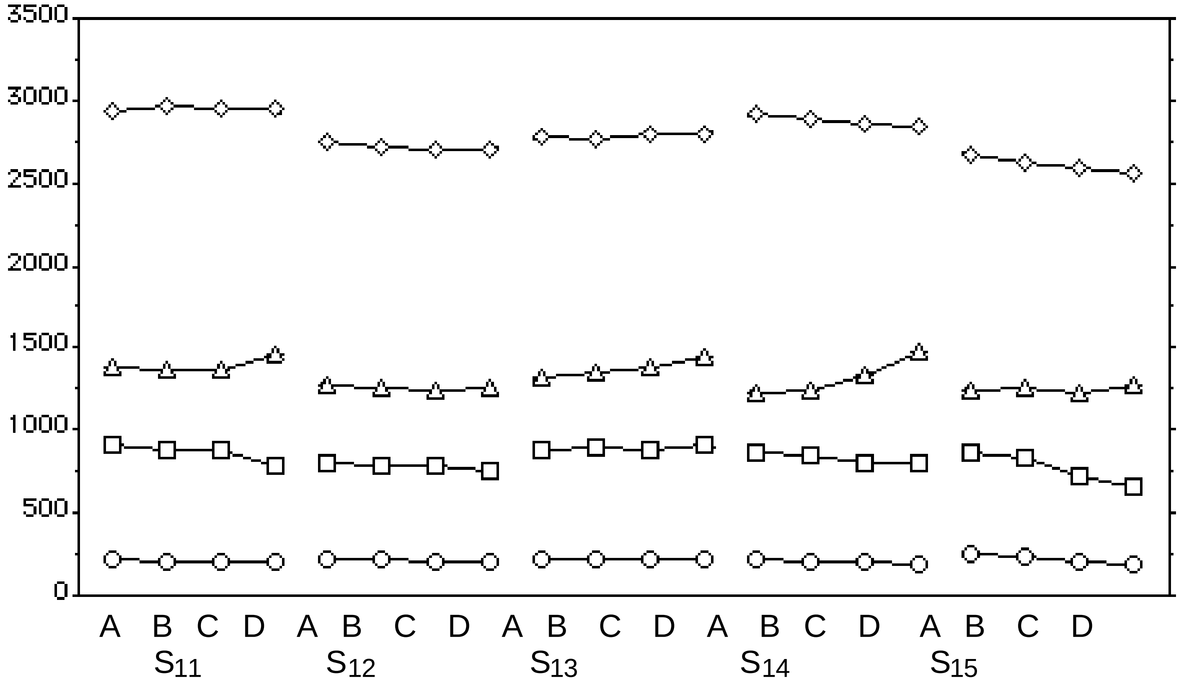


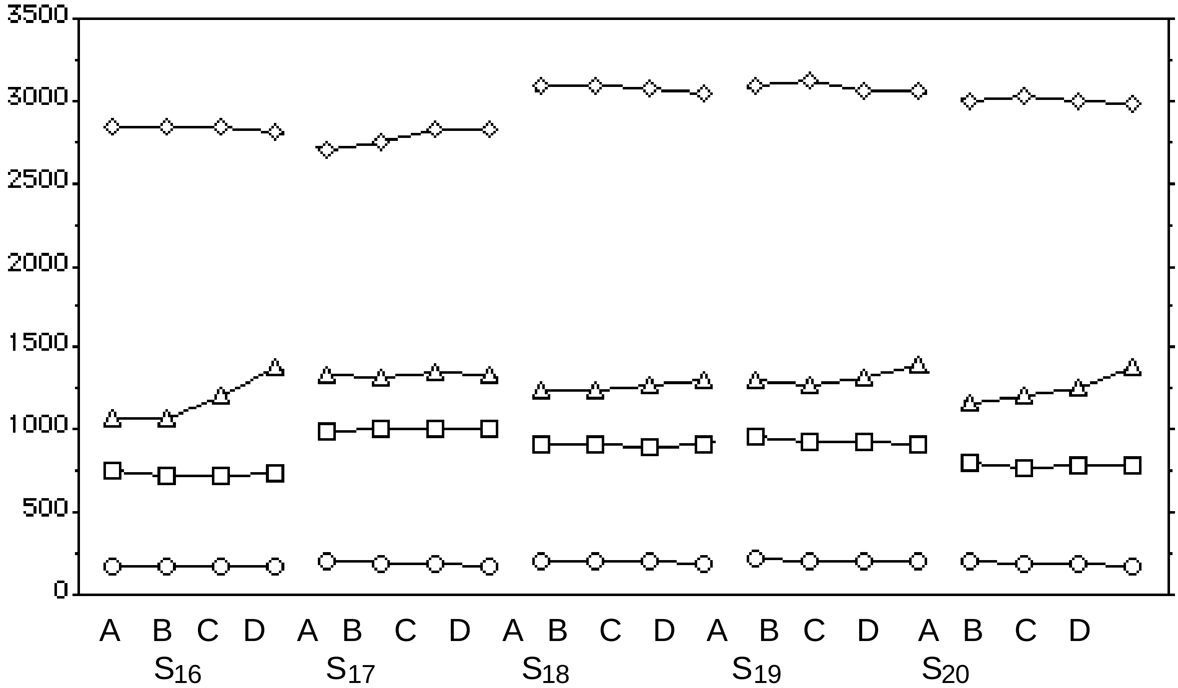
H-1-2. English Female [i] in hid



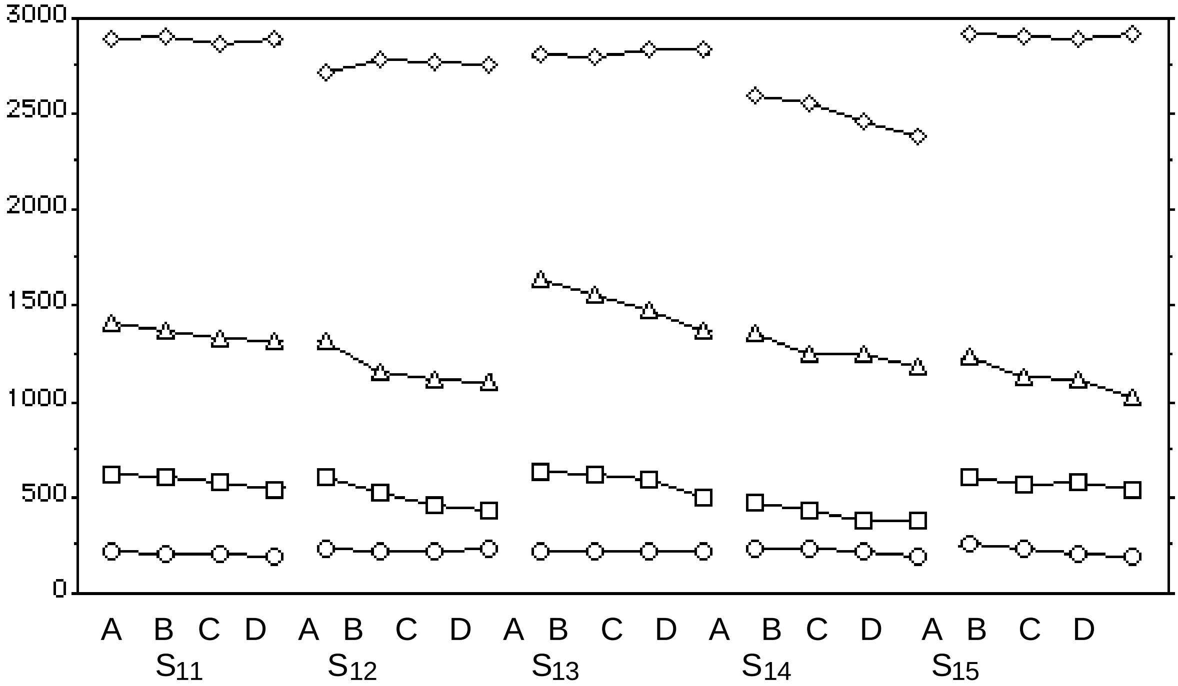


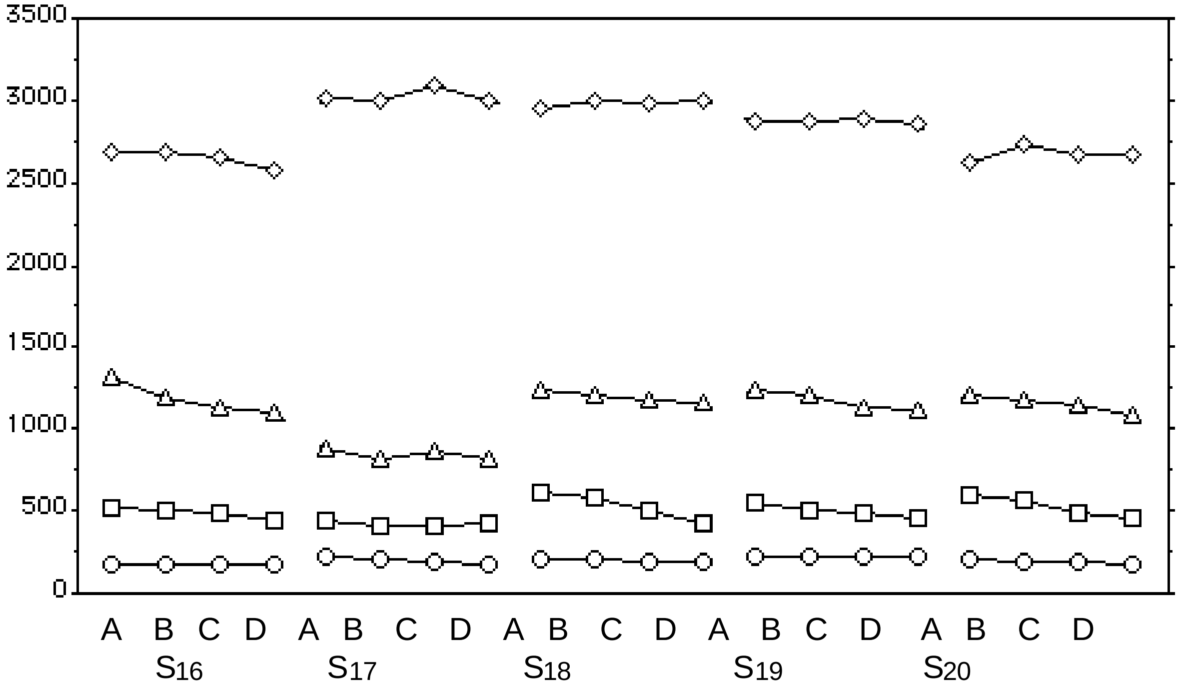
H-1-2. English Female [a] in hod



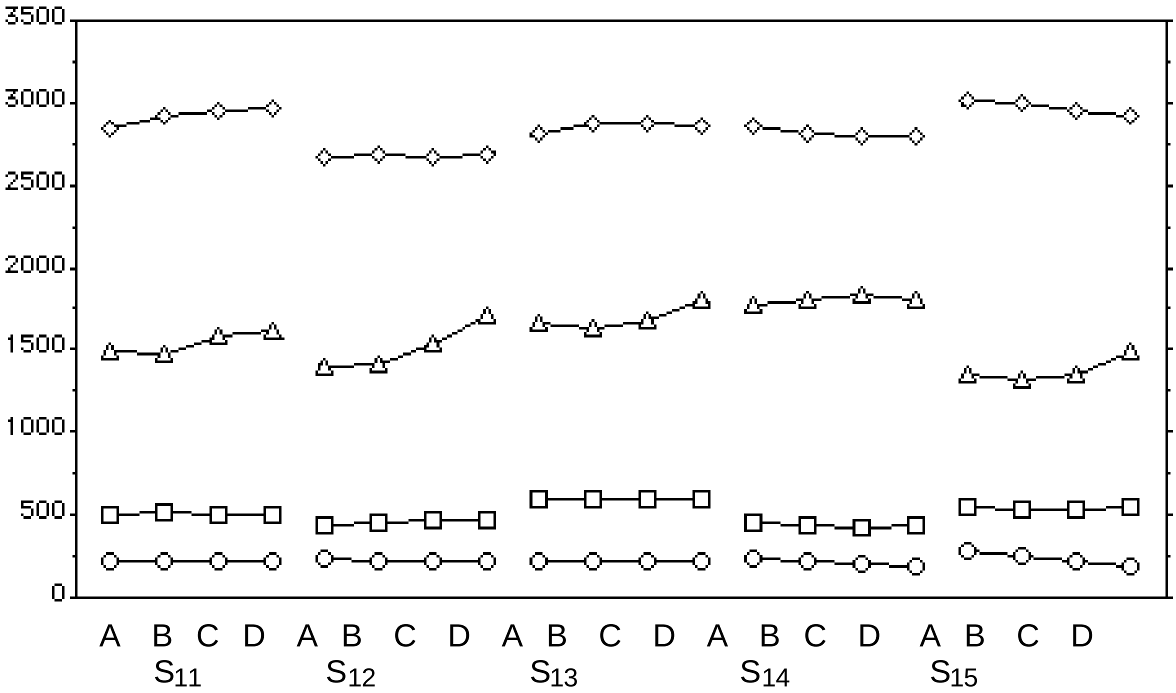


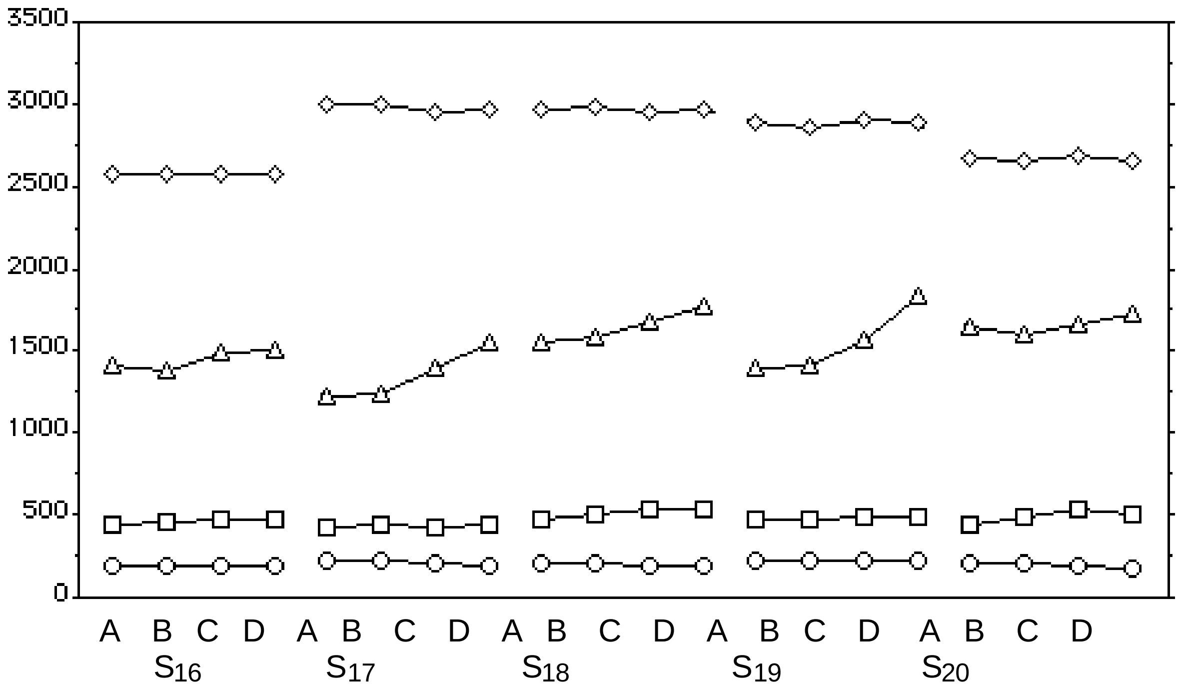
H-1-2. English Female [ou] in hoed



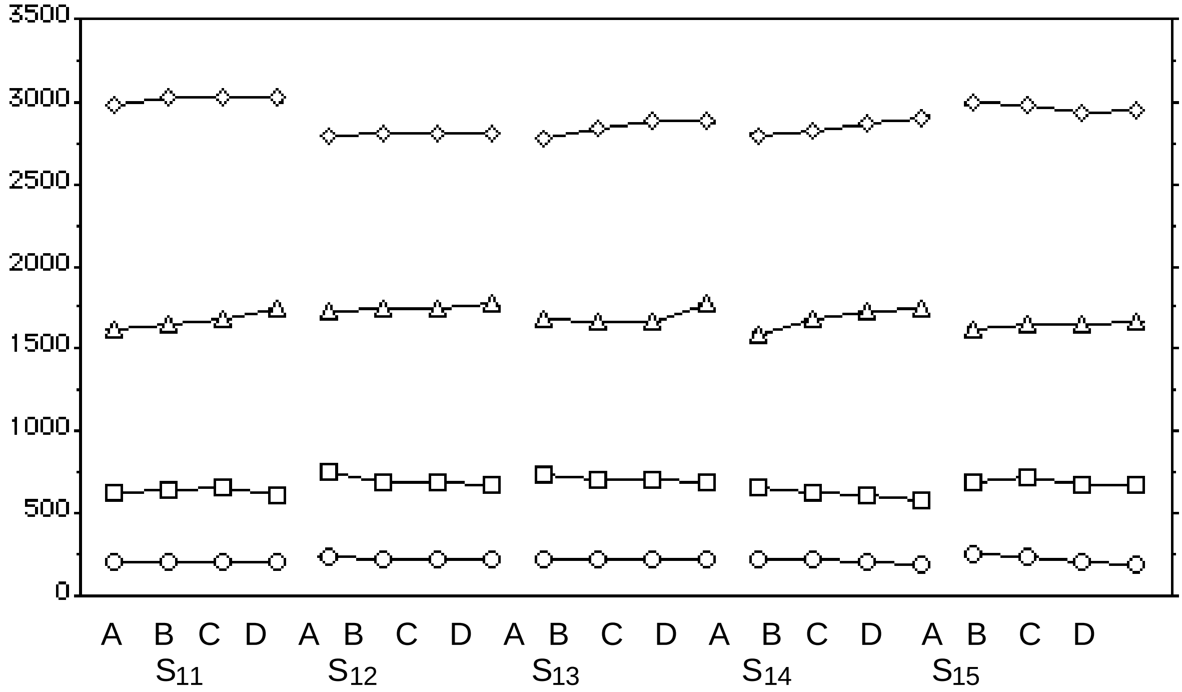


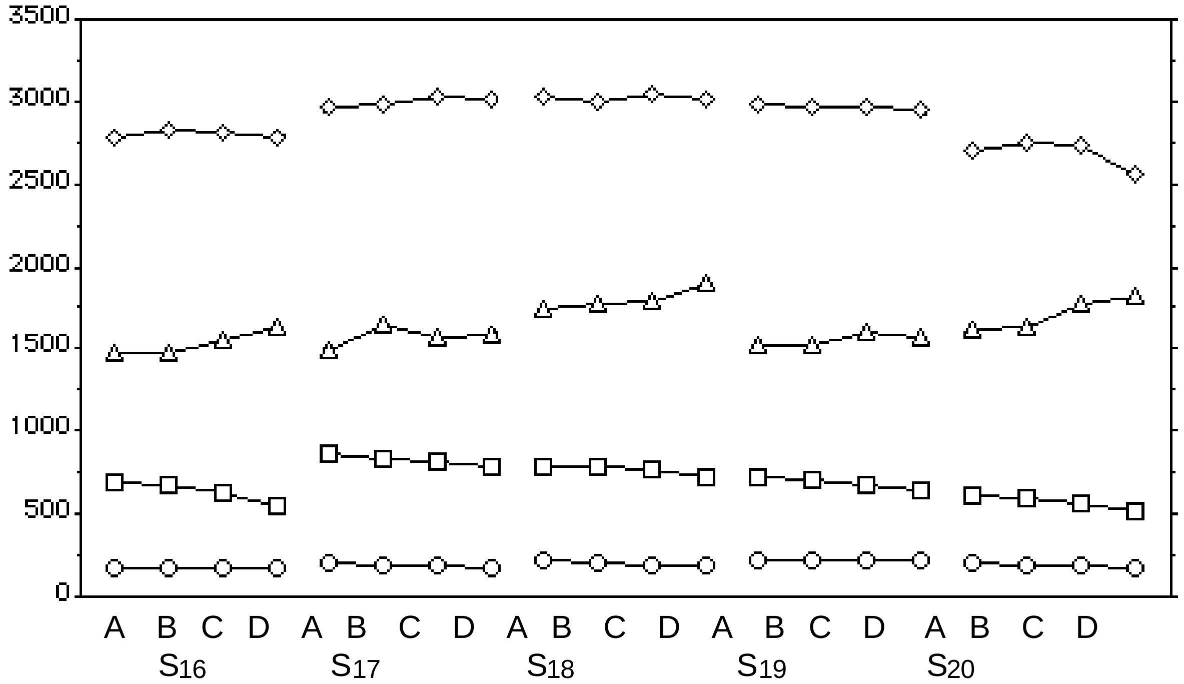
H-1-2. English Female [U] in hood



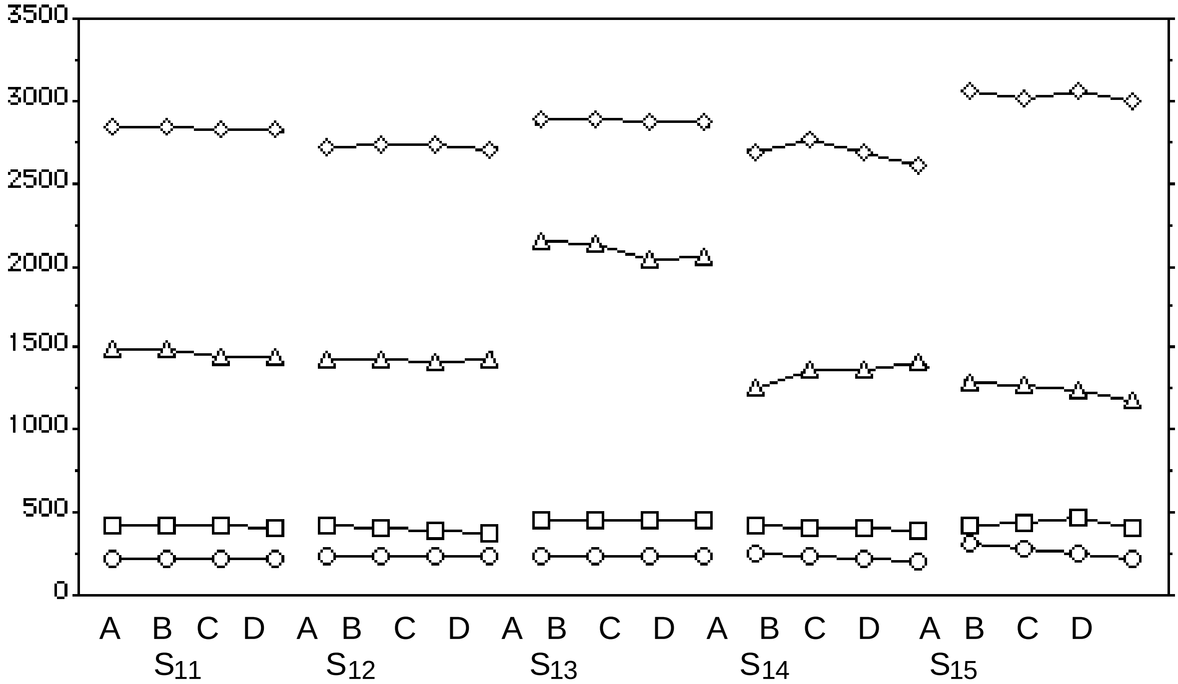


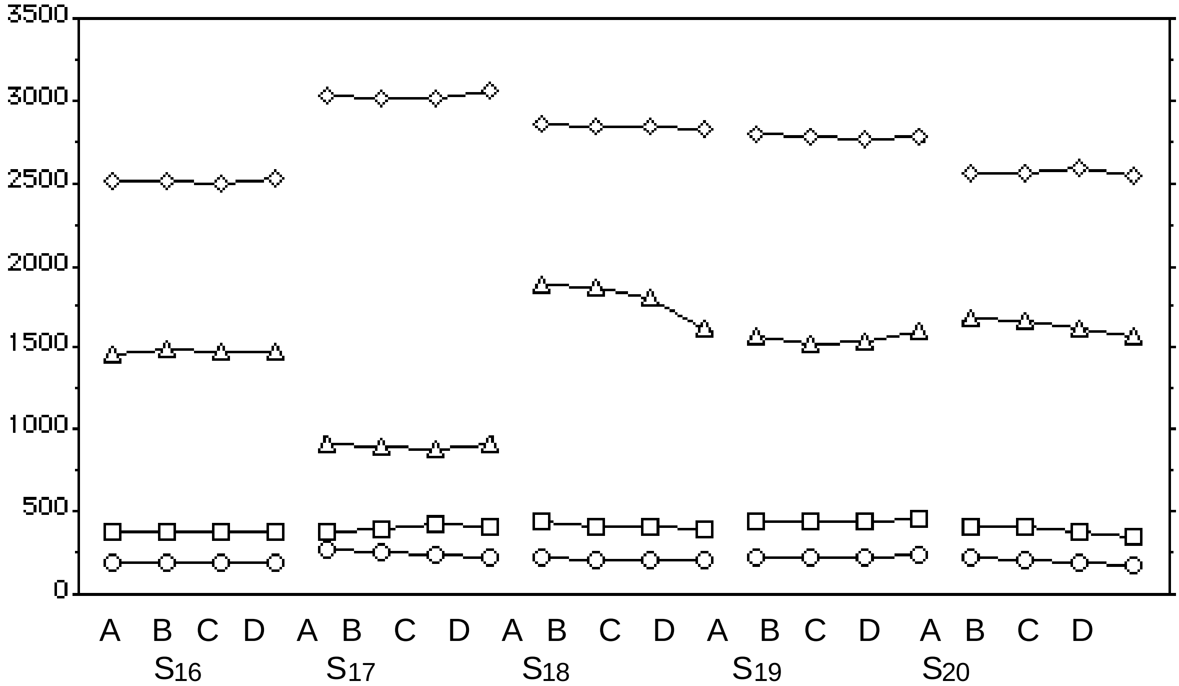
H-1-2. English Female [ʌ] in Hudd



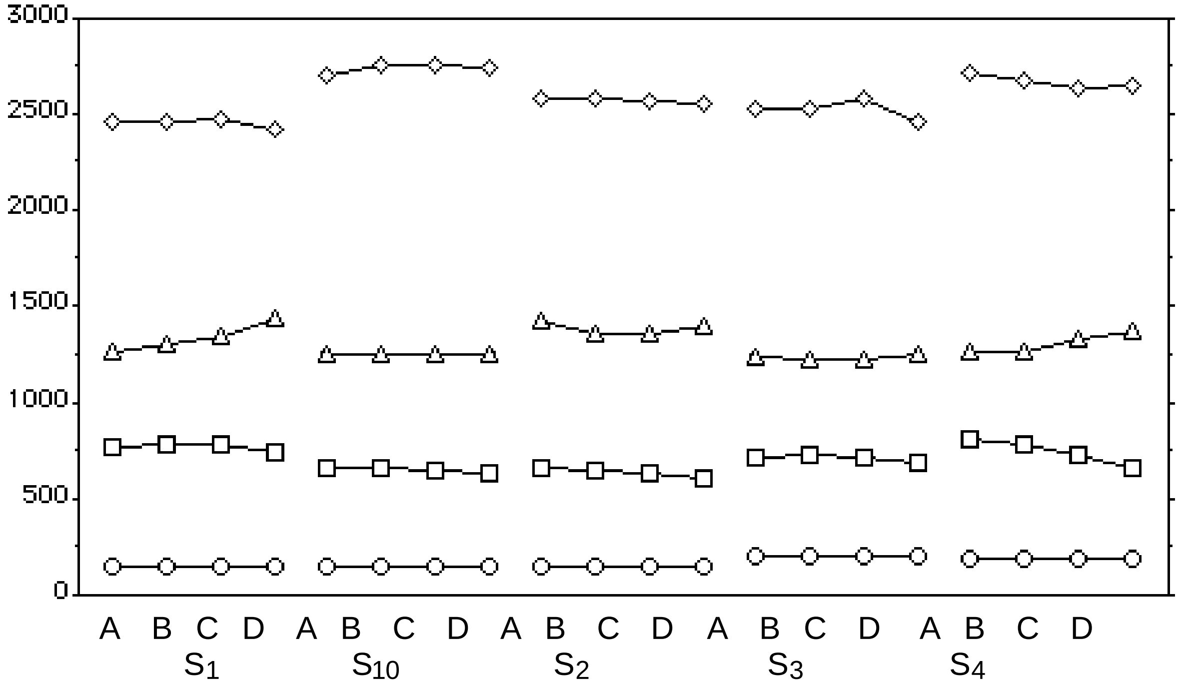


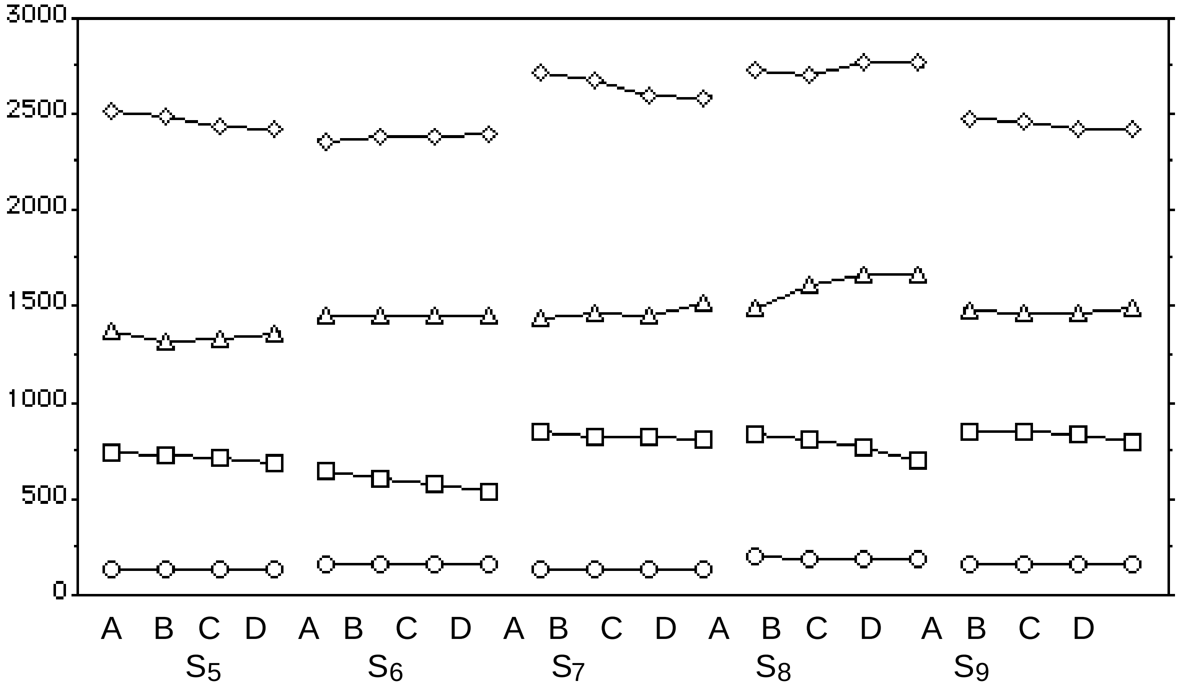
H-1-2. English Female [u] in who'd



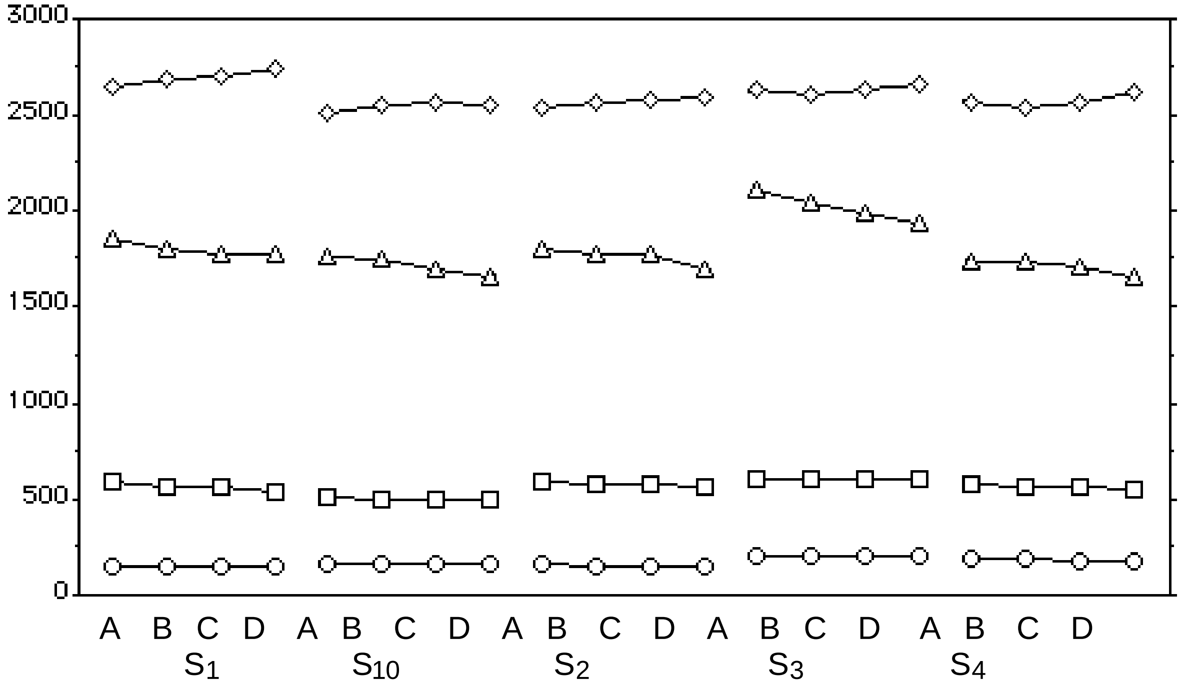


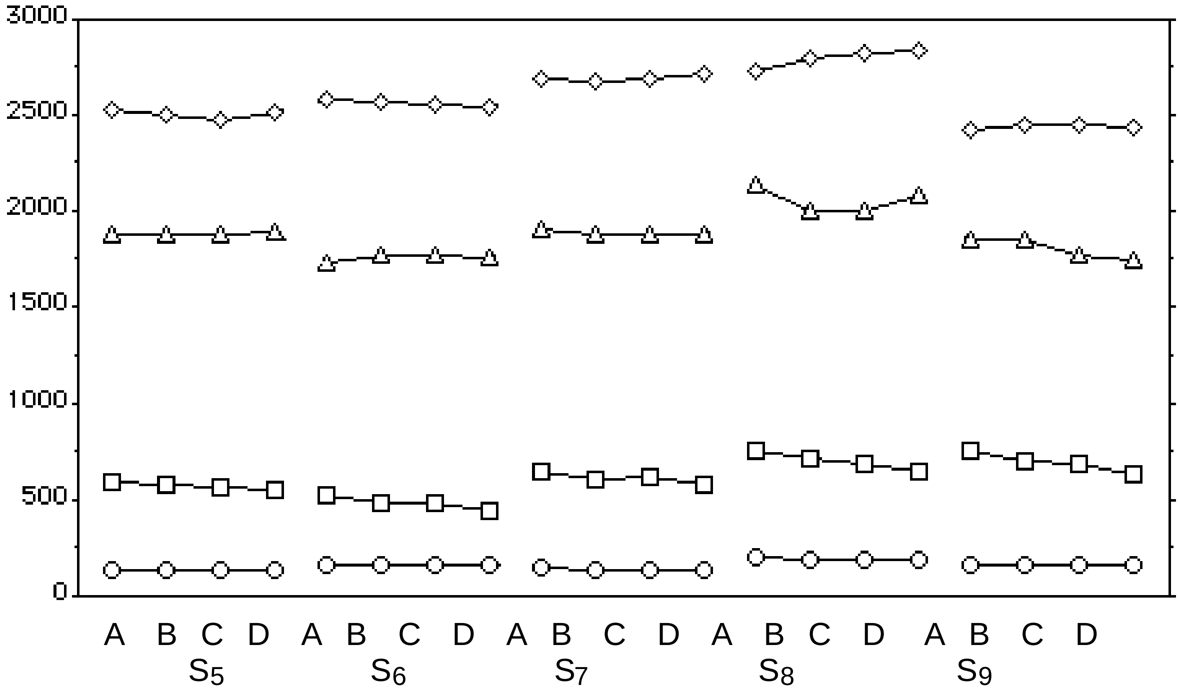
H-2-1. Korean Male [a] in hada



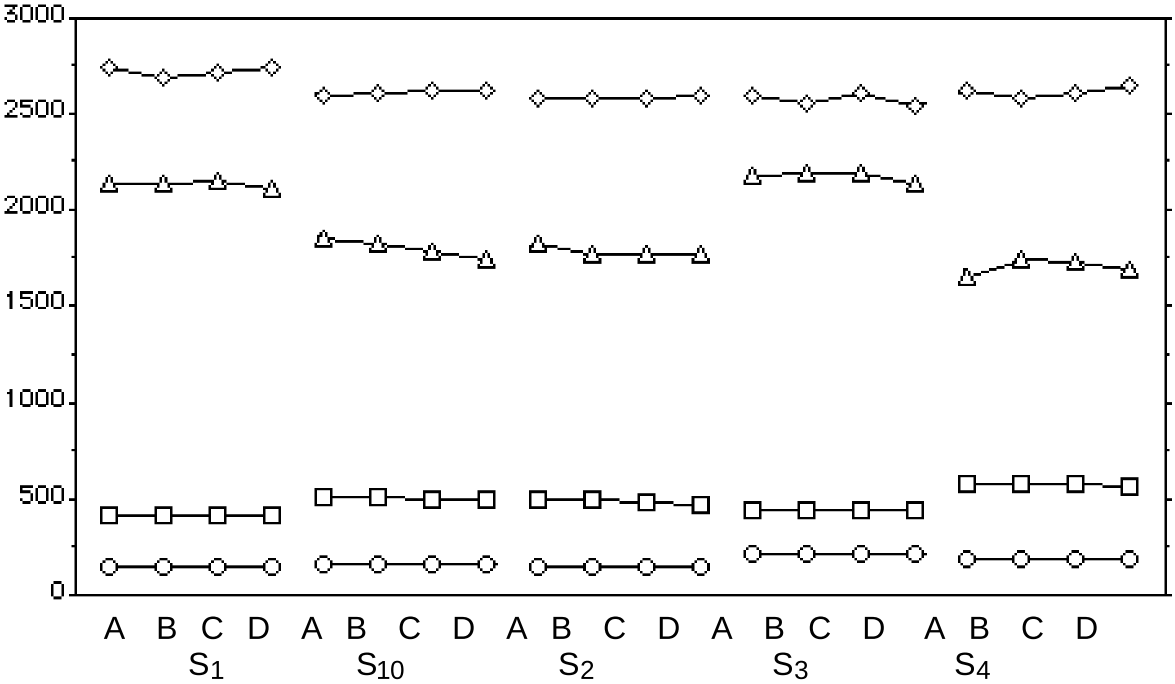


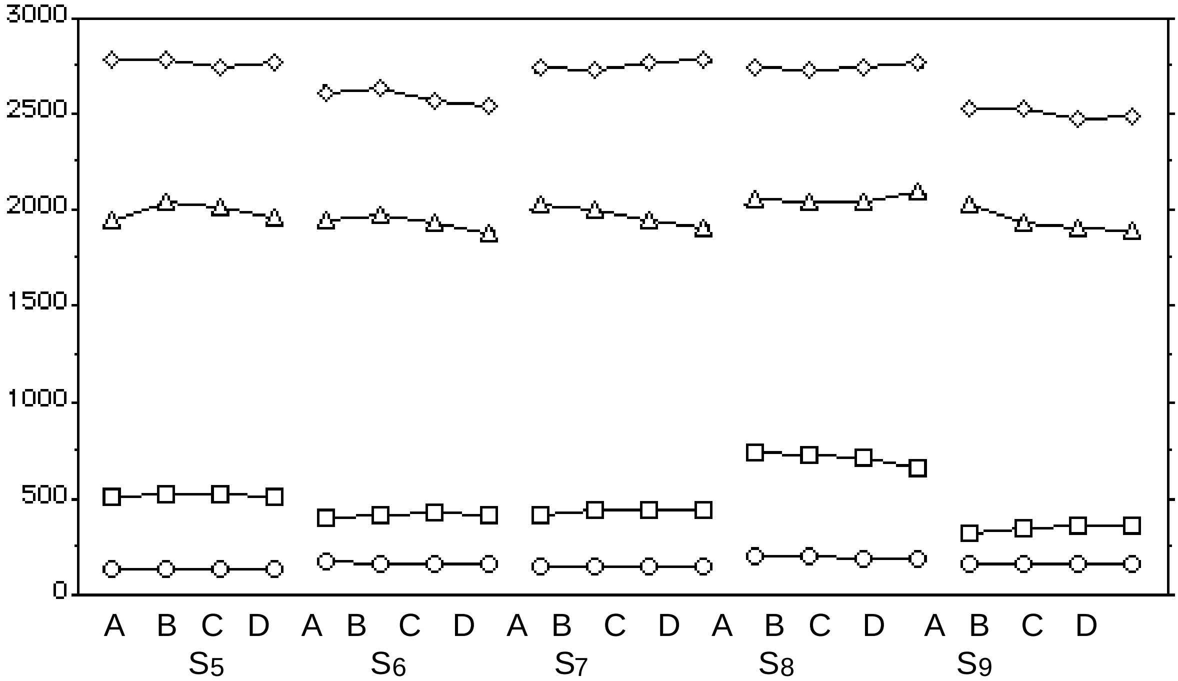
H-2-1. Korean Male [E] in hEda



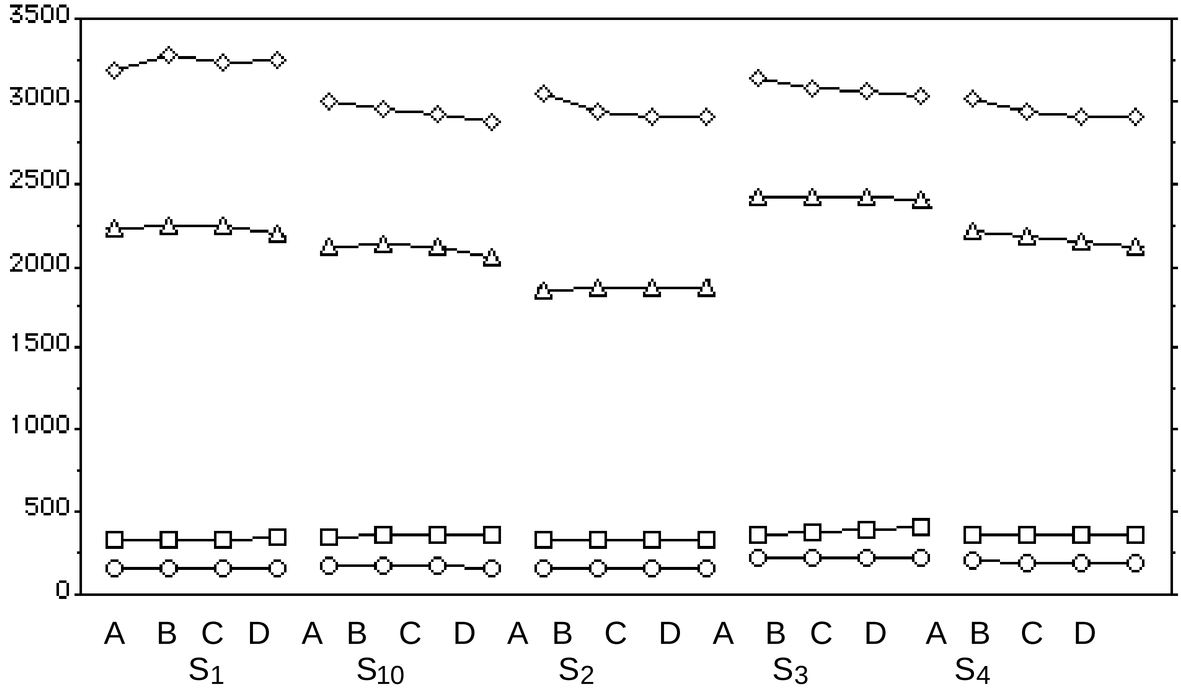


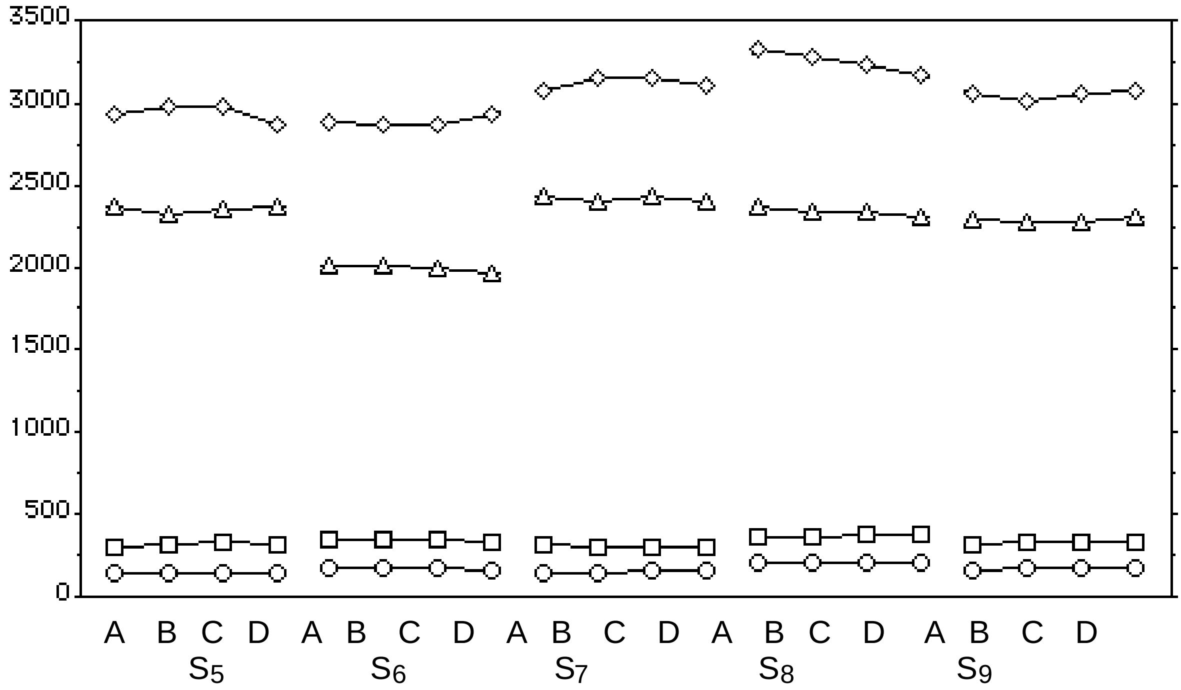
H-2-1. Korean Male [e] in heda



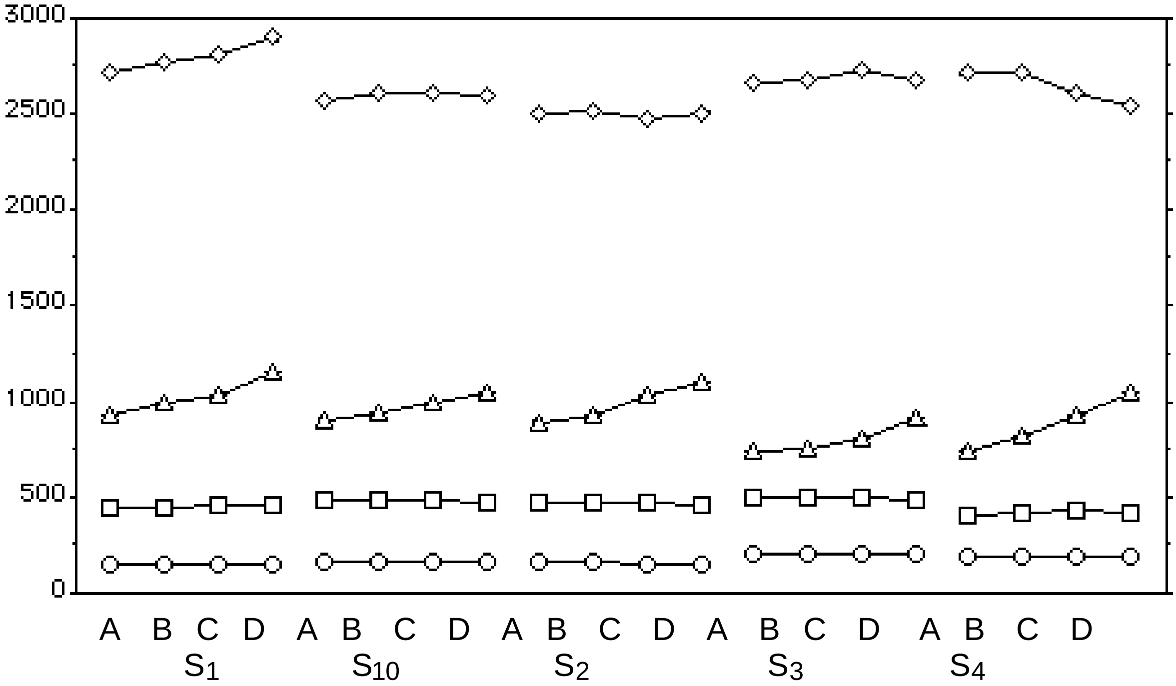


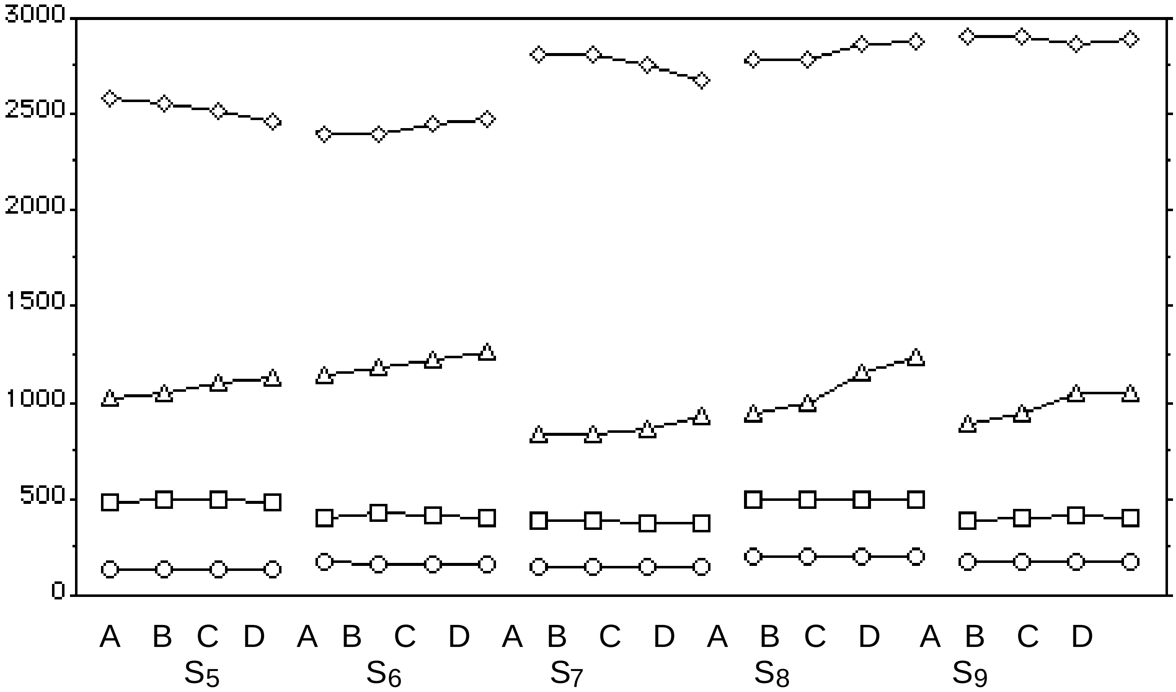
H-2-1. Korean Male [i] in hida



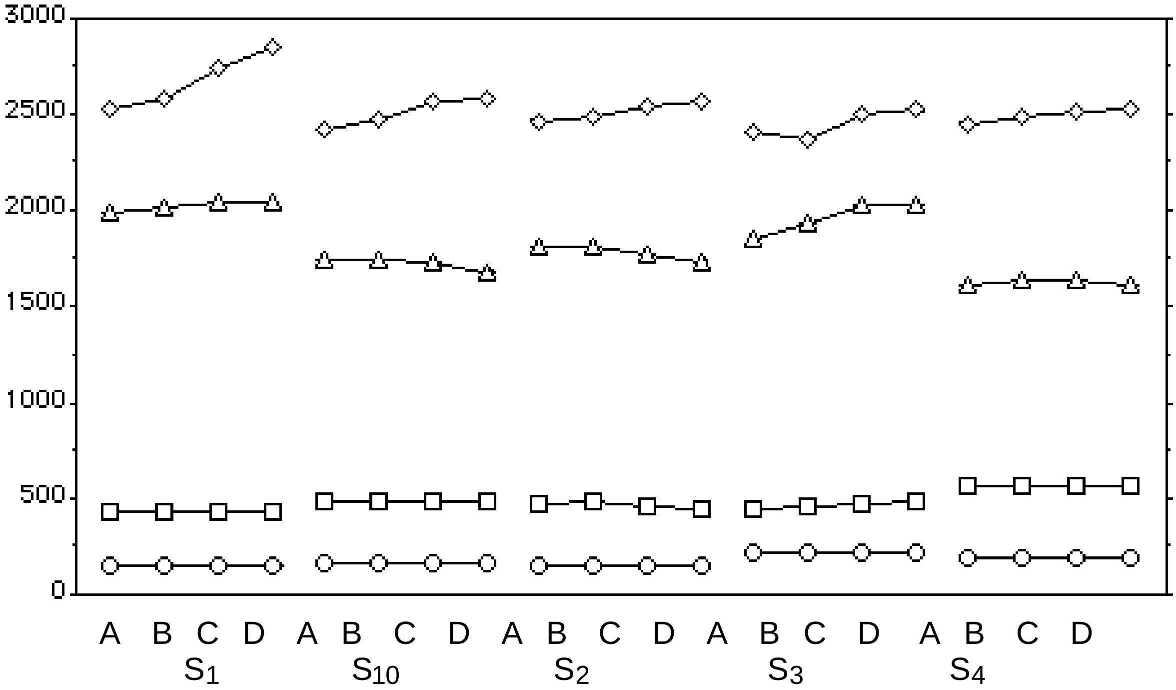


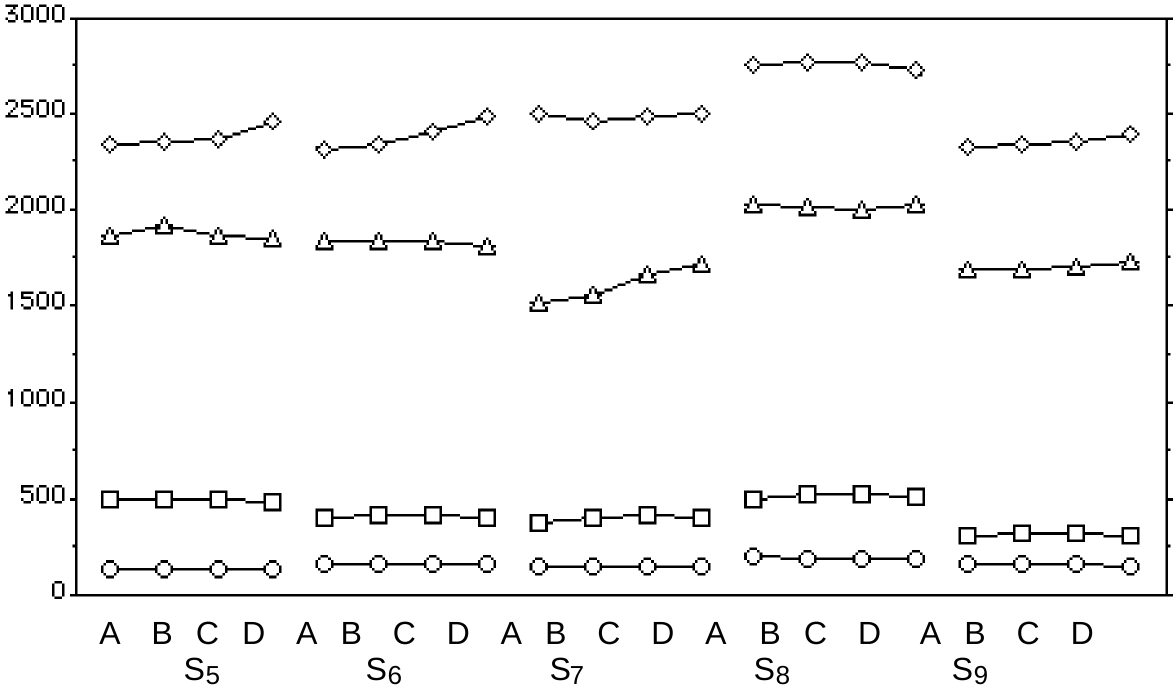
H-2-1. Korean Male [o] in hoda



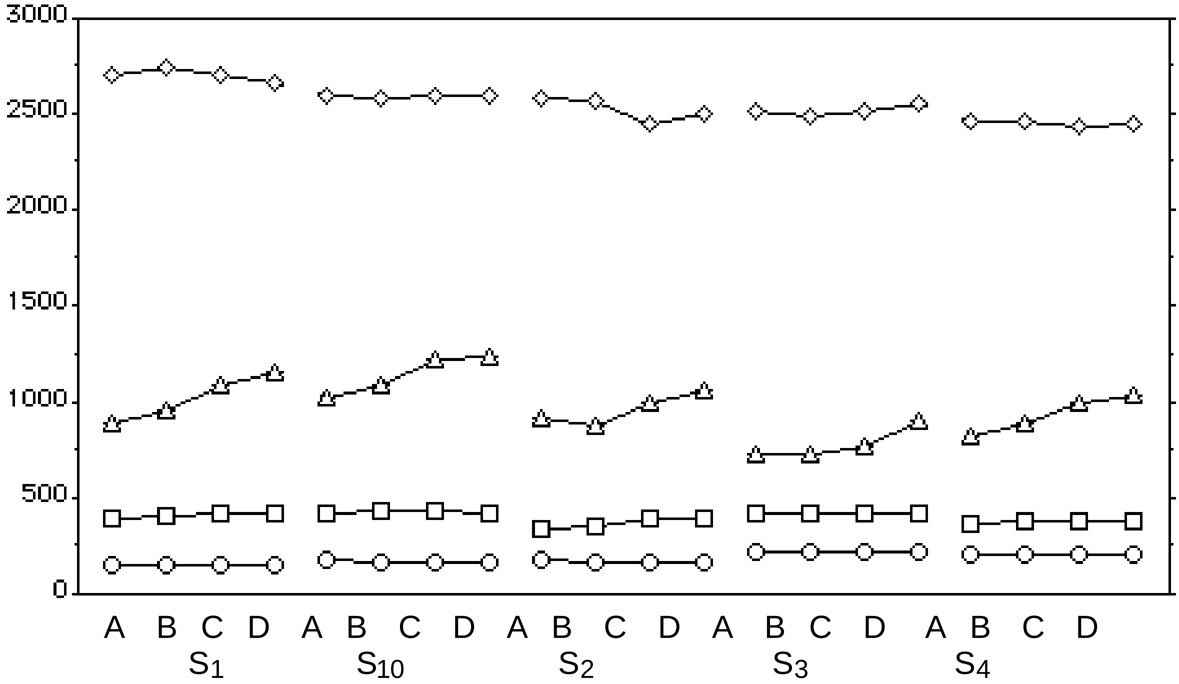


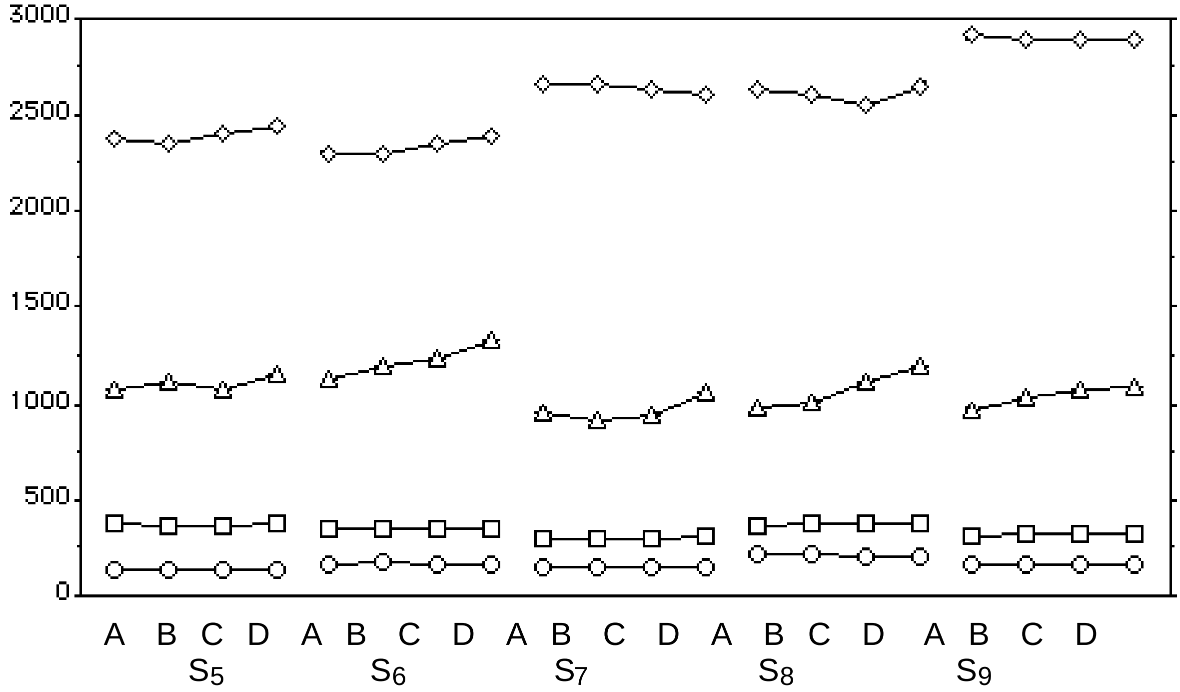
H-2-1. Korean Male [we] in hweda



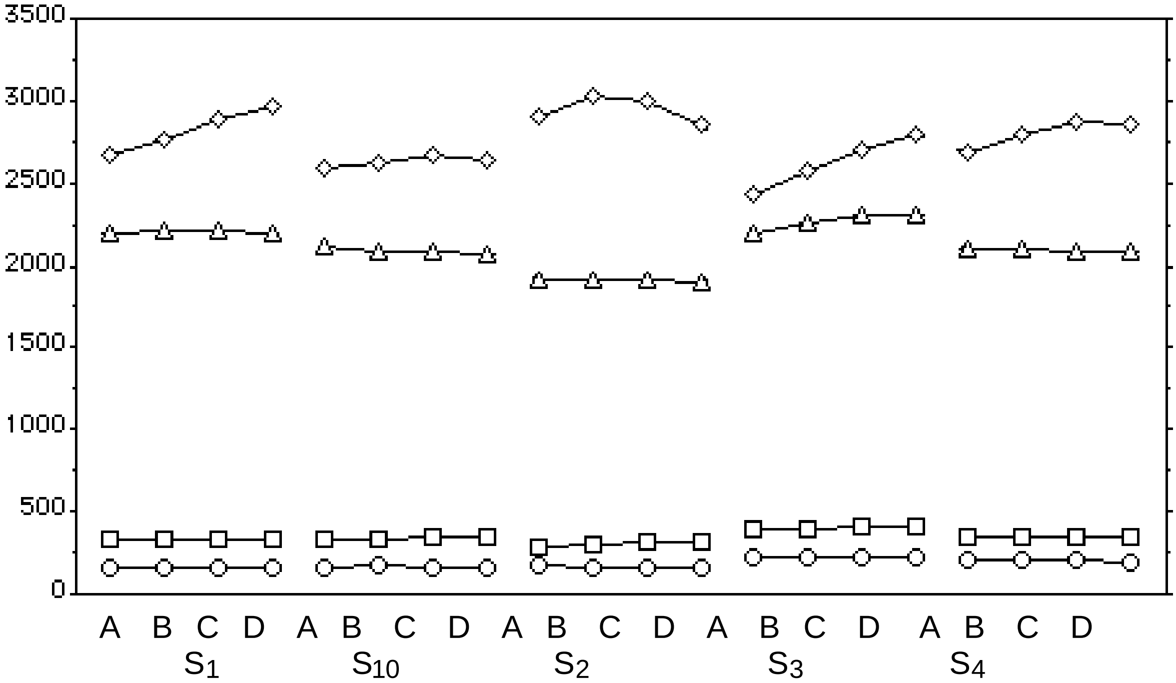


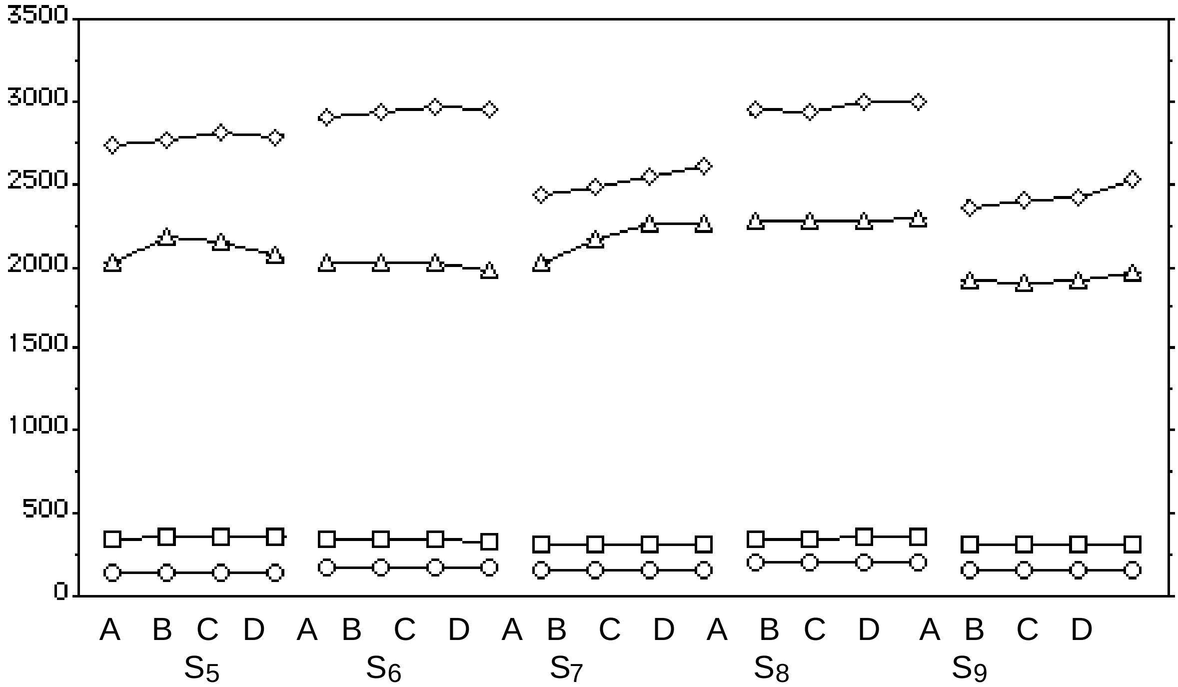
H-2-1. Korean Male [u] in huda



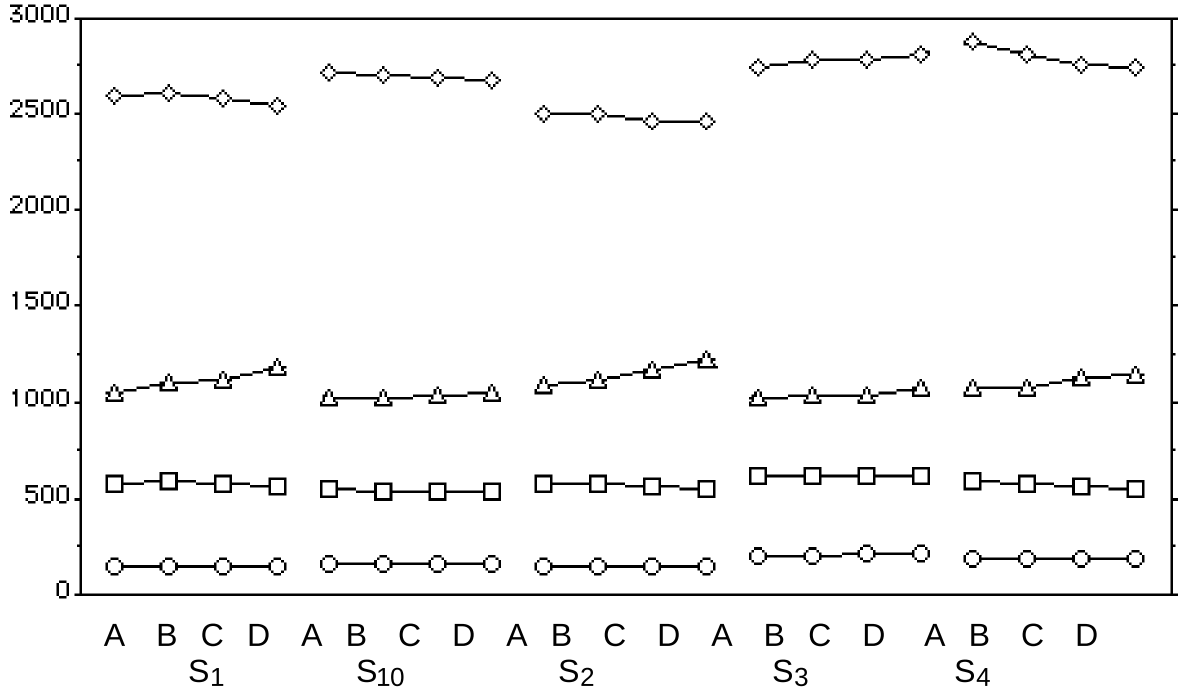


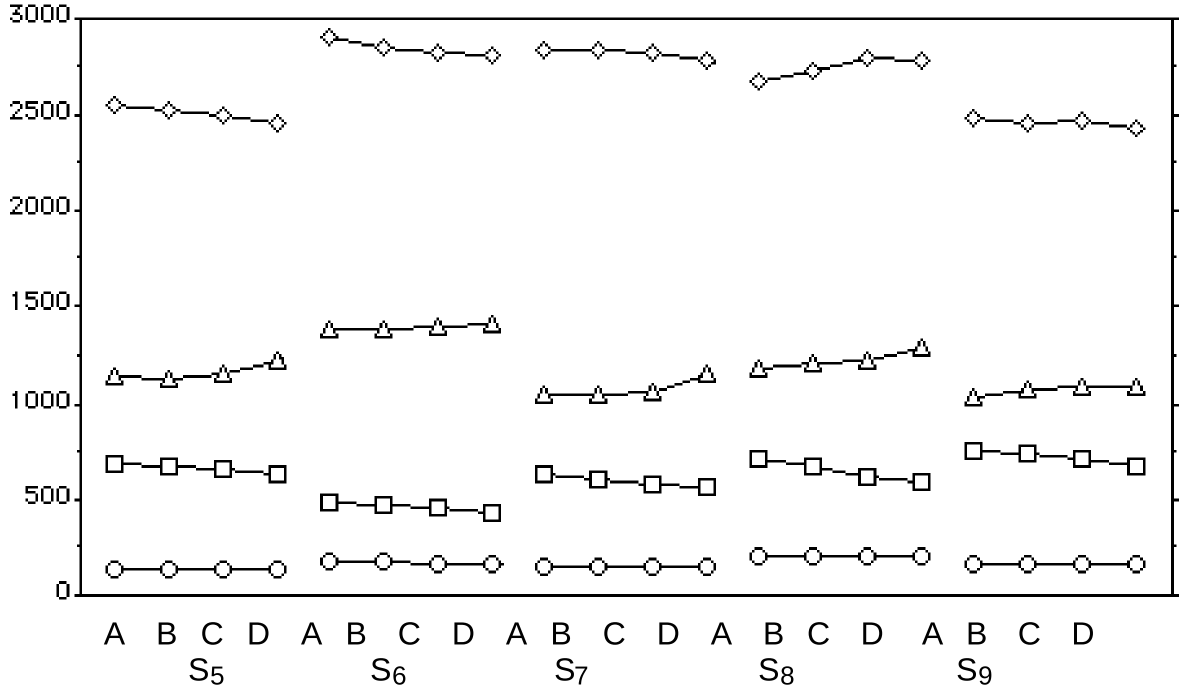
H-2-1. Korean Male [wi] in hwida



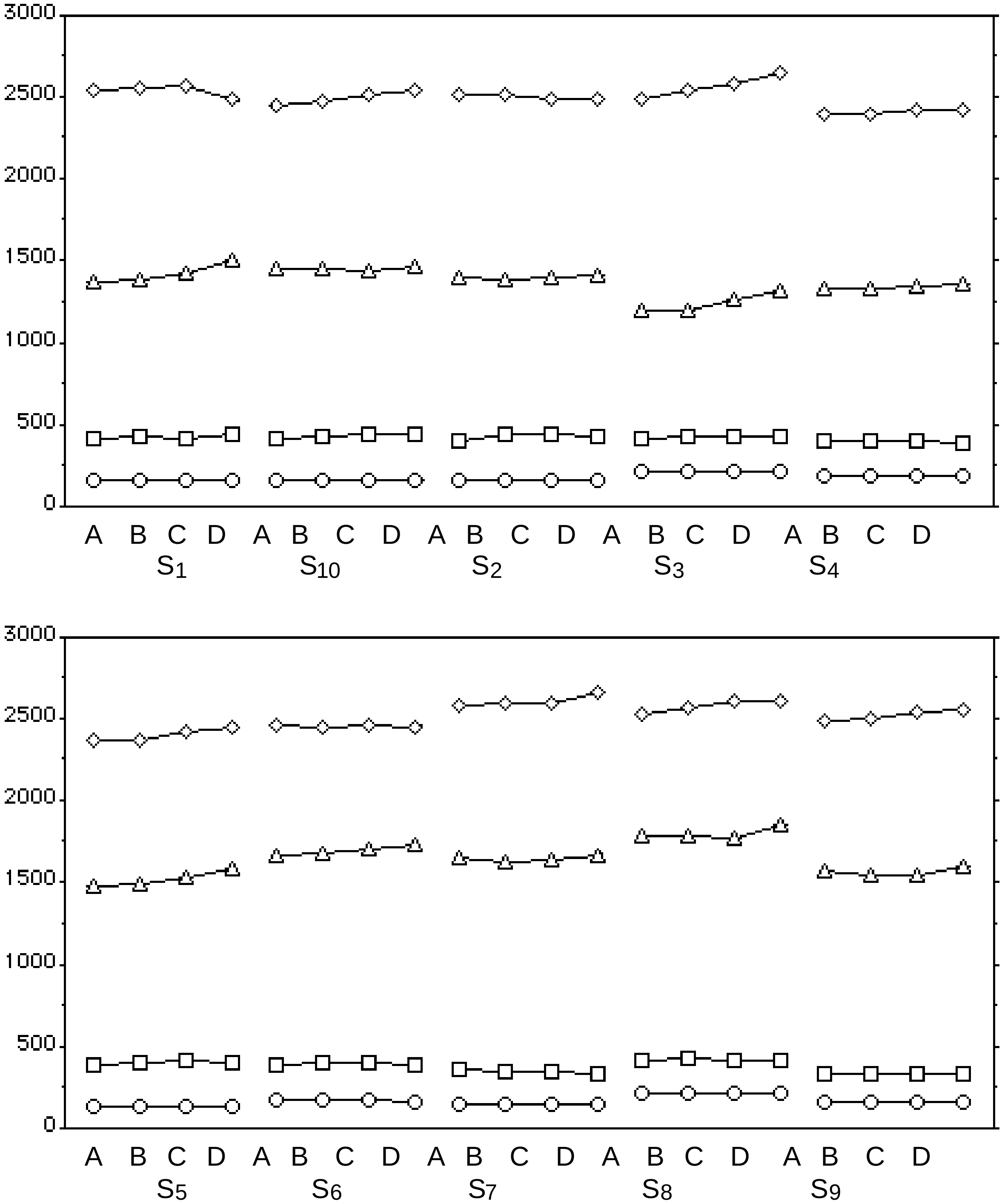


H-2-1. Korean Male [ʌ] in hʌda

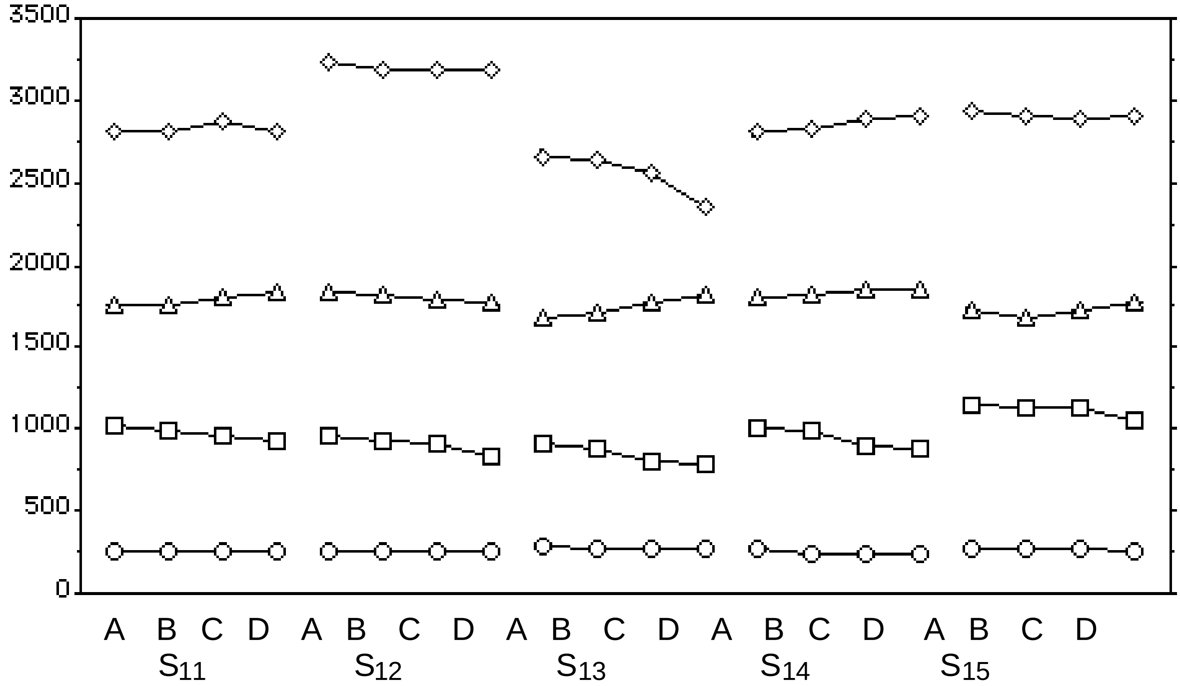


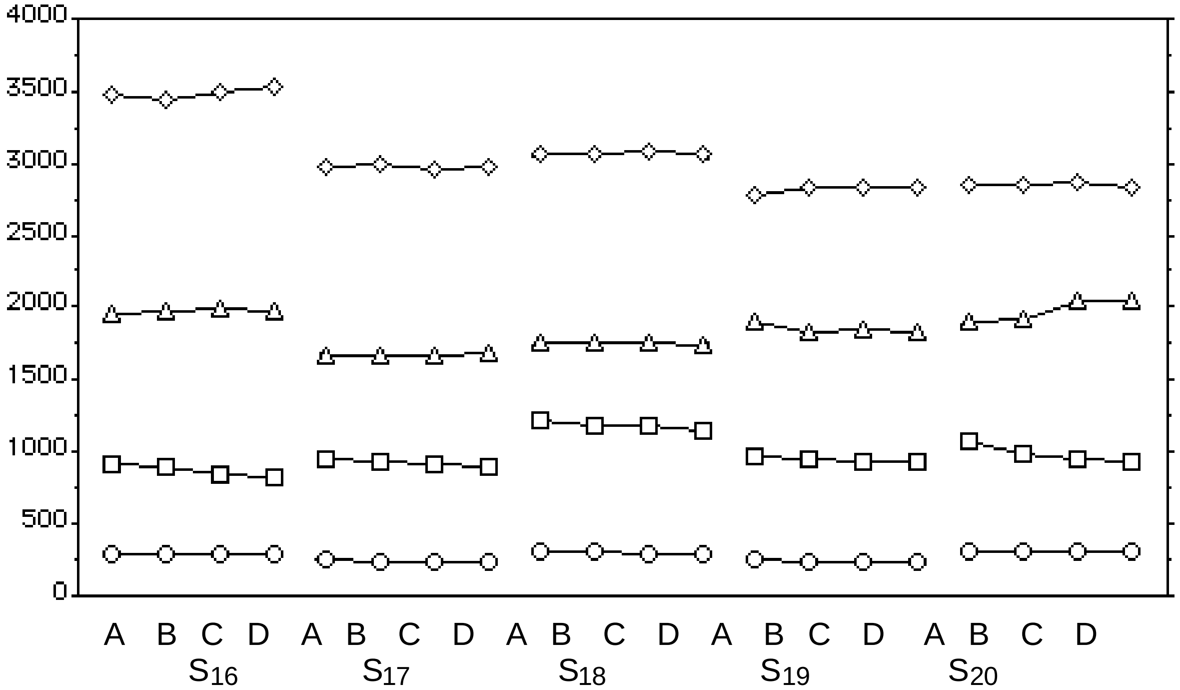


H-2-1. Korean Male [uu] in huuda

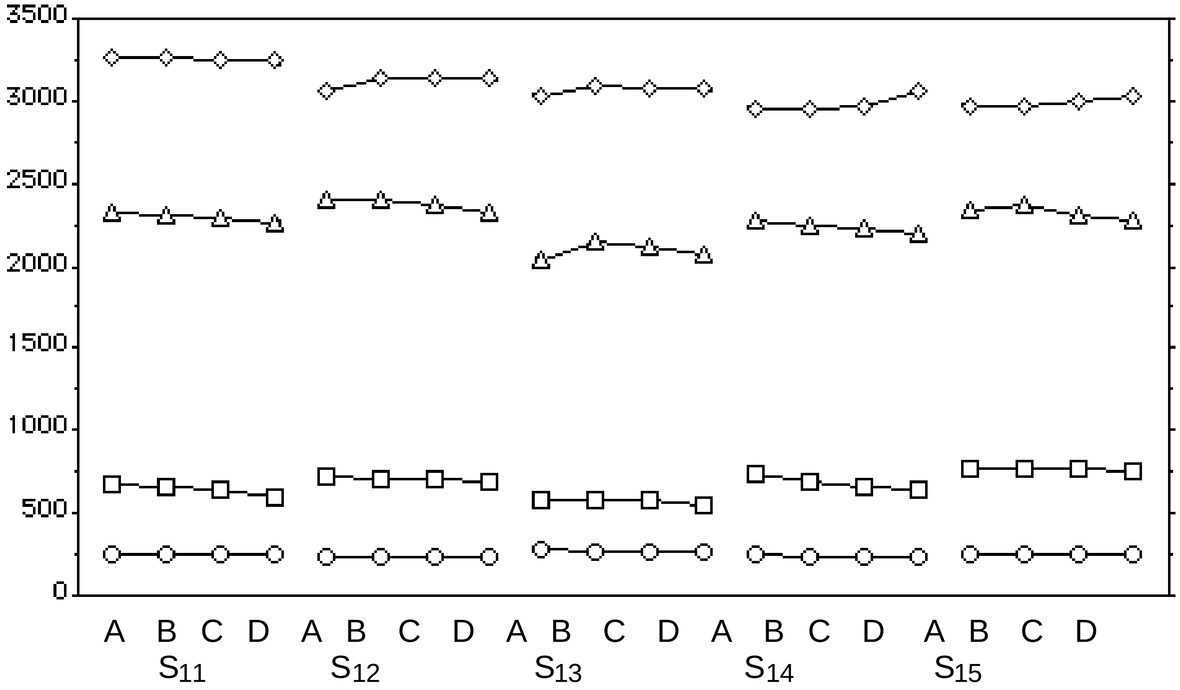


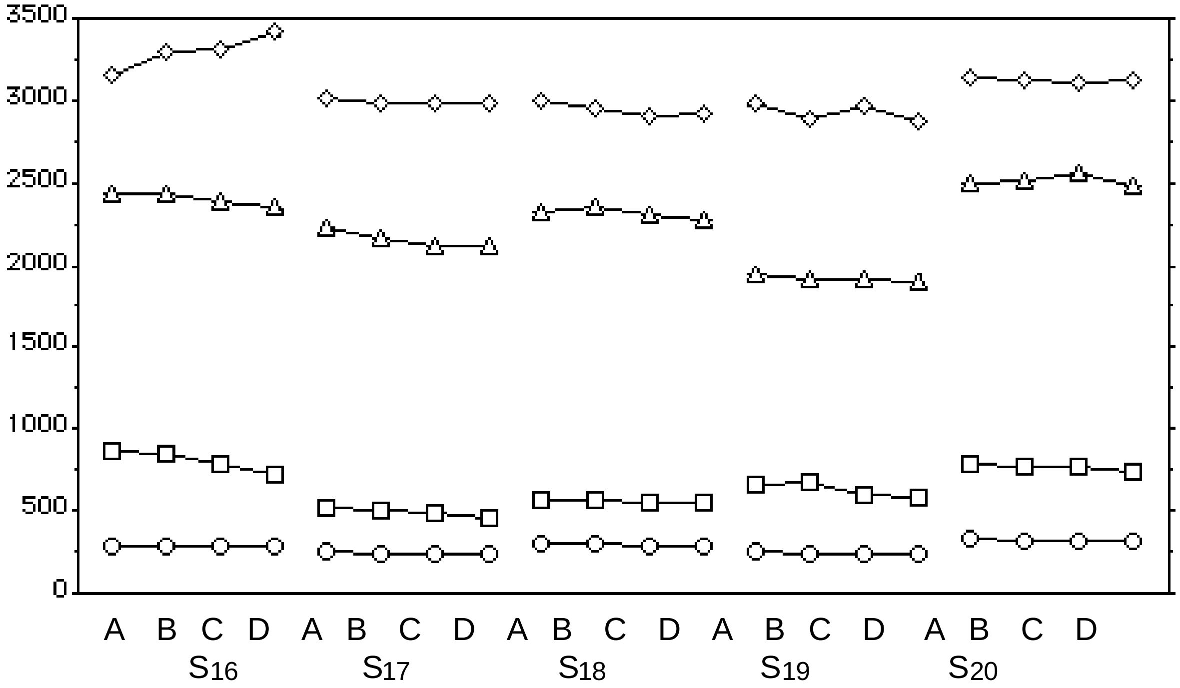
H-2-2. Korean Female [a] in hada



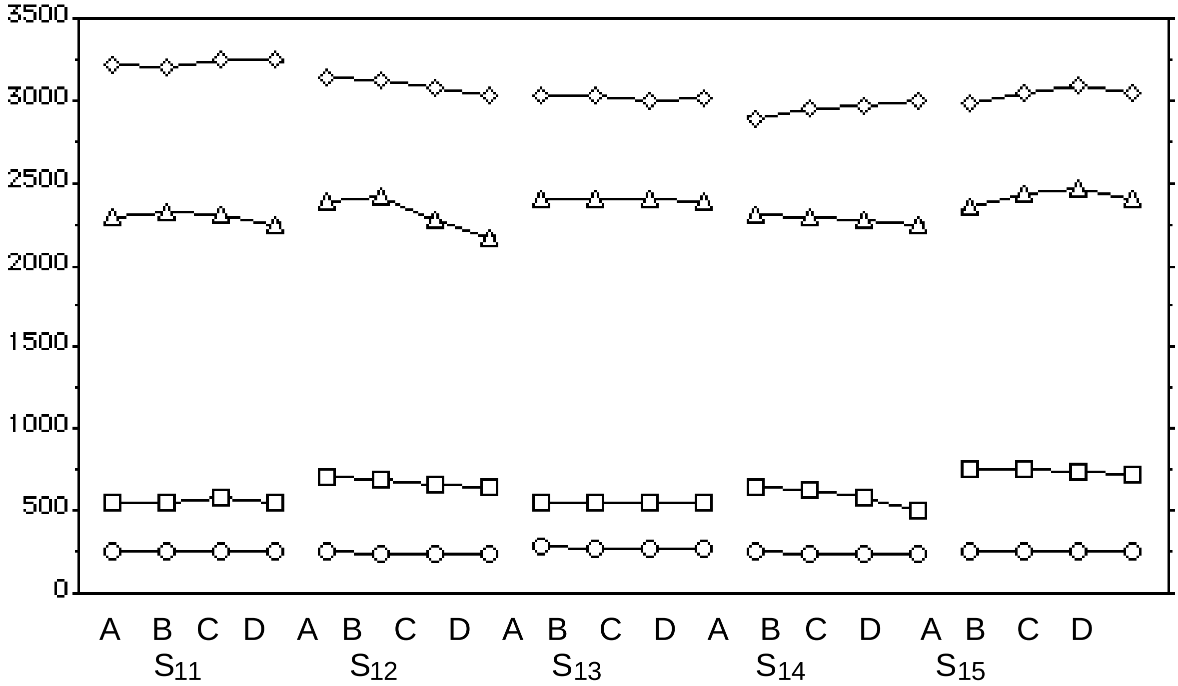


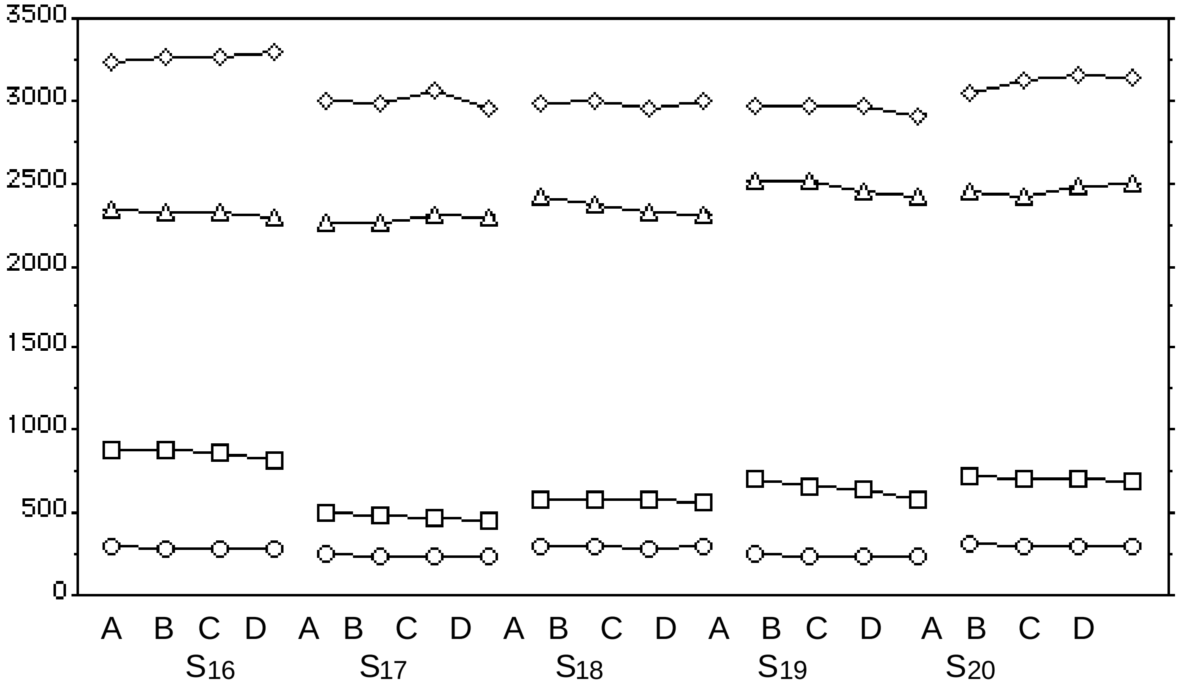
H-2-2. Korean Female [E] in hEda



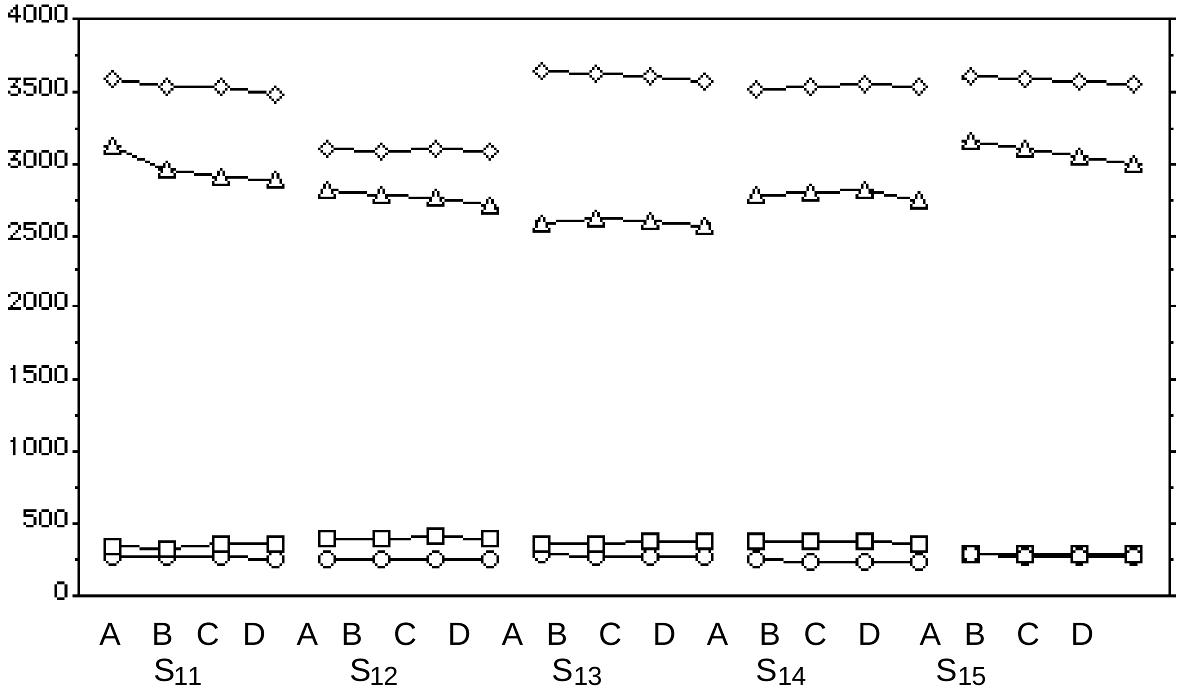


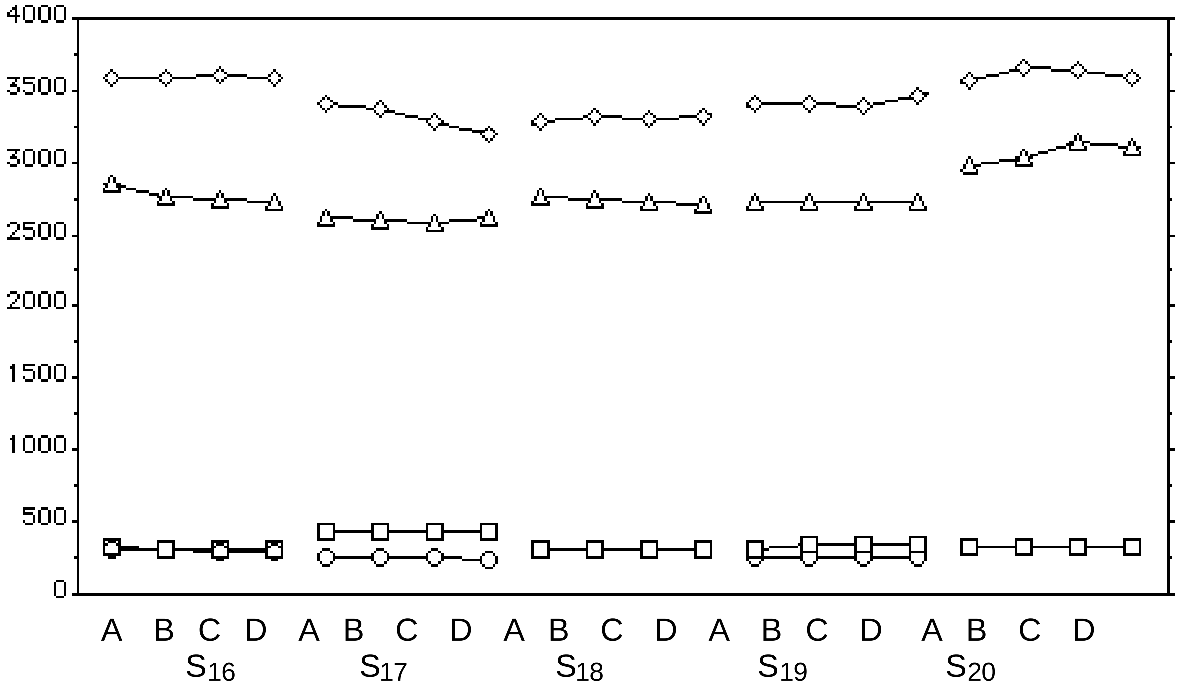
H-2-2. Korean Female [e] in heda



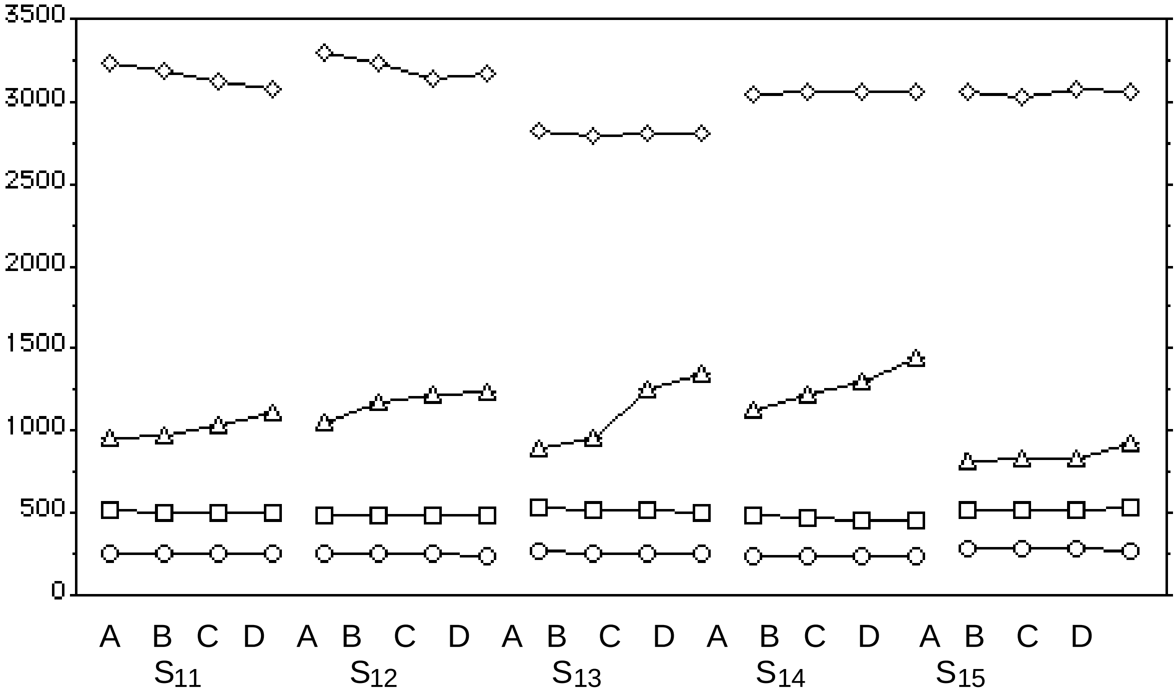


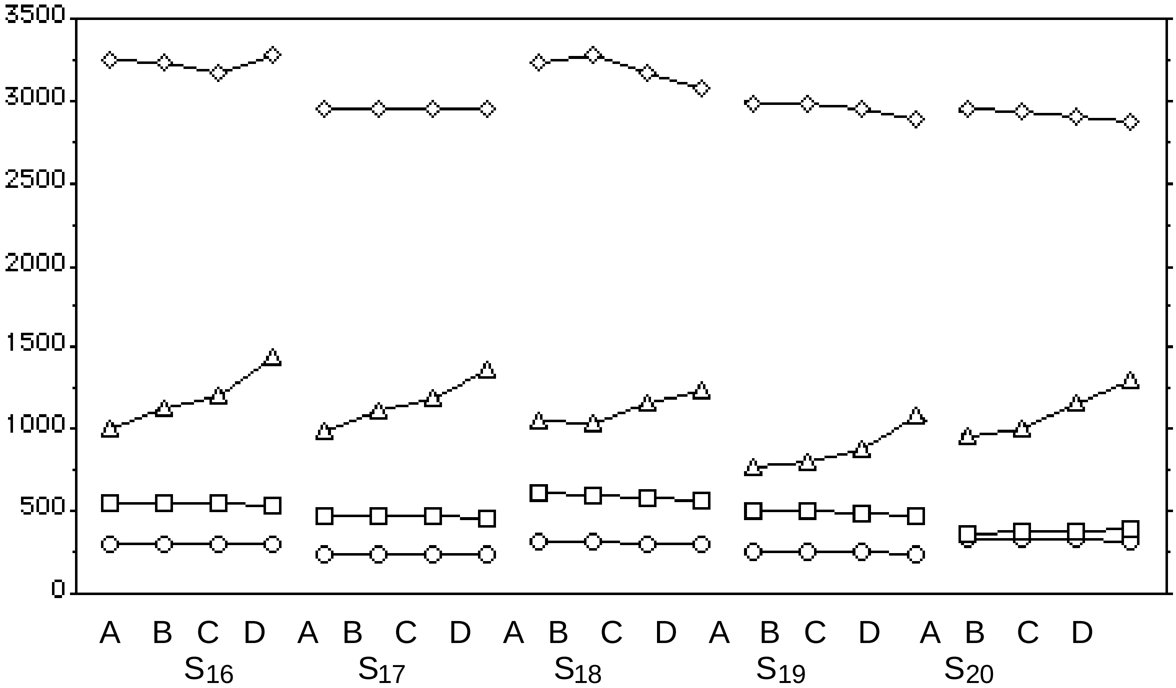
H-2-2. Korean Female [i] in hida



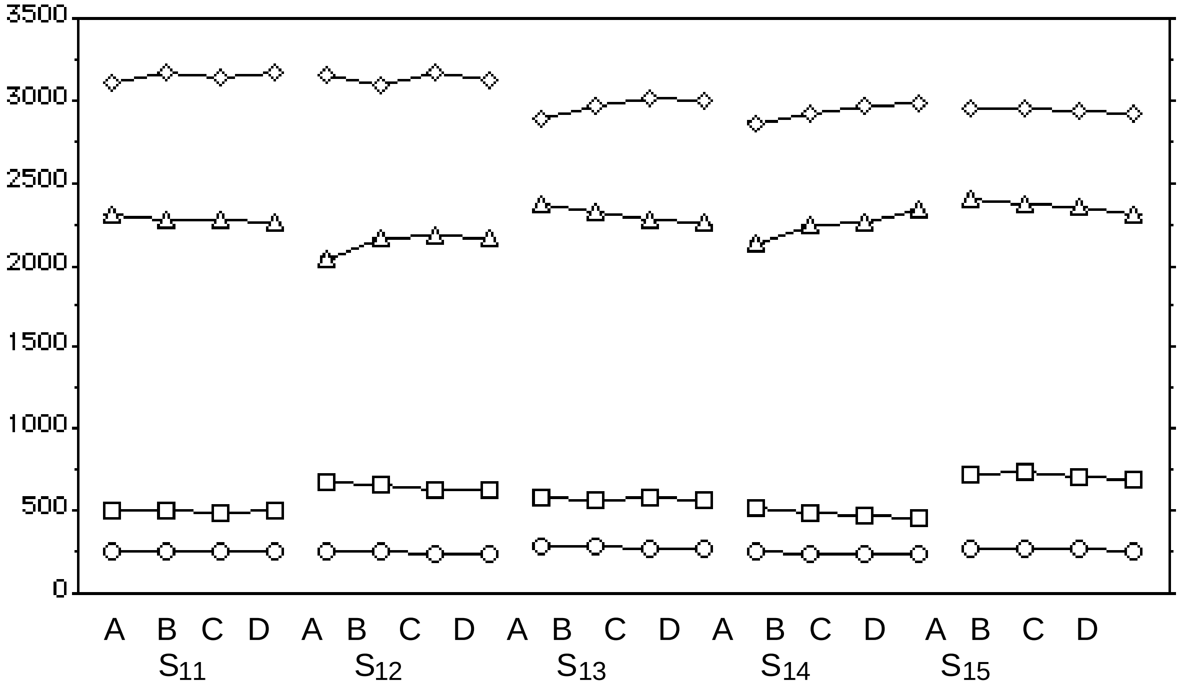


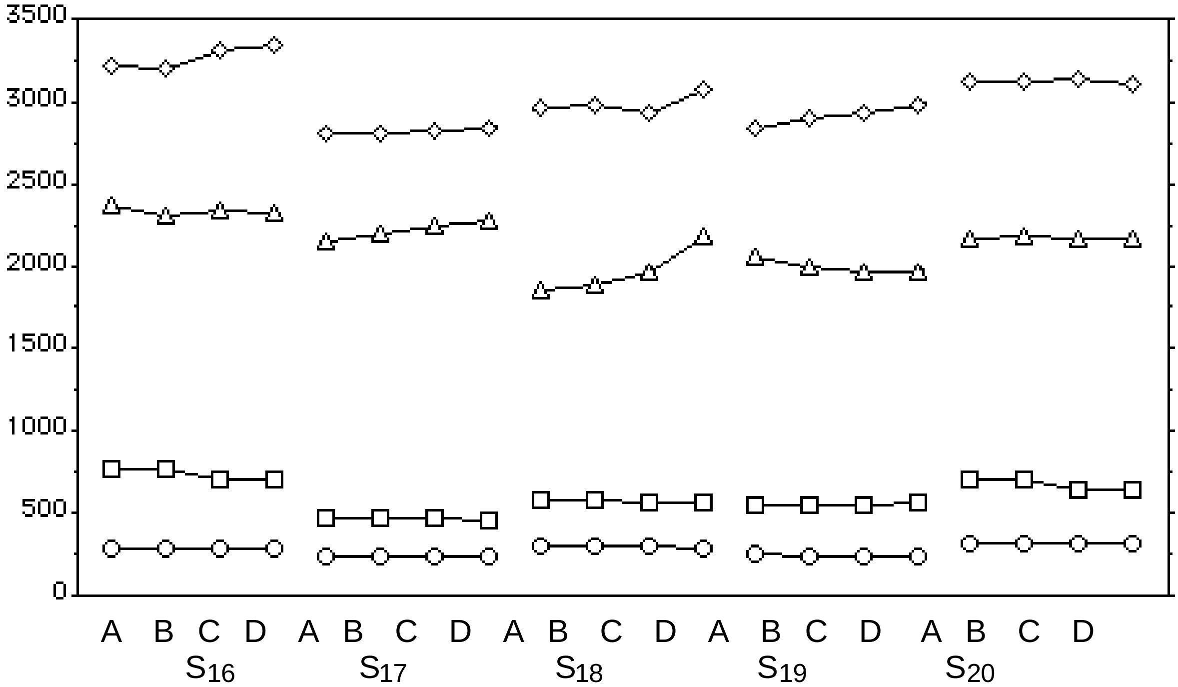
H-2-2. Korean Female [o] in hoda



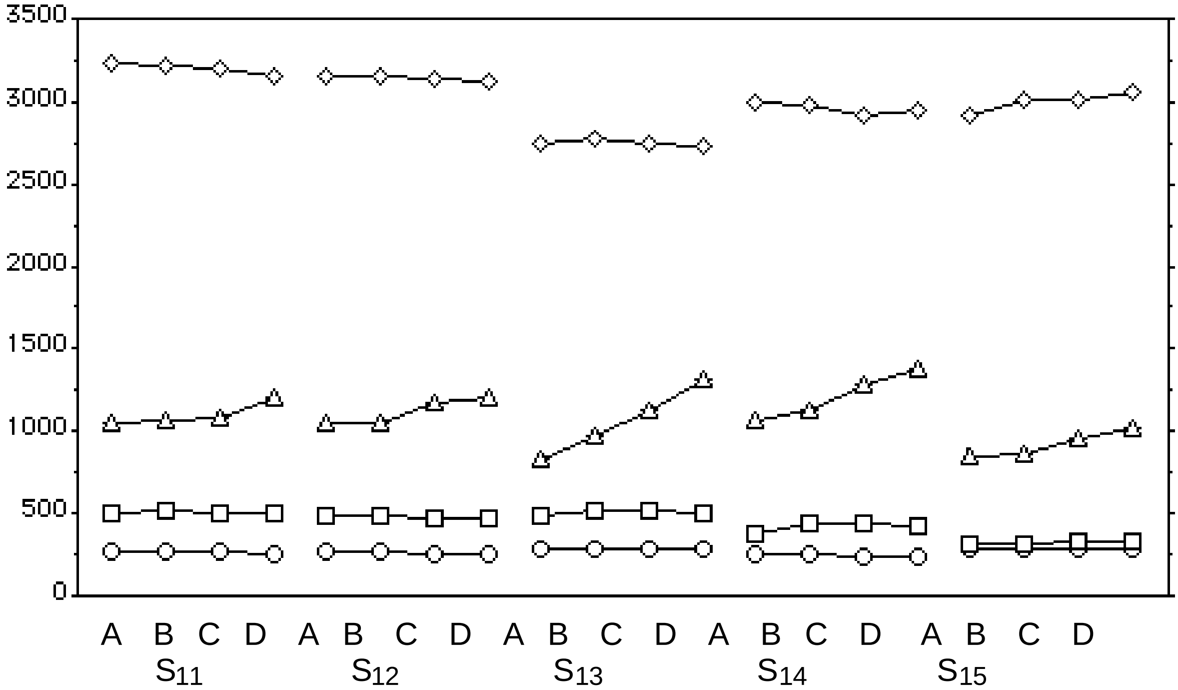


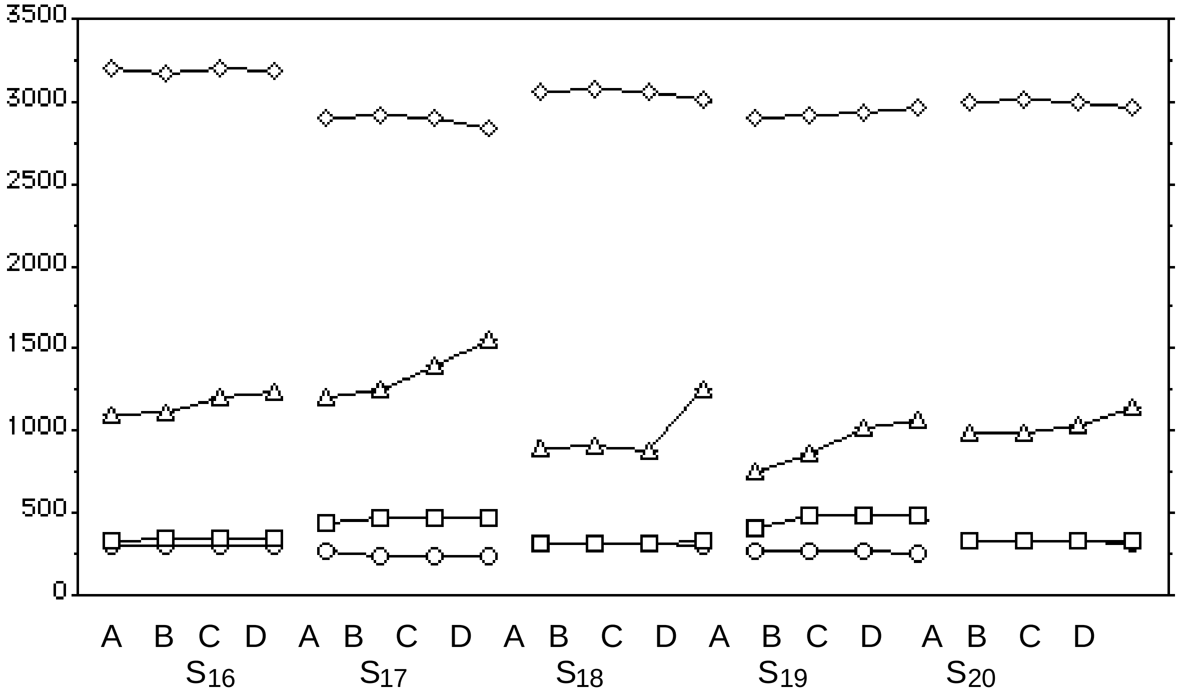
H-2-2. Korean Female [we] in hweda



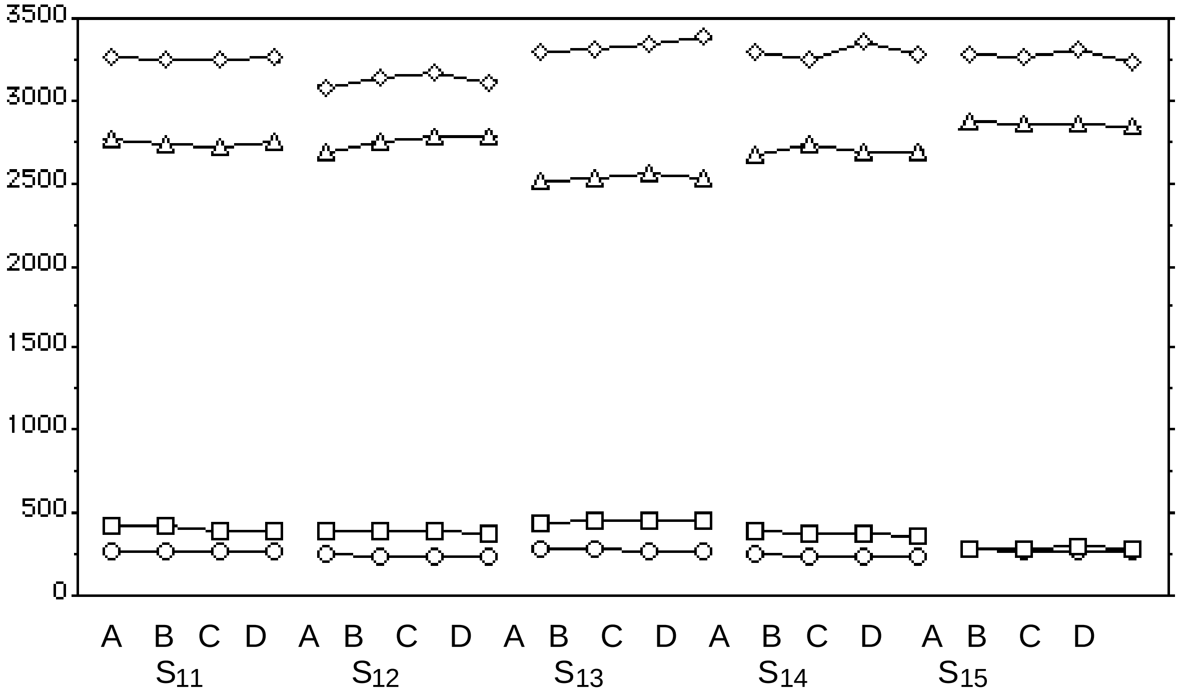


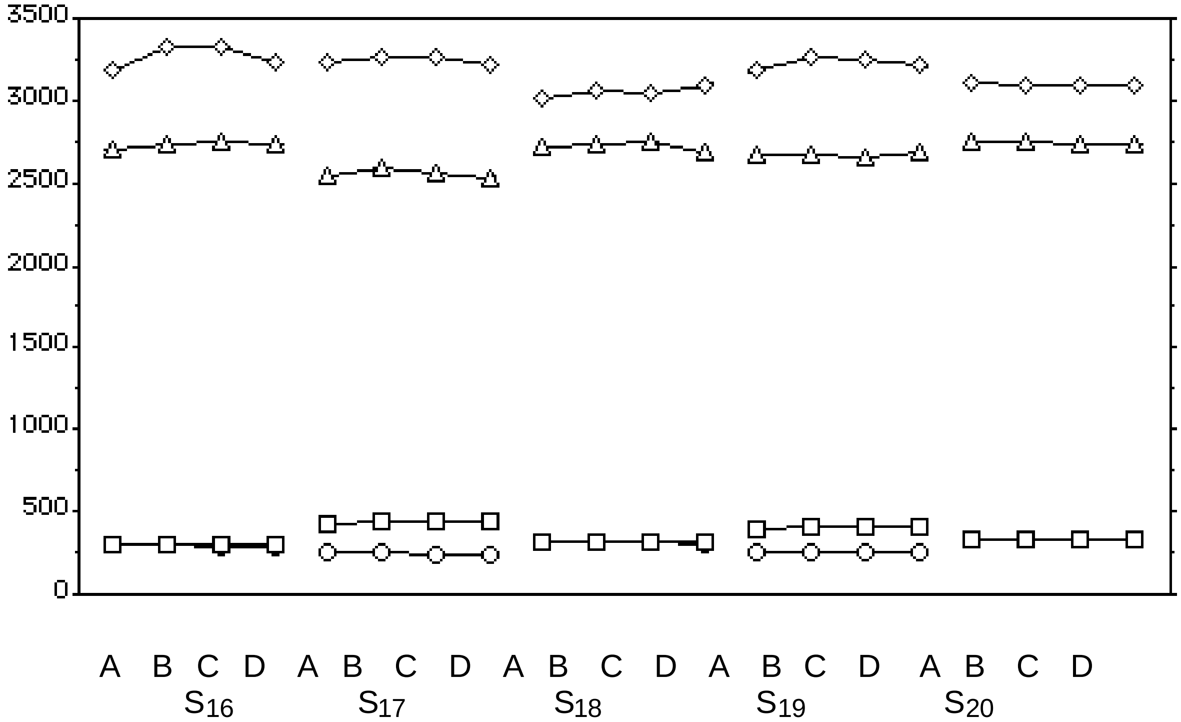
H-2-2. Korean Female [u] in huda



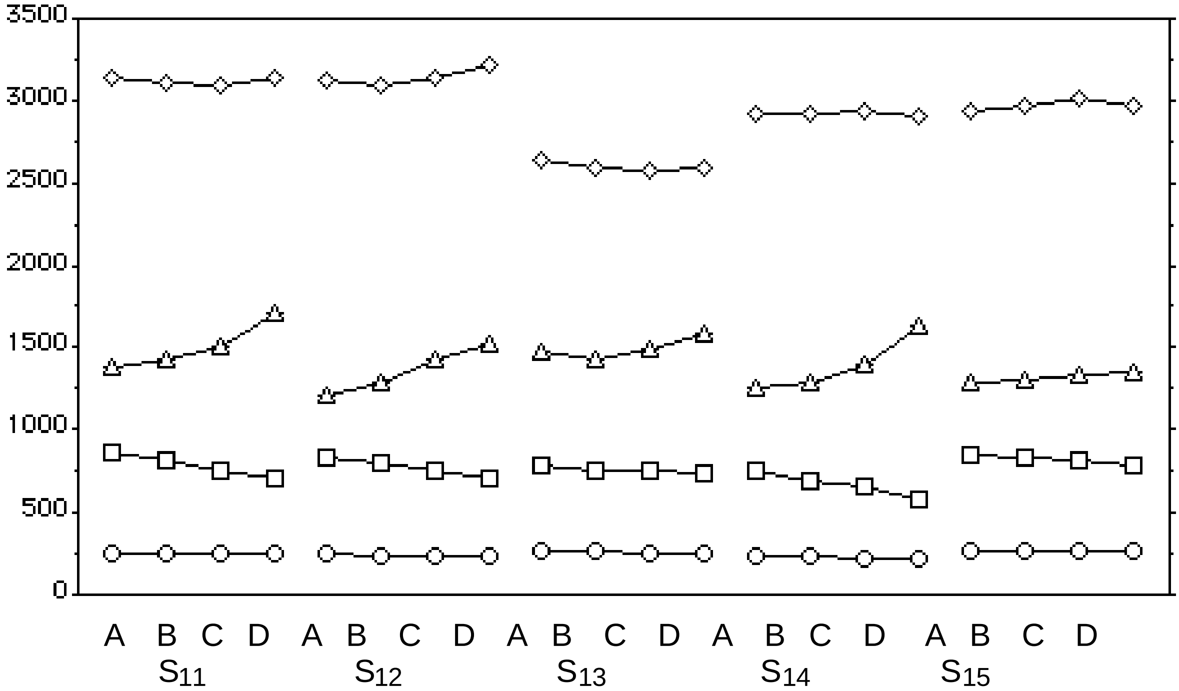


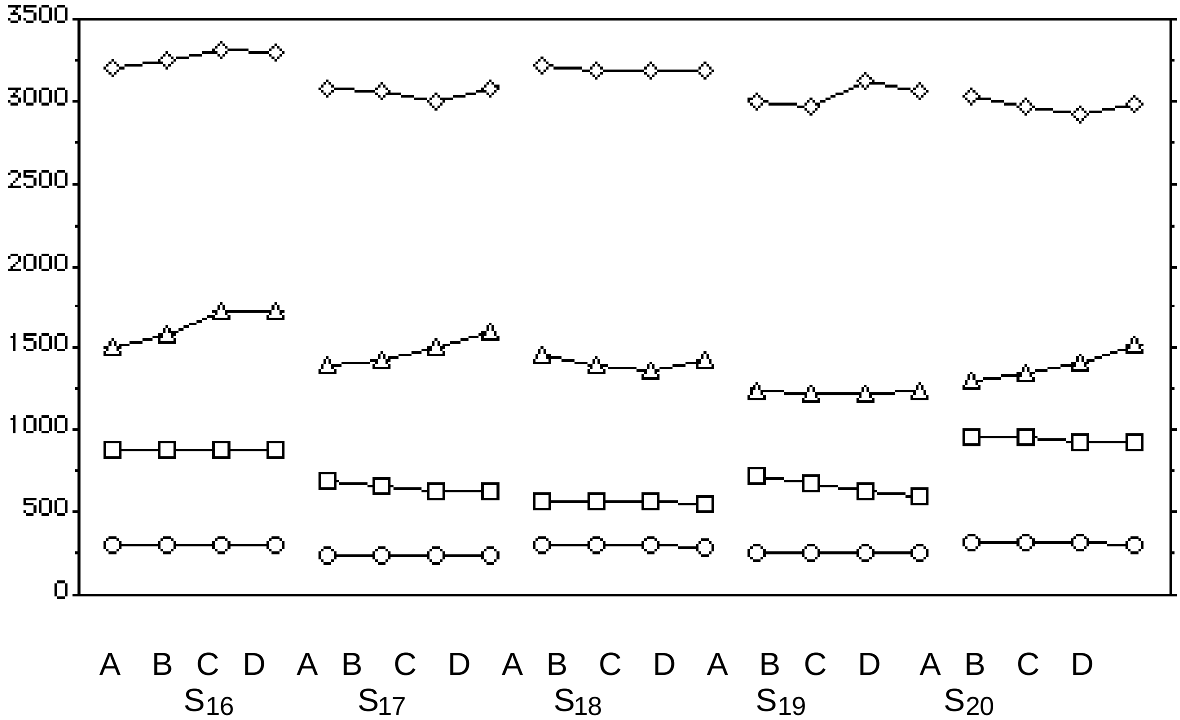
H-2-2. Korean Female [wi] in hwida



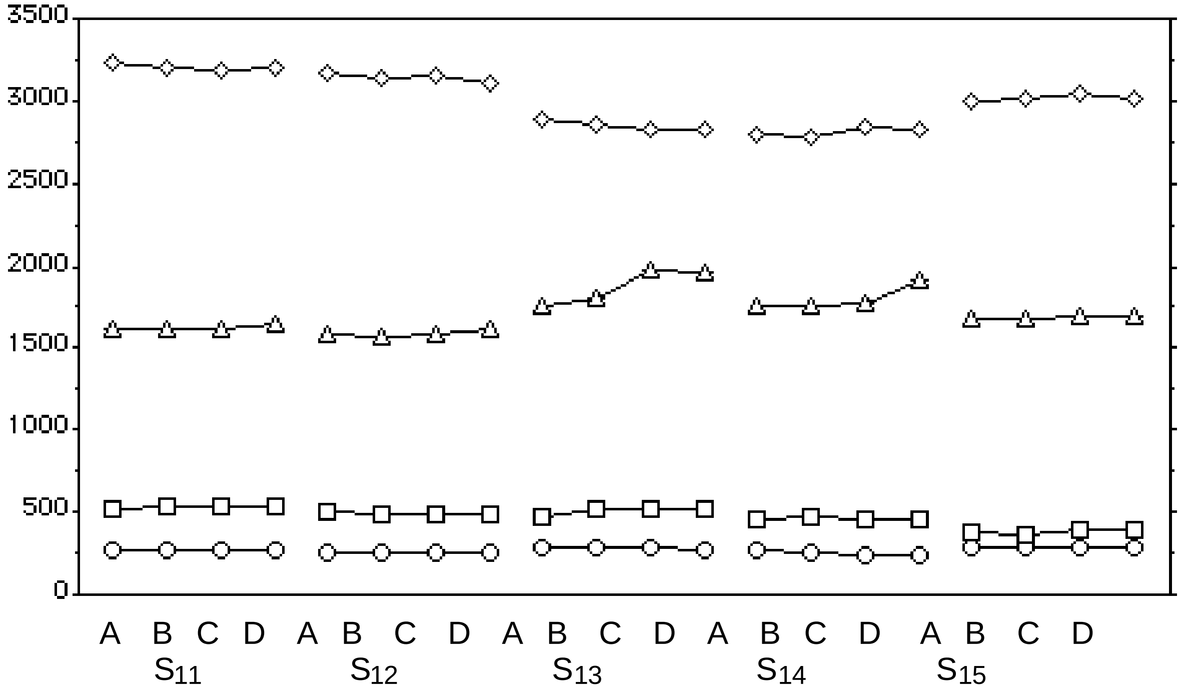


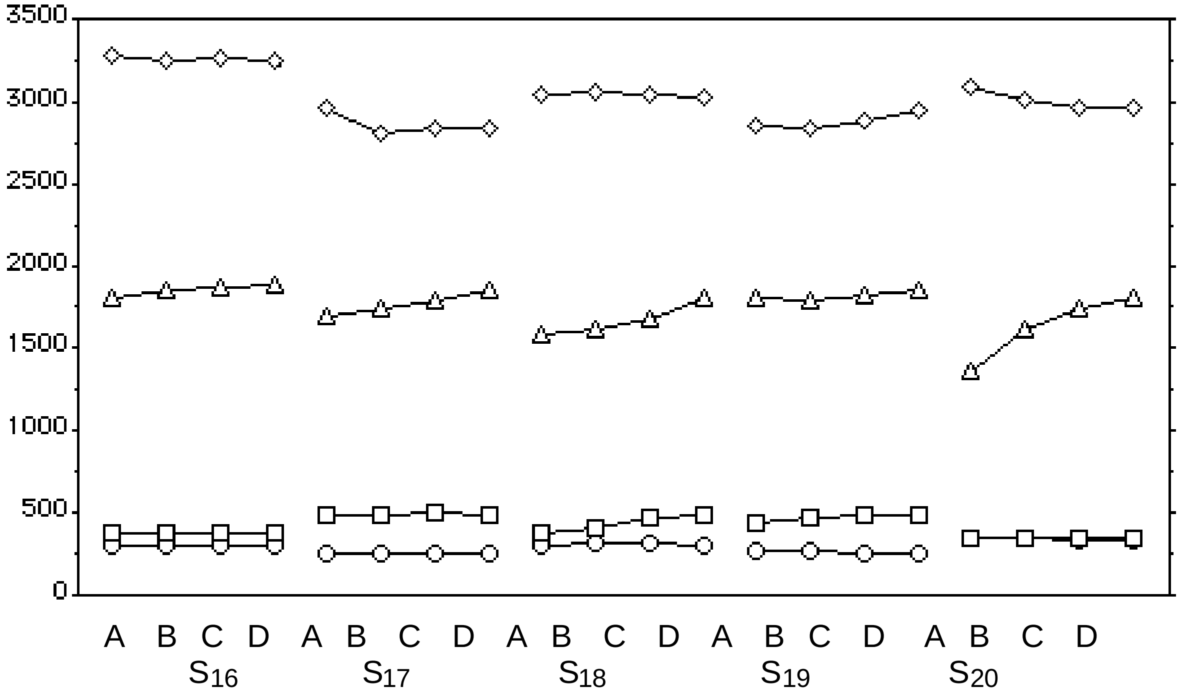
H-2-2. Korean Female [ʌ] in hʌda



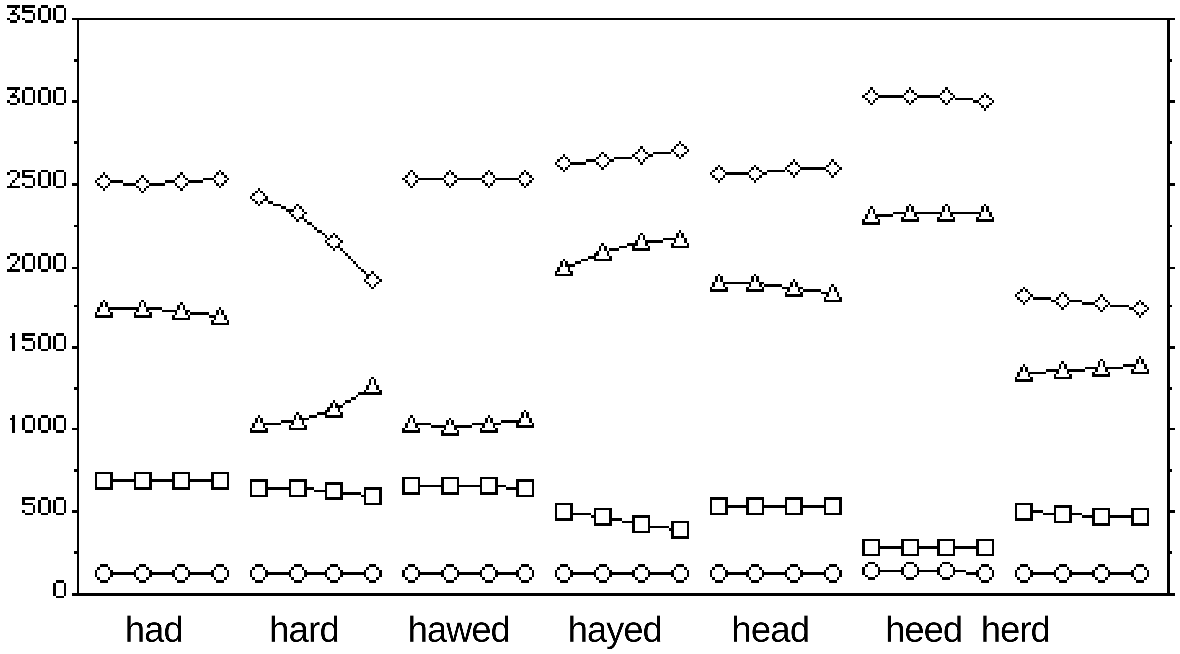


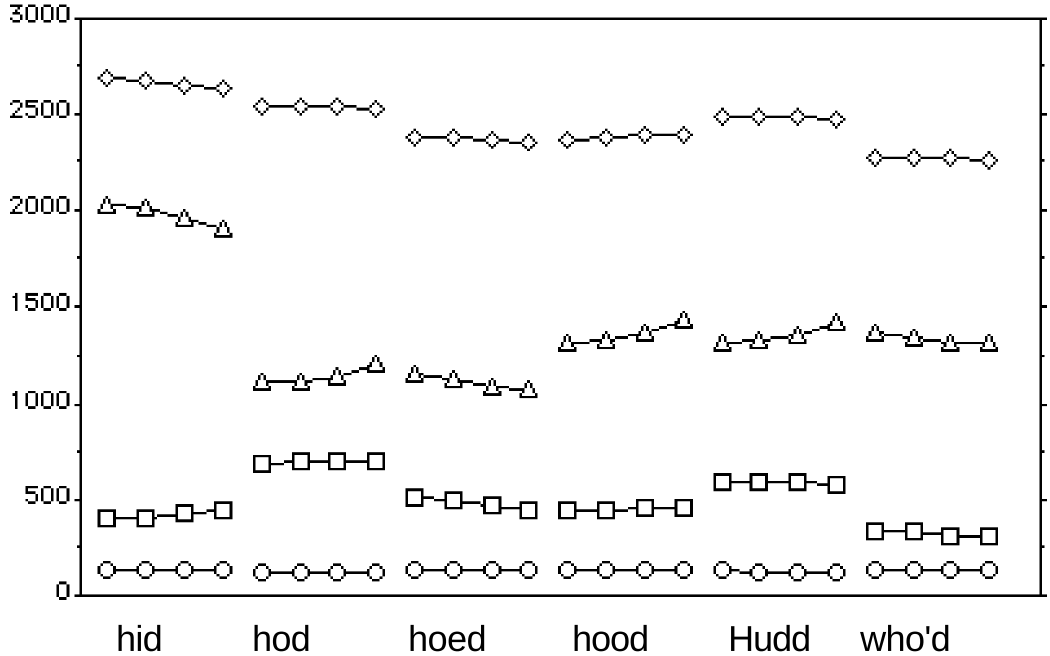
H-2-2. Korean Female [uu] in huuda



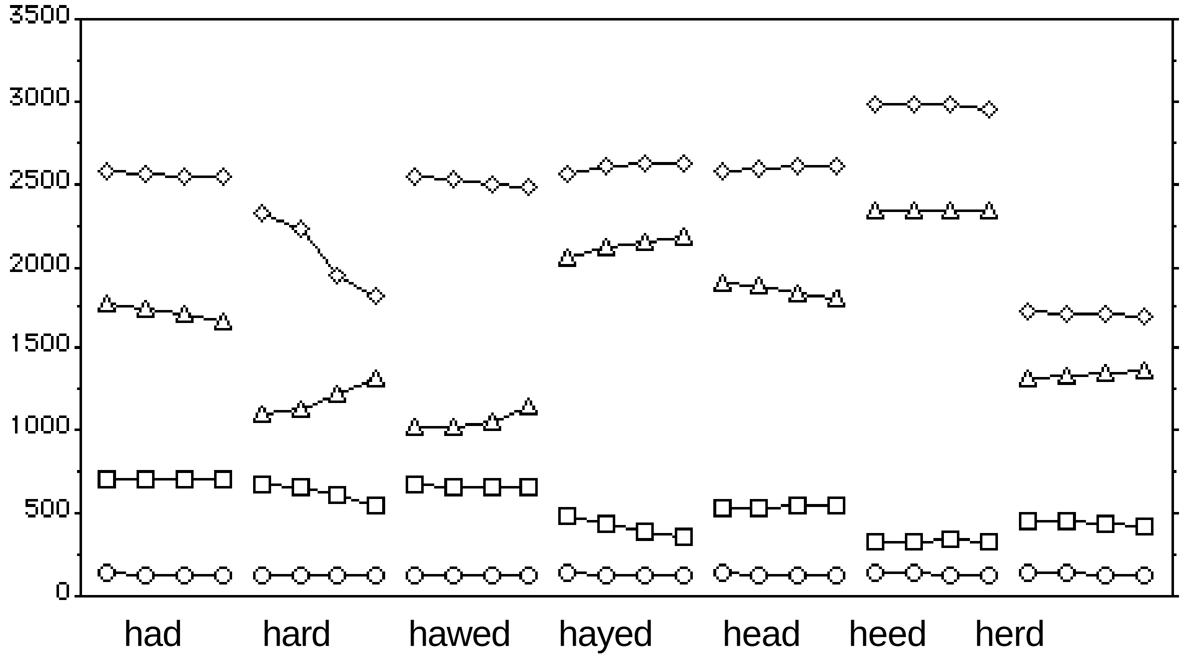


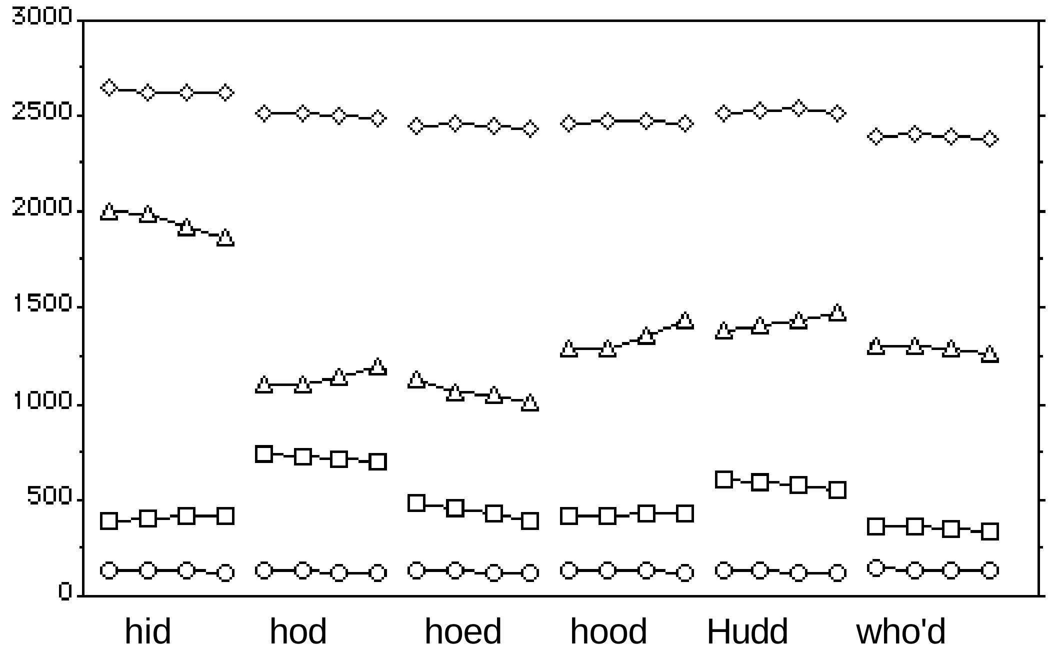
H-3-1. Average of English Male Group



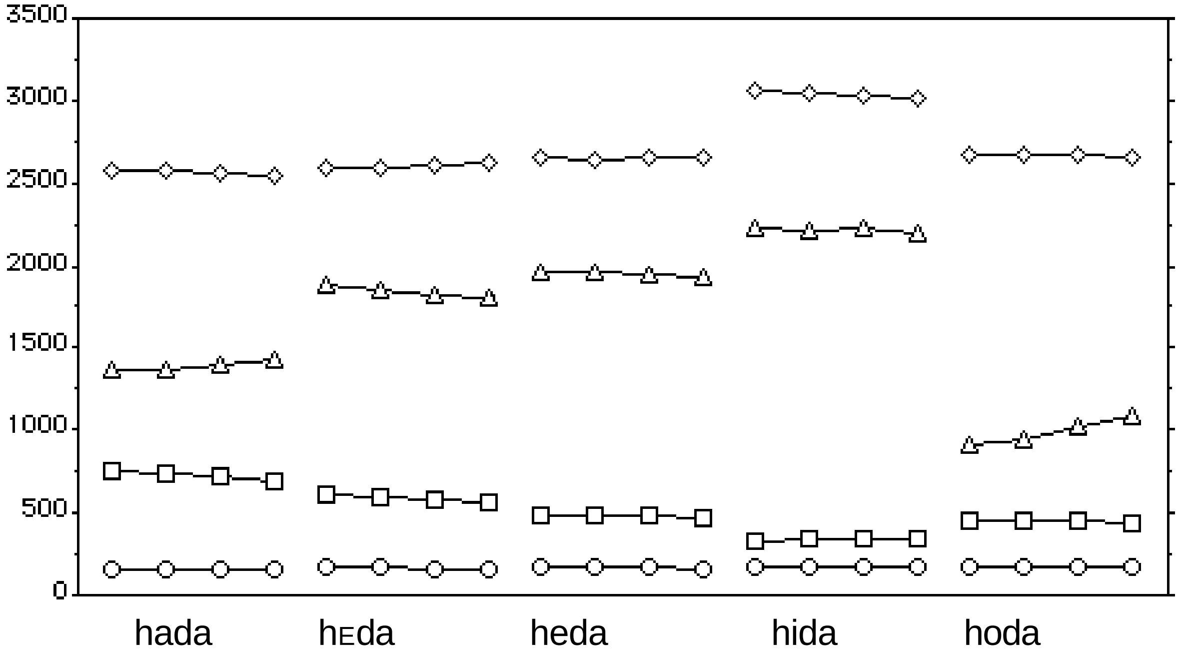


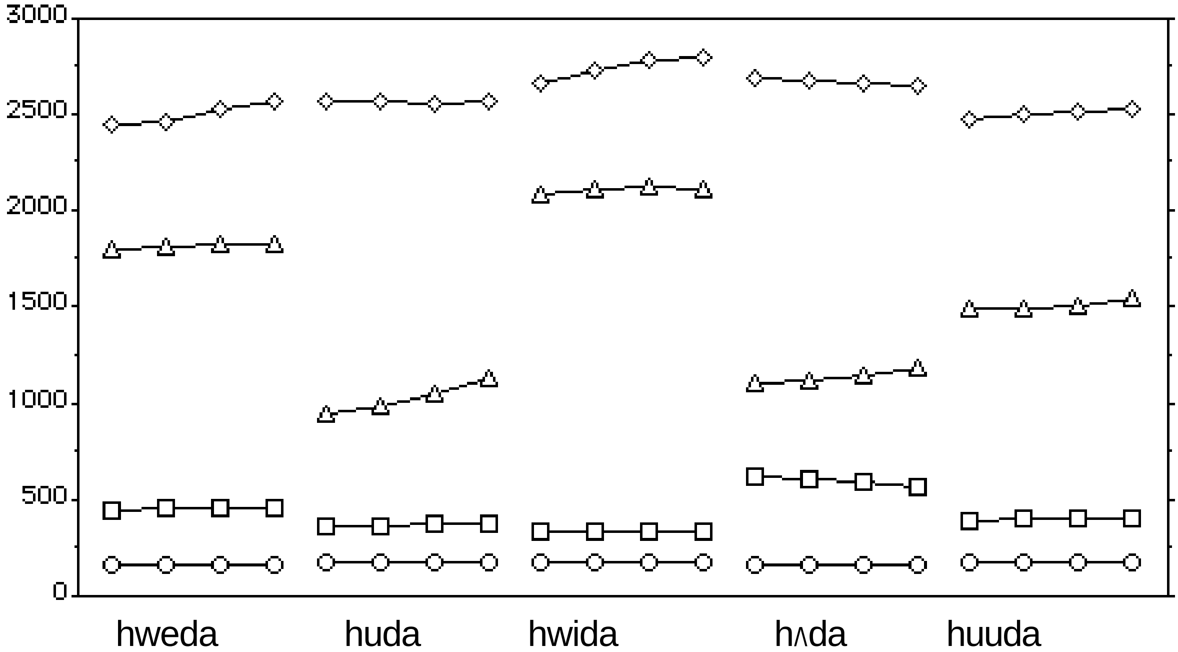
H-3-2. Average of English Female Group





H-4-1. Average of Korean Male Group





H-4-2. Average of Korean Female Group