

A RE-EXAMINATION OF THE MIXED DENTITION ANALYSES

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TABLE OF CONTENTS

	PAGE
INTRODUCTION	4
LITERATURE REVIEW	6
MATERIALS AND METHODS	18
FINDINGS	31
DISCUSSION	42
SUMMARY AND CONCLUSIONS	53
BIBLIOGRAPHY	57
FIGURES 1-17	
FIGURES I-XII	

INTRODUCTION

Numerous methods exist for the analysis of mesiodistal dimensional differences between the primary canine and molars and their successors in the mandibular arch. It appears that the most accurate method of mixed dentition analysis available is that developed by Hixon and Oldfather¹. However, criticism and doubts have arisen regarding this analysis in two main respects. The first is that the analysis has a systematic error; according to Moyers² it is consistently optimistic in predicting mesiodistal dimensions of the mandibular permanent canine and premolars. Secondly, the use and practicability of the analysis is greatly limited because it requires that periapical radiographs of unerupted teeth be taken with a sixteen-inch cone dental x-ray unit, and most dental offices are equipped with short cone x-ray units and some with panoramic x-ray machines.

The purpose of this paper is to re-examine the accuracy of the Hixon-Oldfather and Moyers mixed dentition analyses using a sample

from Portland, Oregon collected by the Child Study Clinic, U.O.H.S.C.

In addition, the method devised by Tanaka and Johnston³ for simplifying the mixed dentition analysis will be examined to see how it compares to the Hixon-Oldfather and Moyers methods. The effect on the Hixon-Oldfather analysis of substituting a correctional factor for radiographic distortion and enlargement based on the method of Huckaba⁴ will be tested. In addition, a new regression formula will be fitted to these data.

It is also the purpose to investigate the applicability of substituting variables of the Hixon-Oldfather analysis with those obtained from panoramic radiographs. This data will be derived from a second sample obtained from the Swift Current Dental Health Region Clinic, Swift Current, Saskatchewan, Canada. The data from this sample will also be examined using the Moyers analysis and Tanaka and Johnston's method.

LITERATURE REVIEW

Many investigations have been undertaken to develop an accurate mixed dentition analysis in order to determine whether the space occupied by the primary canine, first and second molars is sufficient to accommodate the permanent canine, first and second premolars in both maxillary and mandibular arches.

Early attempts at estimation were based on tables of average widths, for example those of Black⁵, but these were seldom appropriate for the individual. Subsequently, two major approaches, radiographic and statistical, were used to obtain valid estimates for a given patient.

Nance⁶ developed a mixed dentition analysis by measuring the space occupied by the mandibular primary canine, first and second molars in the dental arch. Comparing this measurement with the mesiodistal width of their permanent successors, obtained from periapical dental radiographs, he determined, with allowance for leeway space, if there would be sufficient space to accommodate

the successional teeth in the mandibular arch in good alignment.

Nance used mean values obtained from G. V. Black's work, 1.7 mm (3.4 mm total) for each side of the arch, as the value for leeway space . Using a brass wire, he measured the mandibular arch length from the mesiobuccal cusp of the first permanent molar to that on the other side. This measurement was then used to compare the arch length of the mixed dentition with the permanent successional tooth sizes.

Carey⁷, in continuation of Nance's work, correlated the mesiodistal width of the unerupted mandibular canine, first and second premolars, with that of the mandibular incisors. He also determined arch length by using a brass wire measurement from the mesiobuccal line angle of the permanent first molar to that of the opposite side and then compared this with the mesiodistal widths of the successional teeth plus the leeway space (3.4 mm as used by Nance).

Taylor⁸ recognized certain shortcomings in Nance's and Carey's work and made additional adjustments which considered the maxillary

arch, various molar relationships and each individual's amount of leeway space. Taylor took into account the proposed method of orthodontic treatment which included holding back or retaining either maxillary or mandibular first molars; thus, an adjustment for leeway space need not be considered. He did not use an average figure for leeway space; instead, that space was calculated for each patient either from x-rays or by formula.

From measurements of 400 casts, Ballard and Wylie⁹ calculated coefficients of correlation of the relationship between mesiodistal widths of various groups of mandibular teeth. They developed a regression formula with which to predict the mesiodistal widths of the unerupted canines, first and second premolars from measurements of the four mandibular incisors. The correlation coefficient was +0.64 with an average error of 2.5 percent or .6 mm on each side. By comparison the average error found by using measurements made from radiographs for prediction purposes was 10.5 percent, or 2.2 mm on each side, with this error always tending to be in the direction of enlargement. Griewe¹⁰, from measurements of 219 casts,

obtained a correlation coefficient of +0.49 for the same segments of teeth measured by Ballard and Wylie. He also correlated the same segments in the maxillary arch and obtained a coefficient of +0.37. Bolton's¹¹ work confirmed Ballard and Wylie's finding. He obtained a correlation coefficient of +0.65, which closely approximated their calculation of +0.64.

Foster¹², using Ballard and Wylie's formula, found a wide range in the space needed for the unerupted mandibular canines, first and second premolars. He obtained his measurements from models and radiographs and compared them with measurements calculated from the Ballard and Wylie formula. The mean difference was 2.6 mm; the greatest difference was 9 mm. In 64 percent of his cases, measurements of crown widths of unerupted permanent teeth taken from dental radiographs gave values 1 mm more than the formula predictions; within 1 mm in 28%, and smaller by more than 1 mm in only 8 percent of the cases. He concluded that properly taken radiographs could out-predict the formula.

Brown¹³, working on teeth in the maxillary arch only, derived

a prediction formula to determine the size of the unerupted canines, first and second premolars from their correlation with the mesiodistal diameters of the central and lateral incisors. Measurements were taken on 500 maxillary casts divided according to sex. He found a correlation coefficient of +0.602 for females and +0.588 for males. This closely approximates the result Ballard and Wylie obtained ($r = +0.64$) in their investigation of the same teeth in the mandibular arch.

A table with confidence limits has been developed by Moyers² that predicts the sum of the widths of the unerupted canines, first and second premolars from the sum of the mesiodistal widths of the mandibular permanent incisors. For example: At the 50% level of probability, the average size of the unerupted canines and two premolars is predicted. At the 75% level of probability in 75 percent of cases the size of the canine, first and second premolars will not be larger than the given value. The space available in each quadrant is measured from the distal of the lateral incisor to the mesial of the first permanent molar. This value is compared to the

value obtained from the table.

Hixon and Oldfather¹ used forty-one children in their initial study and then added another thirty-five. Their purpose was to find a method of accurately estimating the sizes of the unerupted mandibular canines, first and second premolars. They developed a more efficient regression formula than that derived by Ballard and Wylie, and by Griewe. Cast measurements of the mesiodistal width of the primary teeth and their permanent successors were used as well as radiographic measurements of the primary canines, first and second premolars. Correlation coefficients for each of the twelve predictive combinations and the unerupted segment are shown in the following table:

Predictive Combinations	r
c, d, e cast	.56
1, 2, 2, 1 cast	.69
3, 5 x-ray film	.78
4, 5 x-ray film	.80
3, 4 x-ray film	.82
3, 4, 5 x-ray film	.82
1, 2, 2, 1 cast plus c, d, e cast	.75
3, 4 x-ray film plus 1, 2, 2, 1 cast	.84
3, 4, 5 x-ray film plus 1, 2, 2, 1 cast plus c,d,e cast	.85
4, 5 x-ray film plus 1, 2, 2, 1 cast	.88
4, 5 x-ray film plus 1, 2 cast	.88*

*Most accurate predictive combination

The predictive combination with the greatest accuracy was found to be the cast widths of the central and lateral incisors, plus the film widths of the first and second premolars. The standard error of the estimate was 0.57 mm, i.e., the predicted value was accurate within 0.6 mm for 68% of the cases; within 1.1 mm for 95% of the cases; and within 1.7 mm for 99% of the cases.

Stahle¹⁴ modified Hixon and Oldfather's procedure by measuring the mesiodistal widths of the central and lateral incisors in vivo, along with widths of the unerupted first and second premolars as they appear in the dental radiographs. He found that the combined radiographic width was 1.0 mm more than the true anatomical width for the maxillary bicuspid, and 1.25 mm for the mandibular bicuspid. By using a central incisor-canine width ratio and the corrected radiographic width of the premolars, correlation coefficients were obtained for each sex, and for upper and lower jaws. A coefficient of +0.91 was obtained in the mandibular arch, and +0.89 in the maxillary arch, for males. Both mandibular and maxillary teeth exhibited coefficients of +0.77 for females. The average error was found to be .4 mm in the upper jaw and .52 mm in the lower jaw.

Using radiographs taken at two different target film distances (8 and 16 inches), Bull¹⁵ devised a method to accurately estimate the mesiodistal widths of unerupted teeth. He devised a formula for predicting the mesiodistal dimension of teeth from the two sets of radiographs:

$$Y = \frac{d \times c}{(2d) - c}$$

Y = estimated mesiodistal dimension of the tooth;

d = measurement of tooth on roentgenogram taken at 8 mm
target-film distance;

c = measurement of tooth on roentgenogram taken at 16 mm
target-film distance.

At an 8-inch target-film distance, he found the average dimension measured from the film was 3.3 percent greater than the direct measurement; and at the 16-inch target-film distance the average dimension was 2.3 percent greater than the direct measurement.

Huckaba⁴ developed a formula to accurately correct for x-ray film enlargement. It was necessary to assume that the degree of

magnification is approximately the same for a primary tooth as for the underlying permanent successor on the same film. If this assumption is correct, then the actual size of the unerupted permanent tooth can be calculated within close practical limits. This procedure is followed for the three permanent successors on both sides. He advocated its use in conjunction with Moyers' probability tables.

Recently, Tanaka and Johnston³ re-examined the extent to which Moyers' charts are appropriate to a contemporary orthodontic population. Linear regression equations for the prediction of the mesiodistal widths of the unerupted canines and premolars were calculated for a large sample of recent orthodontic patients. They found confidence belts that matched Moyers' almost exactly. The mandibular incisors showed a correlation of $r = 0.625$ with the maxillary canine and premolars and $r = 0.698$ with the mandibular canine and premolars. The size in millimeters of unerupted canines and premolars at the 75th percentile can be predicted by taking half the width of the mandibular incisors and adding 11.0 mm for the maxillary teeth and 10.5 mm for the mandibular teeth.

Panoramic radiography in dental arch space analysis has been investigated by Rosenberg and Law¹⁶. The degree of the mesiodistal distortion was determined by comparing measurements of the canine and premolar teeth on plaster casts with measurements on panoramic radiographs. Correction equations were determined for the purpose of developing a clinically accurate method for space analysis using panoramic radiographs. Their sample consisted of 71 subjects; each had all twelve permanent cuspids and premolars fully erupted with no overlapping metal restorations obscuring the x-ray film image. Panoramic radiographs and study casts were taken on each patient and measurements compared. In order to compensate for the distortions introduced in panoramic radiographs, regression was used to establish the relationship between the actual tooth size and the panoramic tooth size. The regression relationships were found to be linear. It was determined that each of the twelve tooth types has its own regression equation. They found an average confidence limit of ± 0.89 mm for each tooth in comparison to Hixon-Oldfather's of 1.1 mm for the combined widths of the

mandibular permanent canine and two premolars on each side.

Updegrave¹⁷ and Brueggemann¹⁸ each discussed head position as a material factor in the variation of the degree of distortion with panoramic radiography. An important addition to the panoramic radiographic technique could be a head positioning device, such as a cephalostat. Then much of the variation in the degree of distortion might be eliminated and possibly confidence limits approaching those of Hixon-Oldfather's could be obtained.

Richardson, et al¹⁹, Zach, et al²⁰, and Kane²¹ have all investigated the use of head holders with panoramic radiographs.

Lund and Manson-Hing²² have done studies on focal troughs of three of the more popular panoramic dental x-ray machines. This has helped to explain horizontal and vertical enlargement and distortion found in panoramic radiographs.

This survey of literature has revealed that there are several analyses to predict successional tooth size in the buccal segment and each of these methods claims to be the most appropriate and accurate for clinical use. It is the purpose of this study to

determine the relative merits of three mixed dentition analyses:

Hixon-Oldfather's, Moyers' and Tanaka-Johnston's.

MATERIALS AND METHODS

The data presented in this investigation were collected from two samples. The first sample consisted of dental casts and intra-oral x-ray films of 105 children, 52 females and 53 males, enrolled in the Child Study Clinic at the University of Oregon Dental School. The ages of the subjects at the time mixed dentition records were taken ranged from 5 years 10 months to 10 years 11 months with an average of 7 years 6 months. Records of the permanent dentition were obtained at ages ranging from 10 years to 18 years with an average of 13 years. The subjects lived in or near Portland, Oregon, all were American born of Northwestern European ancestry, and of average or above socioeconomic status. The second sample comprised of panoramic radiographs and dental casts in the permanent dentition of 31 individuals, obtained from the Swift Current Health Region Clinic, Swift Current, Saskatchewan, Canada. Age range of the panoramic radiographs was 7 years to 10 years with average age of 8 years. Dental cast ages ranged from

9 years 10 months to 15 years with an average of 12 years. The sample consisted of 17 females and 14 males, all lived in or near Swift Current. They were of Northwestern European ancestry and of average or above socioeconomic status.

The records selected for these two samples conformed with the following criteria:

- Sample #1
1. Periapical x-rays taken with a cone giving a 19 inch skin-target distance showing clear images of the unerupted mandibular permanent first and second premolars and intact primary molars when possible. Teeth with obvious rotations were not included, with the result that some individuals had incomplete data.
 2. Mandibular study casts, with the primary cuspids, first and second molars present, taken the same time as the periapical x-rays.
 3. Mandibular study casts of the erupted permanent succedaneous teeth, which were free of dental caries and proximal restorations.

- Sample #2
1. Panoramic x-rays taken on one machine prior to eruption of the mandibular first and second premolars.
 2. Casts of the mandibular arch with erupted succedaneous teeth, free of dental caries and proximal restorations.

The impressions for the casts were taken in alginate and poured in white stone for sample one and conventional dental stone for sample two. The intraoral x-ray films were taken by a technician, using a conventional dental x-ray machine with a 16-inch cone. The film was placed in the mouth by the technician and held in place by the subject.

Measurements were made with a finely pointed vernier caliper and read to the nearest 0.05 mm according to methods outlined by Moorrees and others.²³ On the casts and periapical x-ray films the mesiodistal width of the crowns of the individual teeth were measured at right angles to the long axis of the tooth. Where the contact areas were overlapping on the films, the overlap was included in the measurement. In sample #1, mandibular first and second premolars and first and second primary molars were measured from the periapical x-rays.

Measurements of primary teeth were always made from the same x-ray films from which the premolars were measured. The reason being, to incorporate, based on the method of Huckaba, a correctional factor for radiographic distortion and enlargement. The corrected value for permanent premolars was calculated using the formula:

$$X = \frac{X'Y}{Y'}$$

X = corrected value

X' = x-ray image measurement of unerupted premolar

Y = cast measurement of primary molar

Y' = x-ray image measurement of primary molar

Right and left mandibular permanent canines, first and second premolars, central and lateral incisors were measured on study models of best choice. Factors considered were: completely erupted teeth, sharp definition and casts made prior to any caries or restoration of the teeth to be measured.

Measurements for calculation of total anterior crowding change and total leeway space were made from:

a) Casts of mixed dentition

1) Combined measurements of mandibular primary canine,

first and second molars for both sides.

2) Space occupied by mandibular permanent incisors:

from mesial contact of the central incisors to the most mesial point on the primary canine in the line of the arch, on each side.

b) Casts of permanent teeth fully erupted

1) Space occupied by mandibular incisors: as in a) 2).

2) Measurements of mandibular permanent incisors,

canines and premolars were previously measured from these casts.

From Sample #2 both right and left mandibular first and second premolars were measured from panoramic radiographs, when possible depending on clarity and absence of undesirable premolar rotations. Cast measurements were made of right and left mandibular permanent canines, first and second premolars, central and lateral incisors.

Reproducibility of the data used in this investigation was determined by replicate measurements made two weeks following collection of the data. Twenty-one individuals' records were randomly chosen from sample one and from sample two, seven

individuals. All measurements were replicated from the records of these cases.

The S. E. Measure was calculated using the formula:

$$S.E.M. = \sqrt{\frac{\sum (d)^2}{2N}}$$

d = difference between first and second measurements

Analysis of the Data

The collected data were punched onto computer cards and a program was developed to generate the following computations:

- 1) Separate right and left summed values for cast measurements of central and lateral incisors and x-ray measurements of the first and second premolars. For each side predicted values for the combined canine, first and second premolars were generated from Hixon-Oldfather regression formula:

$$x = .647y + 3.493$$

where x = predicted value

y = sum of central and lateral incisors
and x-ray image of first and second
premolars

- 2) Huckaba's corrected values for radiographic measurements of the first and second premolars were substituted into

the summed variables for the Hixon-Oldfather analysis.

The predicted values for the sum of the canine, first and second premolars were derived using the above regression formula for each individual in sample one.

- 3) Moyers' predicted values were calculated for each individual in samples 1 and 2. Summed values of four permanent mandibular incisors were used in a formula developed from Moyers' table. Values for 95, 85, 75, and 65 percent probability levels were computed for each individual using the formula:

$$x = .6 y + a$$

x = predicted value

y = sum of four mandibular incisors

a = constant for various levels of probability:

at 65% level = 8.1

at 75% level = 8.4

at 85% level = 8.8

at 95% level = 9.4

- 4) Tanaka and Johnston's predicted values were calculated for each individual in samples 1 and 2. This analysis is a simplification of Moyers' at the 75 percentile level. Half of the width of the mandibular incisors plus 10.5 mm gives

the predicted value for either mandibular right or left permanent canine and premolars.

- 5) In sample 1, total anterior crowding change and total leeway space for each individual, with complete data, were calculated. Anterior crowding in each dentition, mixed and permanent, was calculated by subtracting the sum of the mandibular incisors from the space available. A negative value indicated presence of crowding; positive value, spacing. The difference between these values in mixed and permanent dentitions was calculated. This was the total anterior crowding change. The leeway space was determined by subtracting the combined width of permanent canine, first and second premolars from the sum of primary canine, first and second molar. The total leeway space equalled the sum of the right and left values.

Statistical Analysis

The samples one and two were considered separately during all of the analyses. The following subsamples were analyzed:

	Sample I N	Sample II N
A. All individual using 1 side only		
1. Females - right sides	43	12
- left sides	36	16
2. Males - right sides	47	12
- left sides	33	13
3. Sexes combined - right sides	90	24
- left sides	69	29
B. Individuals with measurements for both sides with Huckaba variables.		
1. Sexes combined - right sides	39	
- left sides	39	
C. Combined sexes and sides	105	30

(This subsample consisted of all right sides from individuals with measurements only on right side, all left sides from individuals with measurements only on left side and from individuals with both sides, one side was randomly selected. For Sample I there were 25 females and 25 males with right sides and 27 females and 28 males with left sides. For Sample II there were 7 females and 7 males with right sides and 9 females and 7 males with left sides.)

The following statistical analyses were applied:

- 1) Correlation coefficients of the sum of cast measurements of lower canine, first and second premolars with predicted values obtained by Hixon and Oldfather's method, Moyers' method, and Tanaka and Johnston's method were calculated for sample 1 and 2.
- 2) For each method of prediction paired t-tests were used to test significance of the difference between the predicted and the actual values.
- 3) Unpaired t-tests were used to test significance of differences between right and left sides of each sex and between males and females by side.
- 4) a) The dependent variable (see Table V) was regressed on the sum of the central and lateral incisors, x-ray measurements of first and second premolars in samples 1 and 2.

b) In sample 1 the dependent variable (see Table V) was regressed on the sum of the central and lateral incisors

and corrected (Huckaba) x-ray measurements of first and second premolars.

- 5) a) The data for sample 1 were used to generate multiple regressions to improve the accuracy of the predicted values. The input variables were as follows:

Mesiodistal width measurements of:

right central incisor

left central incisor

right lateral incisor

left lateral incisor

Mesiodistal x-ray measurements of:

right first premolar

left first premolar

right second premolar

left second premolar

Huckaba's corrected x-ray values for:

right first premolar

left first premolar

right second premolar

left second premolar

- 6) The data for sample 2 were analyzed in a similar multiple regression approach but no variables for Huckaba's corrected values were available.
- 7) Using the regression formula derived from the regression of the dependent variable (see Table V) on the sum of the central, lateral incisors and x-ray values of first and second premolars for subsample C (above) a table was developed for the range of the independent variables given in Hixon and Oldfather's table. For each predicted value a onesided 70%, 95% and 99% confidence interval was calculated using the standard error about the regression line ($S_{y.x}$):

$$S_{y.x} = \sqrt{\text{Mean Square Residual}}$$

The formula used to calculate the standard error of each predicted value was:

$$S_{\hat{y}} = S_{y.x} \sqrt{1 + \frac{1}{N} + \frac{(x - \bar{x})^2}{(n-1)S_x^2}}$$

Confidence intervals were calculated only to include values

above the predicted value at the 70%, 95% and 99% probability

levels, i.e., a one-tailed t_{n-2} was used. Confidence

interval for $\hat{y} = \left[(t_{n-2}) \quad (S\hat{y}) \right]$.

8) Anterior crowding change in transition from mixed dentition

was correlated with amount of leeway space.

FINDINGS

The results of the analysis of the data are contained in Tables I through XII, histograms appear in figures 1-7 and scattergrams, figures 8-17.

Table I contains the standard error of the measure for the various groups of measurements. Measurement error was very similar between x-ray and cast measurements, ranging from .09 mm to 0.13 mm for x-rays and 0.09 to 0.12 mm for cast measurements. Cast measurements for space available ranged from 0.15 to 0.26 mm.

Table II lists Pearson's correlation coefficients of the actual values of the sum of the permanent canine, first and second premolars with their predicted values obtained by each of the three mixed dentition analyses: Hixon-Oldfather's, Moyers' and Tanaka-Johnston's. In sample one, correlations for Hixon-Oldfather's method ranged from .865 to .899 and were consistently higher than those for Moyers' analysis which ranged from .563 to .659 and Tanaka-Johnston's which had a similar range, .522 to .678. In sample two, correlations had

a far greater variability. Hixon-Oldfather's ranged from .595 to .821, Moyers' from .290 to .843 and Tanaka-Johnston's from .292 to .831.

Paired t-tests between the actual values of the sum of the permanent canine, first and second premolars and their predicted values are tabulated in Table III. Mean differences, standard deviations and t-values, in general, are less for Sample I than for Sample II. The only non-significant differences are found in Hixon-Oldfather's analysis of the left sides of females and the right sides of sexes combined in Sample I. Except for the right side of females, all of the mean differences by Hixon-Oldfather's method are positive indicating that, on the average, the Hixon-Oldfather method in Sample I underpredicted while in Sample II, it overpredicted, as did Moyers' and Tanaka-Johnston's methods in Samples I and II. This is shown by negative values. Moyers' method showed larger negative differences from the 65% through to the 95% probability level. Tanaka-Johnston's values fall between Moyers' 65% and 75% probability levels being closer to the 75%

level. In comparing the three methods with t-tests, the Hixon-Oldfather's mean differences, except for female right sides, were significantly different from those of the other methods in Sample I. In Sample II Hixon-Oldfather's mean differences were not significantly different from those of the other methods.

Table IV gives the results for Sample I of unpaired t-tests comparing the subsample differences between actual and predicted values by Hixon-Oldfather's method. The only significant t-values were found comparing female right to female left sides, and female right to male right sides. The female right-left difference was small and was only significant at .05 level, while the female versus male right sides were significant at .01 level. Female right sides were the only subsample where the predicted values were, on the average, larger than the actual values. There is no clear reason why this was so, except a possible random inconsistency in the data. It was, therefore, considered that since the males showed no difference by sides and the left sides showed no difference by sex, that sexes and sides could be analyzed together.

Regression analysis was used to find the best set of predictor variables for these data. Table V contains a list of the dependent and independent variables used in generating single linear and multiple regressions in this study. In the multiple regressions all the independent variables were allowed to enter. The single regression refers to regressions using the sum of the Hixon-Oldfather variables as the independent variable except where indicated.

Tables VI to IX contain the results for Sample I.

Table VI presents the findings for individuals with all variables on both sides. The dependent variable was regressed on all independent variables which, irrespective of side, were allowed into the regression to predict either side. This resulted in left variables entering to predict right sides and right variables entering to predict left sides. The highest multiple R 's⁽¹⁾ were found to be .964 on the right and .962 on the left. The single regression produced an R ⁽²⁾ of .933 for the right and .900 for the left. When

⁽¹⁾ Multiple R = Highest significant multiple correlation coefficient from multiple regressions.

⁽²⁾ R = Single correlation coefficient from single regressions.

Huckaba's corrected values were substituted for the x-ray measurements of the premolars, the regressions were not improved. The R's were .91 for the right and .89 for the left. Huckaba's independent variables were therefore discarded from further regressions, allowing for more individuals to be included. The mean square residuals were smallest for the multiple regressions, .104 for the right and .121 for the left, and were greatest for the single regression with the Huckaba modification, .246 on the right and .308 on the left. (The mean square residual indicates the scatter and precision about the regression line, in this case, the prediction line.)

In Table VII multiple regressions showed higher correlations over the single regressions in all subsamples but these were not significantly different. Between the subsamples no consistent pattern of entry of the independent variables into the multiple regressions occurred. A comparison of the males with females revealed significant differences between male right compared to female right sides for the single regression. However, the R's

were close, .900 for females and .886 for males. In all subsamples the mean square residuals were less for the multiple regressions than the single regressions.

Table VIII contains the results of the regressions for right and left side subsamples with sexes combined. Higher multiple R's were obtained compared to those from the single regressions: on the right side .897 for the multiple regression and .879 for the single regression, and on the left side .921 and .883 respectively. The mean square residuals were smaller for the multiple than the single regression for both sides. However, significance tests revealed no significant differences between multiple and single regressions or between sides.

Table IX contains regression results with sexes and sides combined. A higher correlation coefficient was found for the multiple regression, .900, compared to the single regression, .889, and smaller mean square residual, .280, compared to .312. The multiple regression accounted for 82% of the variation, while the single regression accounted for only 78% of the variation. A

significant difference was found between the two regressions but these differences were not large and not considered of practical importance. The regression formula for the multiple regression of this subsample was:

$$Y = 1.345 + \overset{b_1}{(1.71)} XSP + \overset{b_2}{(.967)} XFP + \overset{b_3}{(.533)} CCI + \overset{b_4}{(.489)} CLI$$

$b_1 - b_4$ indicate the weight of the various independent variables in the regression formula. For XSP its weight is 1.71, almost twice .967 for the XFP, while $b_3 + b_4$ are still smaller, .533 for CCI and .489 for CLI. The regression formula for the single regression of the sum of Hixon-Oldfather variables is:

$$Y = -1.803 + .850(\text{Hxol Sum})$$

Figures 1 to 7 are histograms of the frequency distributions of the millimeter differences between the actual and predicted values by the different mixed dentition analyses for Sample I subsample with sexes and sides combined. The histograms reveal that the Hixon-Oldfather method consistently underestimates and Moyers and Tanaka-Johnston methods consistently overestimate the size of the unerupted canine, first and second premolars. The

frequency distribution of Moyers' 75% probability level and Tanaka-Johnston's were very similar. Moyers' 65% level overestimated the least of the Moyers' levels. The regression method from the present study overestimated 61.9% of the individuals in Sample I in comparison with the Hixon-Oldfather method which underestimated 58.1% of the individuals. The Moyers' 95% probability level overestimated 98.1% of cases, the 85% level - 93.3%, the 75% level - 83.3%, 65% level - 75.2% and Tanaka-Johnston's 81.1%.

Figures 8 - 12 are scattergrams of the actual and predicted values for the same subsample. Figure 8 shows the actual values and Hixon-Oldfather's predicted values produced a correlation coefficient of .888. Figure 9 shows a scattergram of Moyers' 95% probability level. The correlation coefficient here was only .615 and there is a lot more scatter and less of a linear relationship than seen with Hixon-Oldfather's method. Figure 10 represents the scatter of individuals with the Tanaka-Johnston method. It is quite similar to Moyers' 95% level except for the values. Figures 11 & 12 are scattergrams using the predicted values obtained from the single

and multiple regressions for the present study. The multiple regression (Figure 12) appeared to have slightly less scatter.

Tables X to XII and Figures 13 - 17 contain results of Sample II data analyses.

In Table X the multiple regression results in a higher correlation than the single regression in all subsamples but male lefts where the correlation coefficients were equal at .82. The only significant difference was found for the single regression between female and male lefts: R 's were respectively .800 and .819 and mean square residuals 1.04 and .466. There was a larger range of R 's, mean square residuals and F values than in Sample I. The range for correlation coefficients was .605 to .856 for the multiple regression and .591 to .819 for the single regression. The mean square residuals corresponded with R 's generally except with female lefts in the single regression, where there was a high R , .800, and a high mean square residual 1.04. In all the other subsamples a high R gave a low mean square residual. The wider range for all these measurements is most likely due to the smaller sample sizes.

Regression results for sexes combined, are tabulated in Table XI. As observed previously, multiple regressions produced significantly higher correlations and lower mean square residuals than the single regression on the left side, but on the right side there was no difference. However, once again no consistent pattern of entry of independent variables was apparent. The R's and mean square residuals appeared noticeably better for the left compared to the right side but no statistical difference was found between sides. The multiple R was .831 compared to .811 for the single regression and mean square residuals of .697 and .746 respectively. There, however, was not a large difference between either R's or mean square residuals.

Table XII contains multiple regression results with sexes and sides combined. The multiple R was .735 compared to .661 for the single regression. The mean square residuals were respectively .853 and 1.01. The regressions were significantly different at the .05 level, but there was little practical difference.

Figure 13 shows a scattergram with a rather poor linear relationship for the Hixon-Oldfather analysis with a correlation

coefficient of .663. There is a lot of scatter with the presence of outliers. Figure 14 is of Tanaka-Johnston's method which is not noticeably dissimilar from Hixon-Oldfather's. It is fairly similar to the scattergram done of Sample I individuals with Tanaka-Johnston's method. Figure 15, a scattergram of individuals from Moyers' 95% probability level is very similar to that of Tanaka-Johnston's. Figure 16 shows the scattergram of the multiple regression from the present study with a correlation coefficient of .74. Figure 17 shows a scattergram using the single regression with a correlation coefficient of .66 . It does not appear to be as good a linear relationship as found with the multiple regression.

Anterior crowding change from the mixed dentition to the permanent dentition was found to have a very low correlation with the amount of leeway space, a correlation coefficient of $-.027$ was calculated from the present data.

DISCUSSION

The results of this study indicate that the Hixon-Oldfather analysis, in comparison with Moyers' and Tanaka-Johnston's methods, was the most accurate method for predicting the size of the unerupted permanent canine, first and second premolars. The Hixon-Oldfather analysis produced correlation coefficients that were consistently higher (Table II) and differences between actual and predicted values (Table III) that were significantly lower than those obtained by Moyers' and Tanaka-Johnston's methods. The scattergrams (Figures 8-10) denoted greater precision of the scatter of individuals with the Hixon-Oldfather analysis indicating the superiority of the prediction. The correlation coefficients for the Hixon-Oldfather method had a narrow range (.865-.899) which compared favorably with Hixon and Oldfather's $r = .88$. No differences in correlations occurred between males and females, in contrast to Stahle who found a significant sex difference: .89 for males and .76 for females. In agreement with Moyers, this study found that the Hixon-Oldfather method more frequently underpredicts the size of the permanent

successors; only female right sides were overpredicted in size (Table IV). Tanaka-Johnston and Moyers' 65% through 95% levels consistently overpredicted the size of the permanent successors. The Moyers' 95% level overpredicted the size of the successors in 98% of cases. This accounts for the fact that the mean differences were greatest for the Moyers' 95% level. At the 65% level the size of successors were less than the predicted value only 74% of the time. Tanaka-Johnston's method overpredicted in 83% of the cases. The histogram results of Hixon-Oldfather's method confirm Moyers' finding. He indicated that 75% of the time it underpredicted, but in the present study, the Hixon-Oldfather method was found to underpredict only in 58% of cases.

In sample II the Hixon-Oldfather method did not produce a more accurate prediction compared to the other methods. The main factor believed important here was the large amount of x-ray distortion on the panoramic radiographs. Sample size was also a factor; with a small sample, a greater variability exists and this is evidenced in the wide range of the correlations. The reason for the Hixon-Oldfather

method generally overpredicting in Sample II can be attributed to x-ray enlargement. The scattergrams for all three methods have similar patterns. The use of panoramic x-rays with the Hixon-Oldfather method is, therefore, of no value.

Several findings resulted from using the data to generate multiple and single regressions in an attempt to improve the accuracy of the prediction. A multiple regression was done employing Huckaba's corrected values for the first and second premolars in an effort to improve prediction efficiency. In all subsamples the correlation coefficients in which the Huckaba corrections were substituted were less and the mean square residuals were greater than the comparable regressions using the standard Hixon-Oldfather variables. Consequently, the Huckaba modifications were discarded. A possible explanation may be the increased measurement error with the Huckaba modification, which involves three different measurements to calculate the corrected values.

When all the independent variables were allowed to enter for individuals with data on both sides (Table VI), left-side variables

entered to predict right sides and right-side variables entered to predict left sides. This could possibly result from actual differences due to measurement error or distortion of x-rays being greater on one side, coupled with the high correlation of bilateral tooth size. The result is not considered spurious but a function of contralateral differences in the data.

When the differences between actual and predicted values by Hixon-Oldfather's method were compared by sex and side, the only significant differences were found to be between right and left sides for females and between male and female right sides. As mentioned, the female right sides were the only subsample where the Hixon-Oldfather method overpredicted the size of the permanent successors. An explanation for this was not readily apparent but the female right and left side differences were both close to zero and the difference between the sides was only 0.2 mm. The female right side was considered anomalous and since males did not have differences and male and female left sides were not different, sexes and sides were combined.

Sex and side differences were also tested by comparing multiple and single regression results for males and females by side.

Differences between single and multiple regressions were also tested.

In Sample I significant differences were found only between male right sides and female right sides for the single regression only.

However, since the R's were close, .900 for females and .885 for males, the differences are not thought to be of practical importance.

It was then decided to combine sexes and determine if there was a significant difference by side. Sides were compared for the multiple and single regression and no significant difference was found. Sides and sexes were then combined to determine which were the best prediction variables with the multiple regression and whether the multiple regression and single regression were significantly different. A significant difference between the regressions was found, but the difference was not large enough to warrant use of the multiple regression in the clinical situation.

Generally, improved correlation coefficients and mean square residuals were obtained in Sample I with the multiple regression

approach. The significant variables entering the multiple regressions for the various subsamples did not show a consistent pattern and for practical purposes, the sum of the variables used by Hixon-Oldfather are easier to use, being only one number. What the multiple regression did reveal, however, was the importance of the x-ray variables as predictors. The multiple regression formula for the combined subsample, $Y = 1.345 + 1.71 \text{ XSP} + .967 \text{ XFP} + .533 \text{ CCI} + .489 \text{ CLI}$, displays how much more significant are the x-ray over the cast measurements of the incisors. The second premolar appears to have the greatest significance, possibly because there is generally less x-ray distortion in the second premolar area, and the central incisor has more weight than the lateral incisor. In fact, Stahle suggests that it may be unnecessary to include the lateral incisor width. The importance of the x-rays explains why the Hixon-Oldfather method is superior over the other methods considered in this study.

The multiple and single regressions in this study gave slightly better results than applying Hixon and Oldfather's formula, but this is expected since the regressions were developed from this present

data, and sample as well as population differences could be anticipated.

Hixon-Oldfather's formula was:

$$Y = 3.493 + .6474 X$$

compared to single regression equation of the present data:

$$Y = -1.803 + .850 X$$

which accounts for the different estimated values.

The histogram of the single regression from the present study showed a more desirable overprediction of 61.0% compared to Hixon-Oldfather's of 58.1% underprediction. The scattergrams of Sample I showed a similar scatter pattern for Hixon-Oldfather's method and the multiple and single regression methods of the present study. The multiple regression was the better of the three, indicating its slightly increased accuracy.

In Sample II, when testing for sex and side differences by comparing regression equations for males and females, a significant difference was found for the single regression with male left sides to female left sides (Table X). Correlation coefficients were very close though, .800 for females and .819 for males, so, there was

little practical difference. Sexes were combined and sides were compared for significant differences. There appeared to be a large difference between the sides but due to the small sample size and wide variability the regressions were not significantly different. When sexes and sides were combined, a small significant difference was found between the multiple and single regressions. Generally, improved correlations were obtained with the multiple regression, but like Sample I, no consistent pattern of independent variable entry existed. However, unlike Sample I, x-ray variables did not always enter the multiple regression. The scattergrams (Figures 13-17) were all very similar in Sample II. The one with the least scatter and highest correlation was the multiple regression, as mentioned in the previous discussion.

Underprediction, one of the main criticisms of the Hixon-Oldfather method, can, for practical purposes, be eliminated by adding confidence intervals for each estimated value to include individuals with larger teeth at various levels of probability. Hixon-Oldfather, in their paper, included the standard error of

the estimated value ($S \hat{y}$) which apparently was derived for only the mean value of the independent variable. However, Sokal and Rohlf²⁴ point out that the variability about the regression line, is, in part, a function of the distance of a given value from its mean.

TABLE XIII

Combined Sexes and Sides (n = 93)

Measured Sum	Estimated Value		Confidence Intervals					
	Hxol	Present Study	Hxol 68%	Hxol 95%	Hxol 99%	Present Study 70%	Present Study 95%	Present Study 99%
23mm	18.4	17.8	+ 0.6	+ 1.1	+ 1.7	+ .31	+ .98	+ 1.40
24mm	19.0	18.6	all levels	all levels	all levels	+ .30	+ .96	+ 1.37
25mm	19.7	19.5				+ .298	+ .94	+ 1.35
26mm	20.3	20.3				+ .297	+ .94	+ 1.34
27mm	21.0	21.2				+ .29	+ .93	+ 1.33
28mm	21.6	22.0				+ .298	+ .94	+ 1.34
29mm	22.3	22.9				+ .30	+ .95	+ 1.35
30mm	22.9	23.7				+ .30	+ .960	+ 1.37

For the present study:

$$\bar{X} = 26.97$$

$$S^2_x = 1.60$$

$$S_{y.x} = .558$$

$$S \hat{y} = S_{y.x} \sqrt{1 + \frac{1}{n} + \frac{(x - \bar{x})^2}{(n-1)S^2_x}}$$

$$S \hat{y} = .558 \sqrt{1 + \frac{1}{93} + \frac{(x - 26.97)^2}{(92)(1.60)}}$$

Table XIII shows estimated values obtained by Hixon and Oldfather and by the present study and the confidence intervals for the various independent variables. Hixon and Oldfather only presented one value

at 68%, 95% and 99% confidence levels. In this study, the standard error about the regression line ($S_{y \cdot x}$) was used to calculate the standard error for each estimated value ($S_{\hat{y}}$). The smallest standard error of the estimated values was that for 27 mm because this value was closed to the mean (26.97 mm). The one tail 70% confidence interval for the 27 mm value was +.29 mm, 95% confidence interval was +.93 mm, and the 99% was +1.34 mm. The largest confidence interval was +.31 mm at 70%; +.98 mm at the 95% and +1.40 mm at the 99% interval. These came at the lower end of the range of independent variables. At the 30 mm value the 70% interval was +.30 mm, the 95% interval was +.967 mm and at the 99% confidence interval it was +1.372 mm. The measured Hixon-Oldfather variables for the present sample had a mean of 26.97 mm which was almost identical to Hixon and Oldfather's sample mean of 26.98 mm suggesting close sample resemblance.

In the present study there appeared to be no correlation between anterior crowding change from the mixed to permanent dentition and the amount of leeway space. This indicates that in the natural

development of the dentition, lower anterior crowding does not undergo any decrease by utilizing leeway space.

SUMMARY AND CONCLUSIONS

This study attempted to compare Hixon-Oldfather's, Moyers' and Tanaka-Johnston's methods of predicting the size of the unerupted mandibular permanent canine, first and second premolars. The data were obtained from periapical radiographs and study models of 105 individuals (52 females and 53 males) from the longitudinal growth study conducted by the Child Study Clinic, School of Dentistry, University of Oregon Health Sciences Center, Portland, Oregon. A second sample of 31 subjects (17 females and 14 males) was obtained from the Swift Current Health Region Clinic, Swift Current, Saskatchewan, Canada. This sample had study models and panoramic radiographs. The records were analyzed to see if measurements of the unerupted premolars from the panoramic radiographs could be usable in the Hixon-Oldfather analysis. The data were analyzed using Pearson's product moment correlation coefficients, paired and unpaired t tests and multiple and simple linear regressions.

The following conclusions are drawn from the findings of this

investigation:

1. The Hixon-Oldfather mixed dentition analysis had superior accuracy of prediction over the two other methods.
2. The Hixon-Oldfather method generally underpredicts the size of the permanent successors. This problem can be eliminated by adding to the estimated value the appropriate confidence interval. In this way individuals with actual values at the high end of the distribution are included. This is the same method used by Moyers in employing different probability levels. In fact this study found that Moyers' method increasingly overpredicts the actual values from the 65% through to the 95% level of probability.
3. Tanaka-Johnston's method is as accurate as Moyers' 75% level and clinically more practical to use .
4. Regression analysis produced improved predictions compared to Hixon and Oldfather's method.
5. Corrected values of the unerupted premolars by Huckaba's method, which were substituted in the single regression, did not improve

the prediction efficiency.

6. Multiple regressions in general gave superior results to the single regression. However, the difference between the multiple and single regressions did not warrant clinical application of the more complex multiple regression formula. In addition no consistent pattern of entry of independent variables into the multiple regressions occurred for the various subsamples.
7. The multiple regression equation, $Y = 1.345 + 1.71 \text{ XSP} + .967 \text{ XFP} + .533 \text{ CCI} + .489 \text{ CLI}$, indicated the importance of the x-ray variables as predictors. The second premolar was more important than the first premolar probably because of less x-ray distortion in that region. The central incisor was more important than the lateral incisor. Inclusion of x-ray variables is considered to be the primary reason for the superiority of the Hixon-Oldfather method over the other two analyses.
8. The importance of minimal x-ray distortion is further emphasized by the finding that the Hixon-Oldfather method using measurements from the panoramic radiographs was not any better than the two

other methods. Panoramic radiographs are, therefore, of no value for use in the Hixon-Oldfather analysis.

9. No systematic sex or side differences were apparent in the study. The difference between sides in females and between male and female right sides is thought to be a function of the data.
10. Lower anterior crowding change during the development of the dentition was not related to available leeway space.

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FREQUENCY

SAMPLE I

n= 105

Sexes Combined
Either Side

20

15

10

5

< -2.0 -1.75 -1.50 -1.25 -1.00 -.75 -.50 -.25 0 .25 .50 .75 1.00 1.25 1.50 1.75 <2.0

Millimeter difference between actual and predicted value by
Hixon-Oldfather's Method.

FIGURE 1

FREQUENCY - number of individuals

SAMPLE I
105 Individuals
Sexes Combined
Either Side

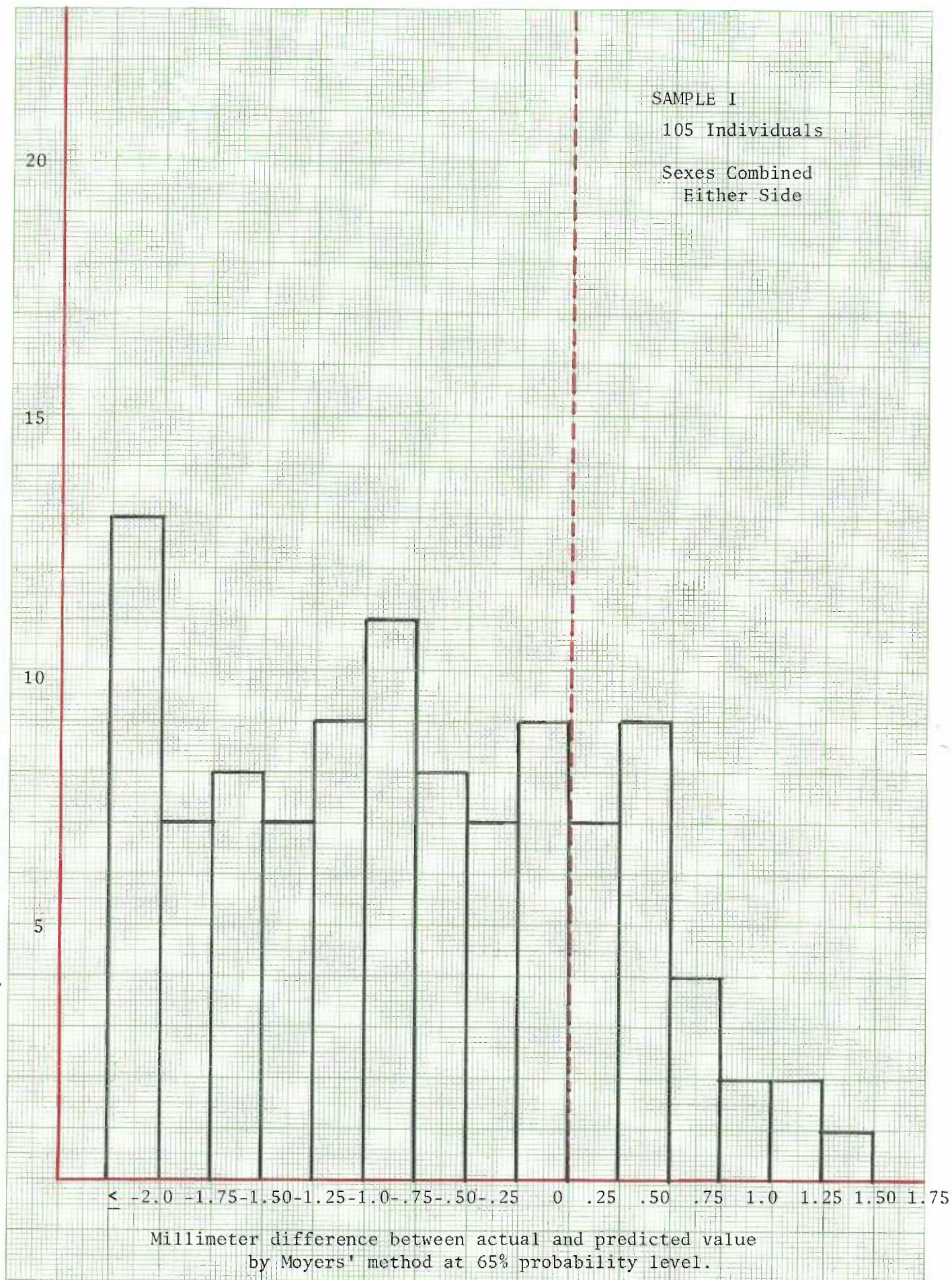


FIGURE 2

FREQUENCY

SAMPLE I

n = 105

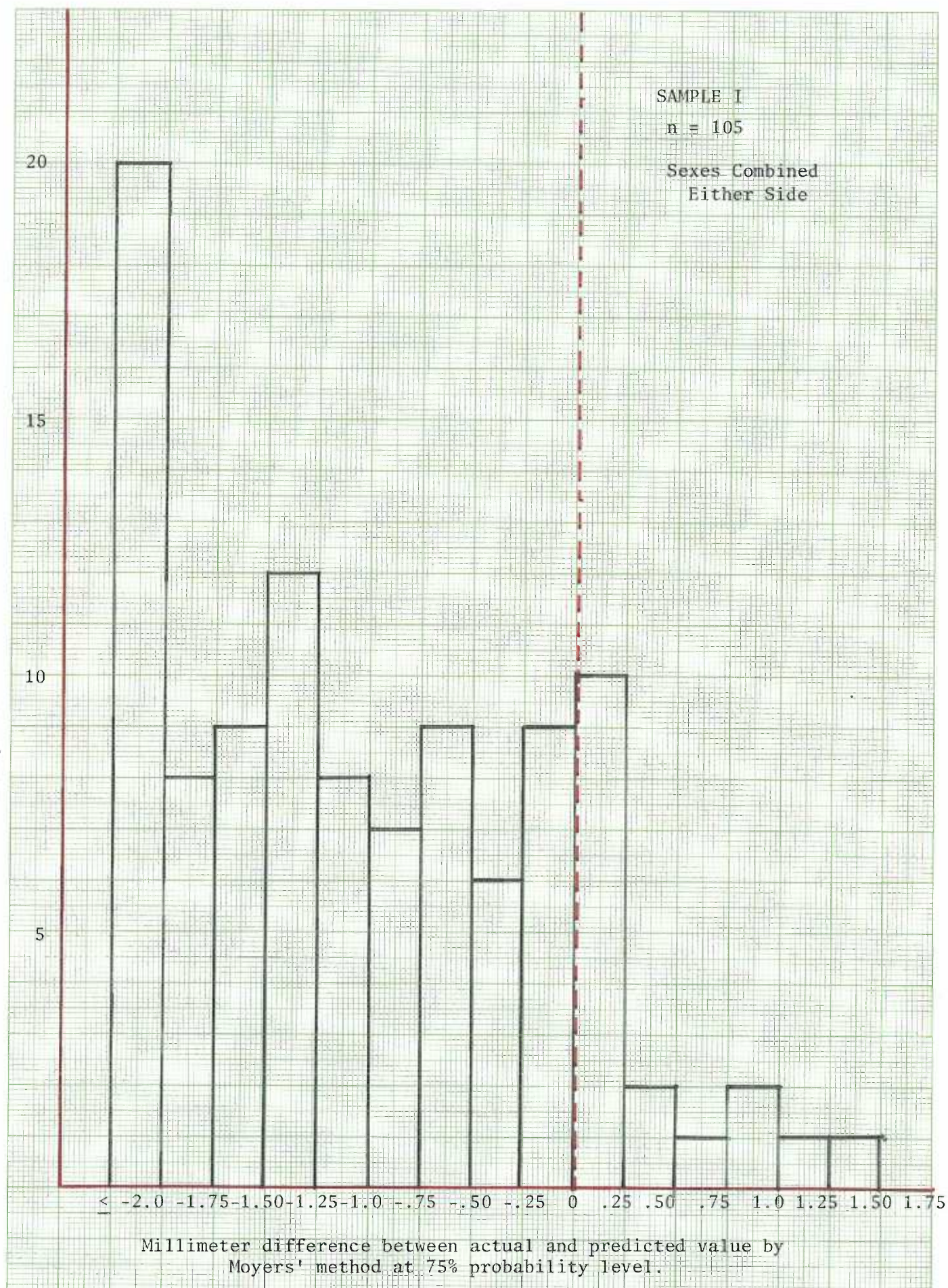
Sexes Combined
Either Side

FIGURE 3



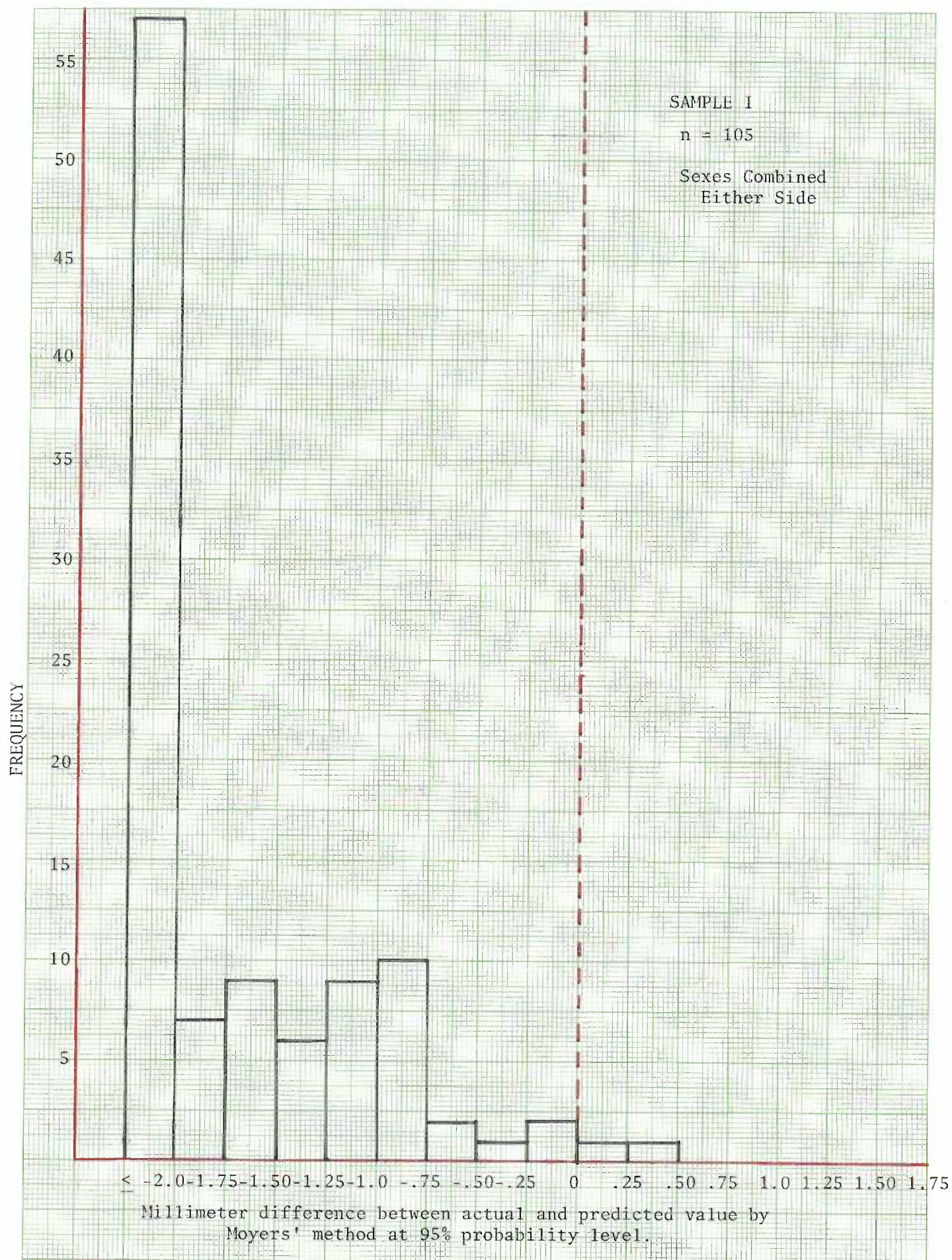


FIGURE 5

FREQUENCY - number of individuals

SAMPLE I
105 Individuals
Sexes Combined
Either Side

20

15

10

5

< -2.0 -1.75 -1.50 -1.25 -1.0 -0.75 -0.50 -0.25 0 .25 .50 .75 1.0 1.25 1.50 1.75

Millimeters difference between actual and predicted value
by Tanaka-Johnston method.

FIGURE 6

FREQUENCY

SAMPLE I

n = 105

Sexes Combined
Either Side

25

20

15

10

5

< -2.0 -1.75 -1.50 -1.25 -1.00 -0.75 -0.50 -0.25 0 .25 .50 .75 1.00 1.25 1.50 1.75

Millimeter difference between actual and predicted value
by regression formula B. (see Table IX).

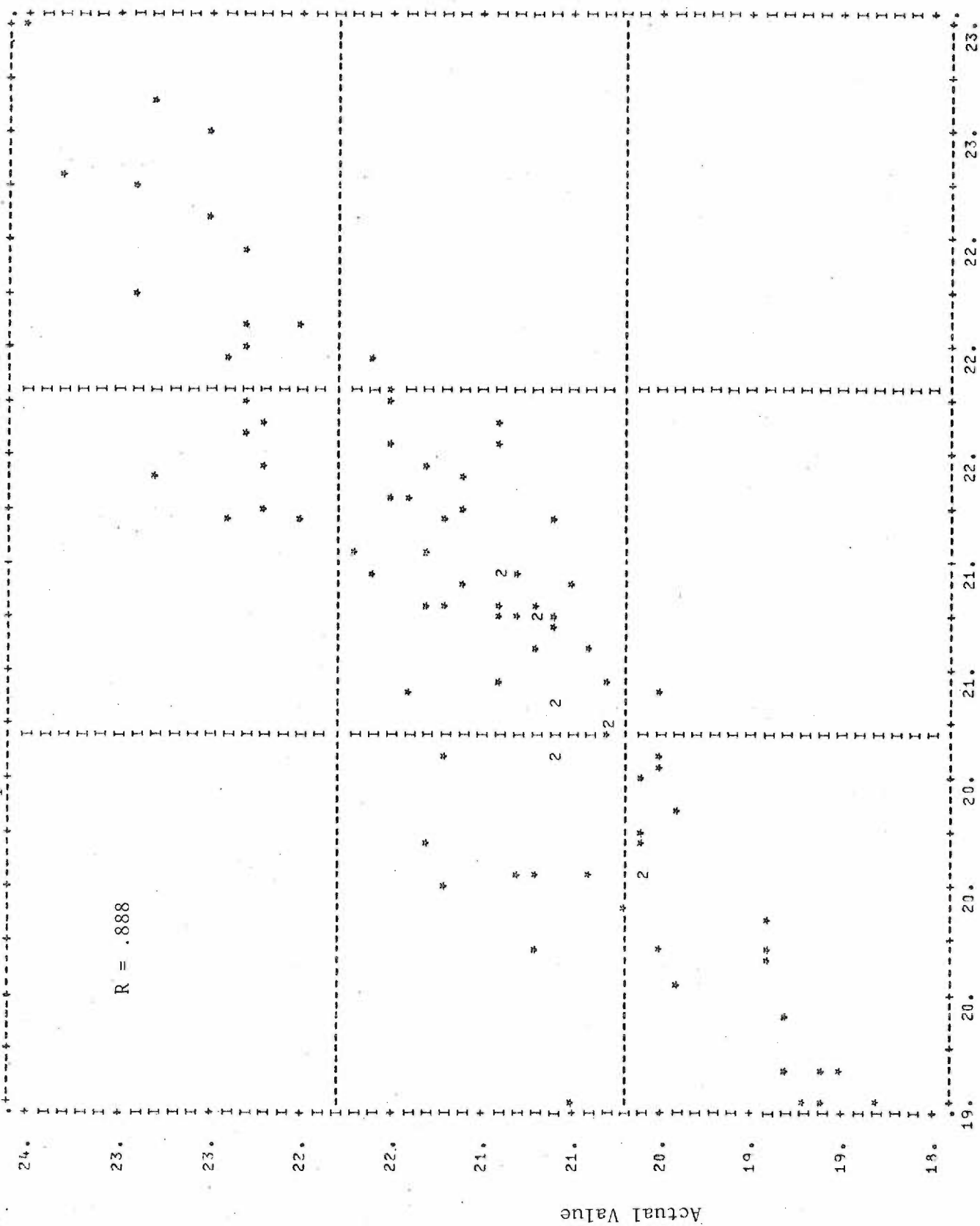
FIGURE 7

FIGURE 8

Sample I Sexes and Sides Combined n = 93

$R = .888$

FIGURE 8



Hixon-Oldfather's Predicted Value

FIGURE 9

Sample I Sexes and Sides Combined n = 105

FIGURE 9

Actual Value

R = .615

Moyers' 95% Predicted Value

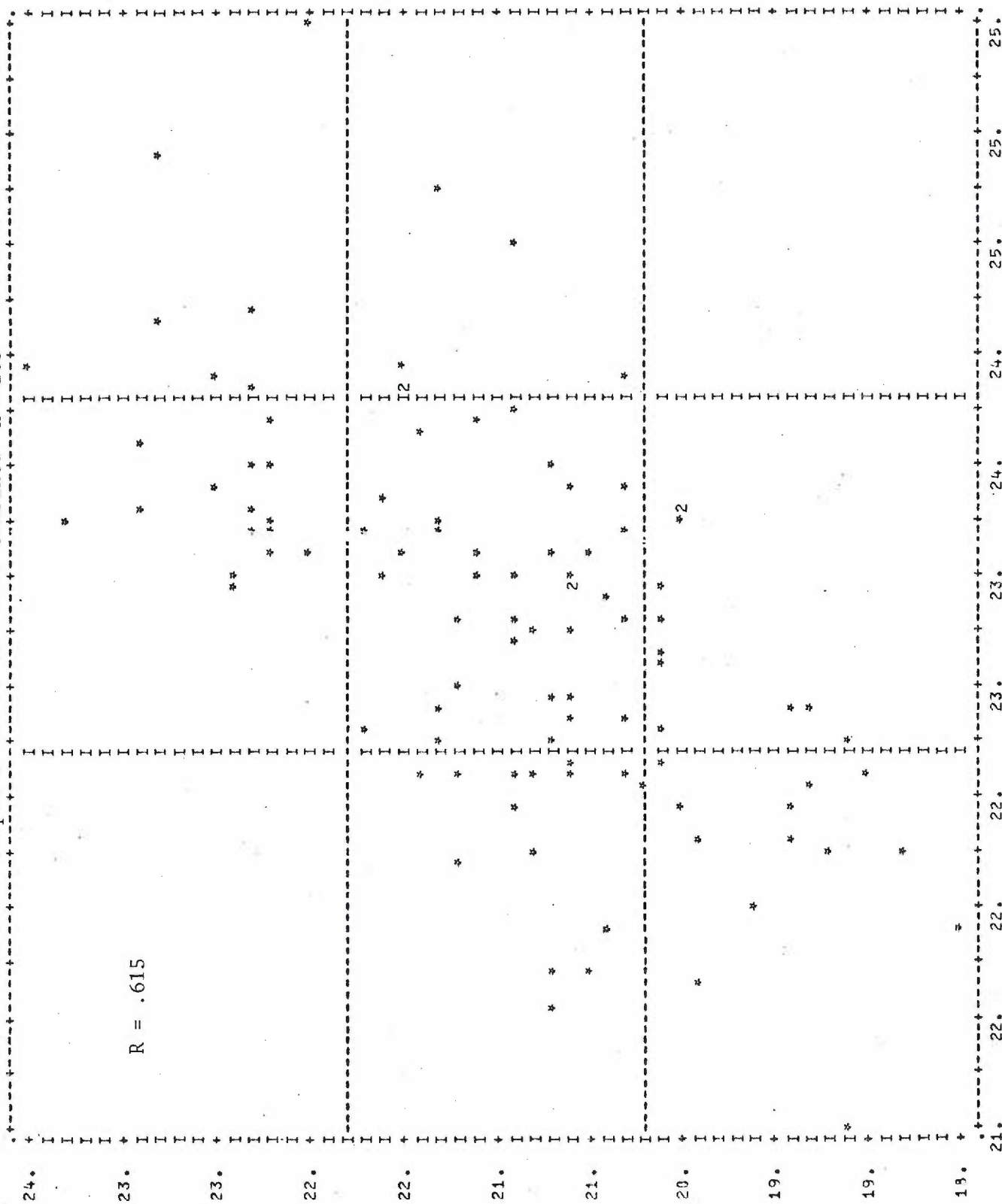


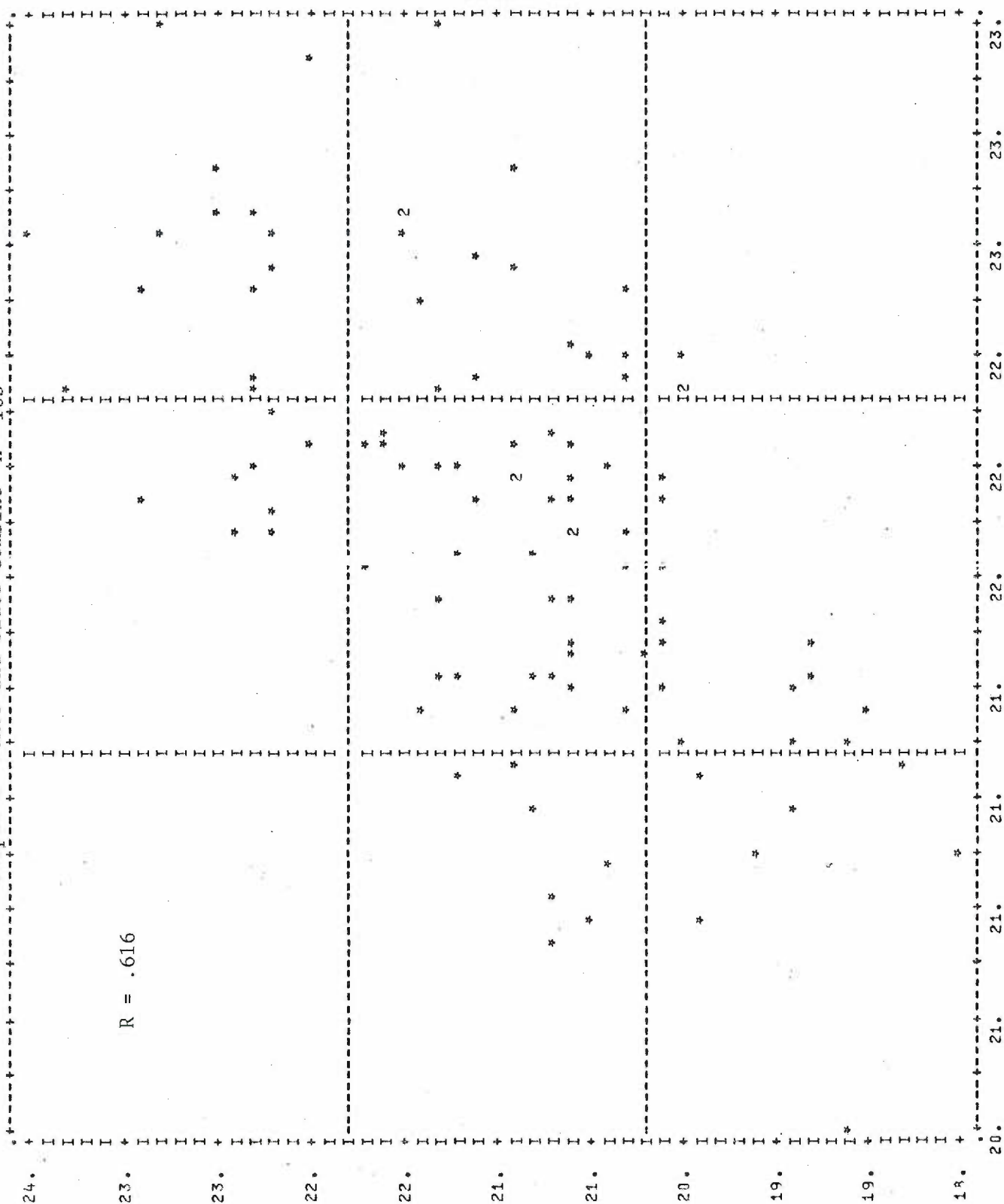
FIGURE 10

Sample I Sexes and Sides Combine n = 105

R = .616

FIGURE 10

Actual Value



Tanaka Johnston's Predicted Value

FIGURE 11

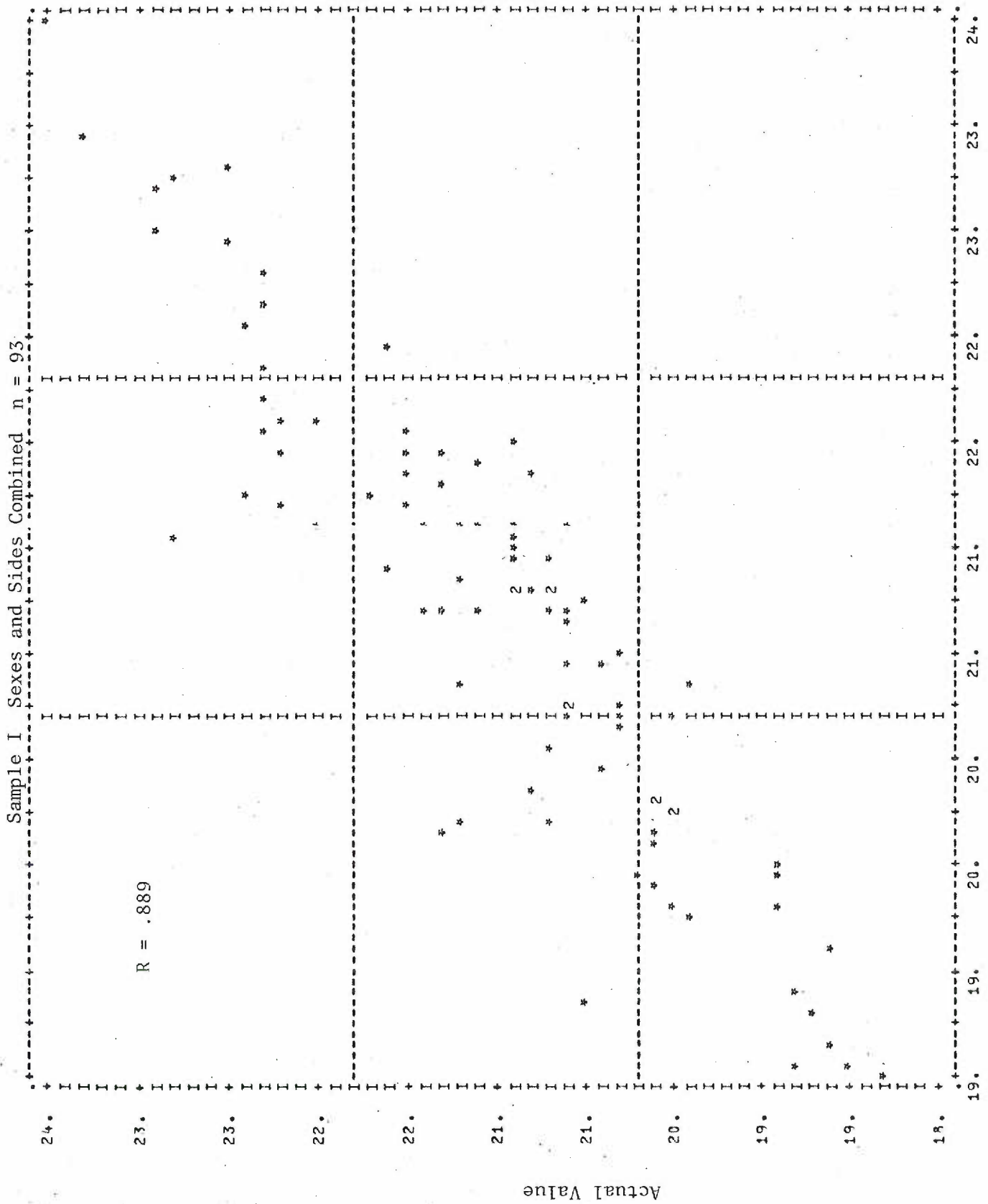
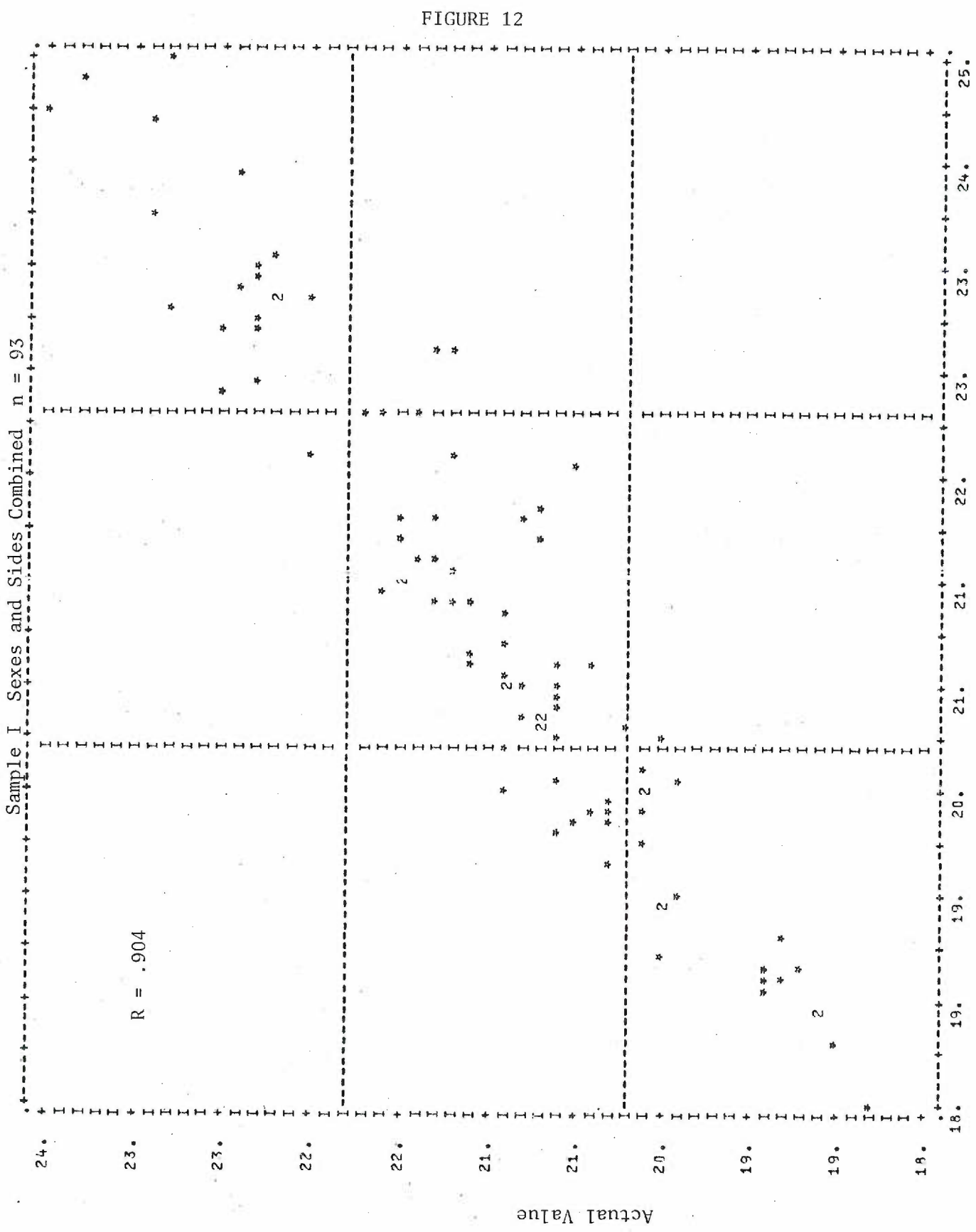
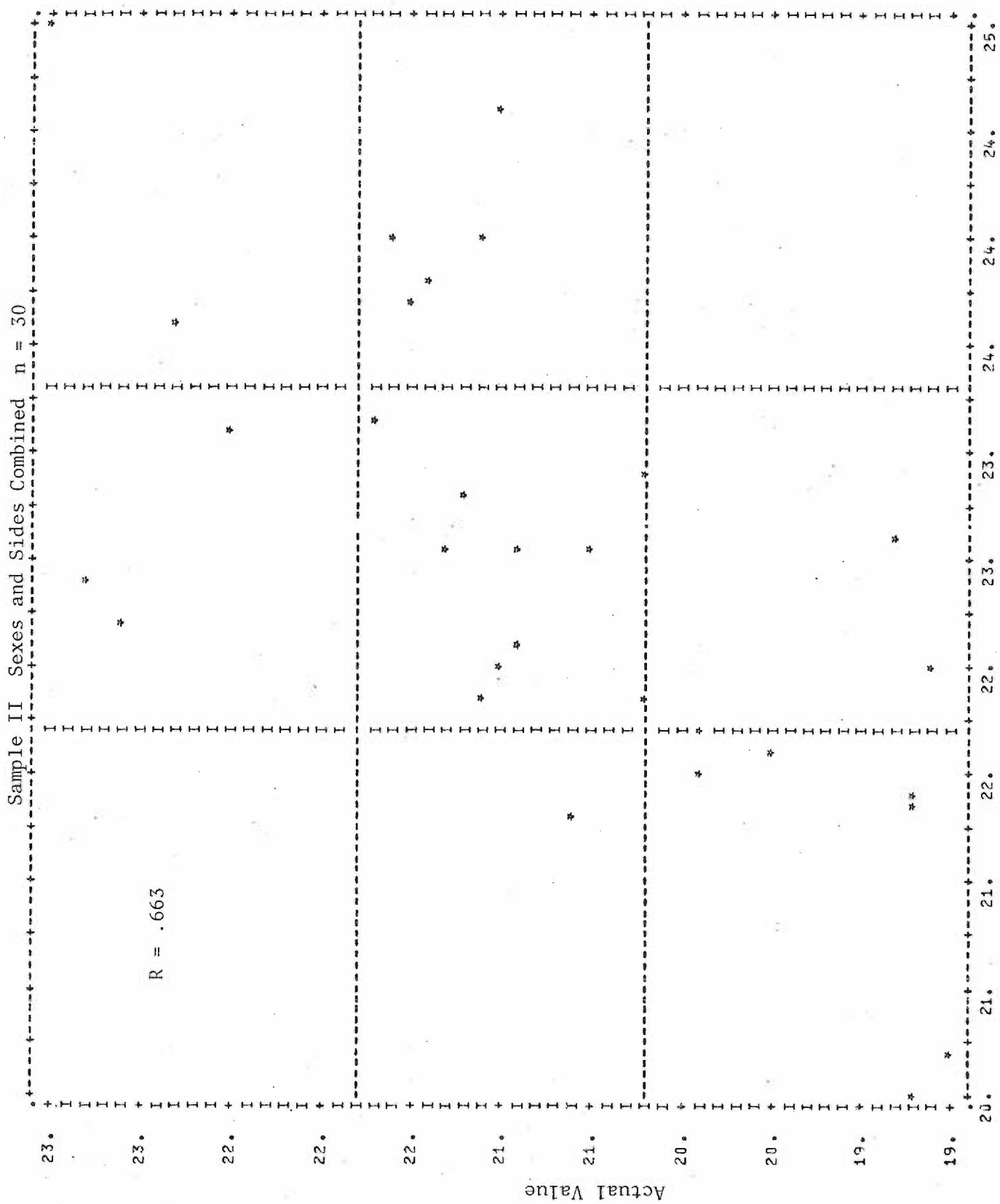


FIGURE 12



Multiple Regression's Predicted Value

FIGURE 13

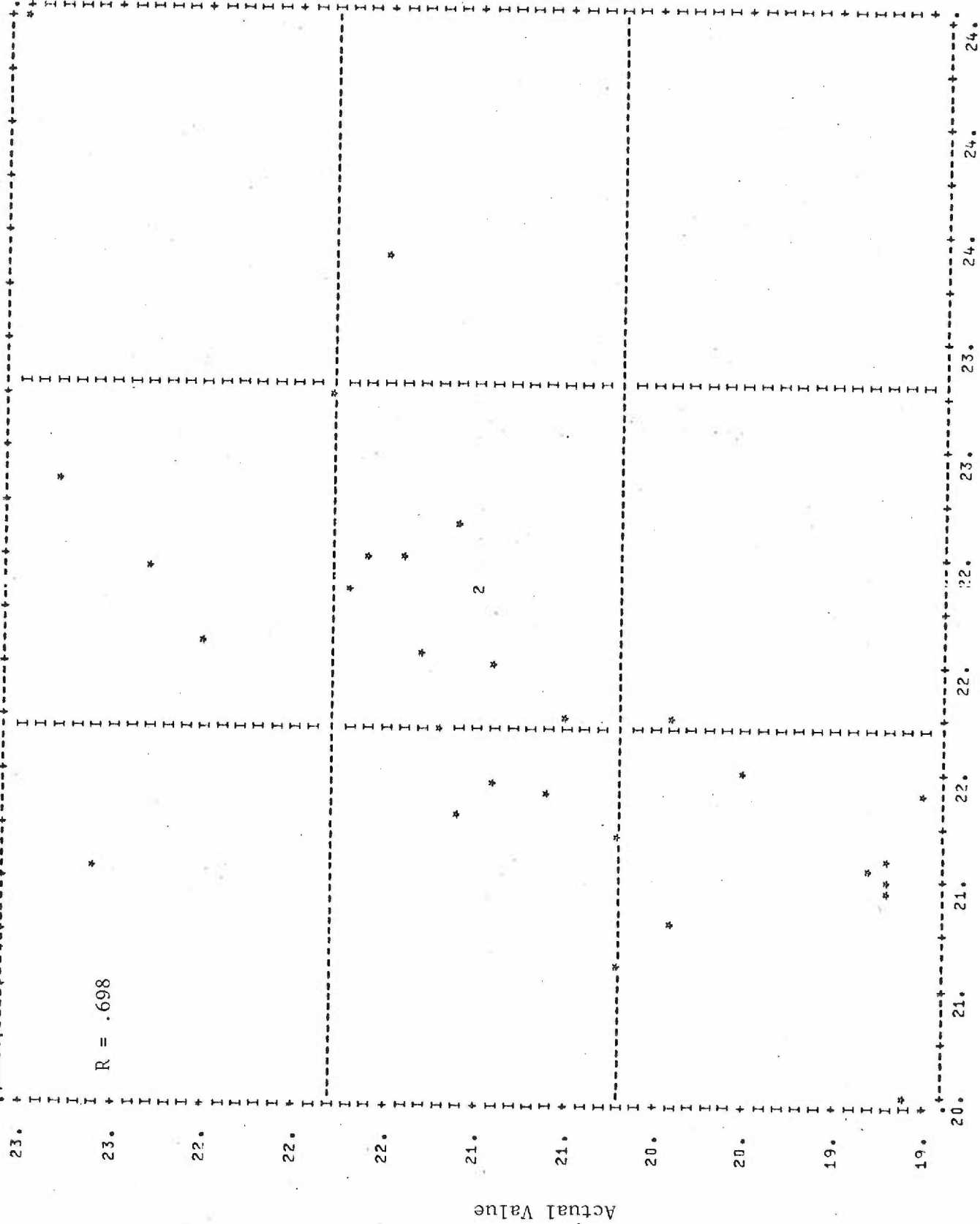


Hixon-Oldfather's Predicted Value

FIGURE 14

Sample II Sexes and Sides Combined n = 30

FIGURE 14

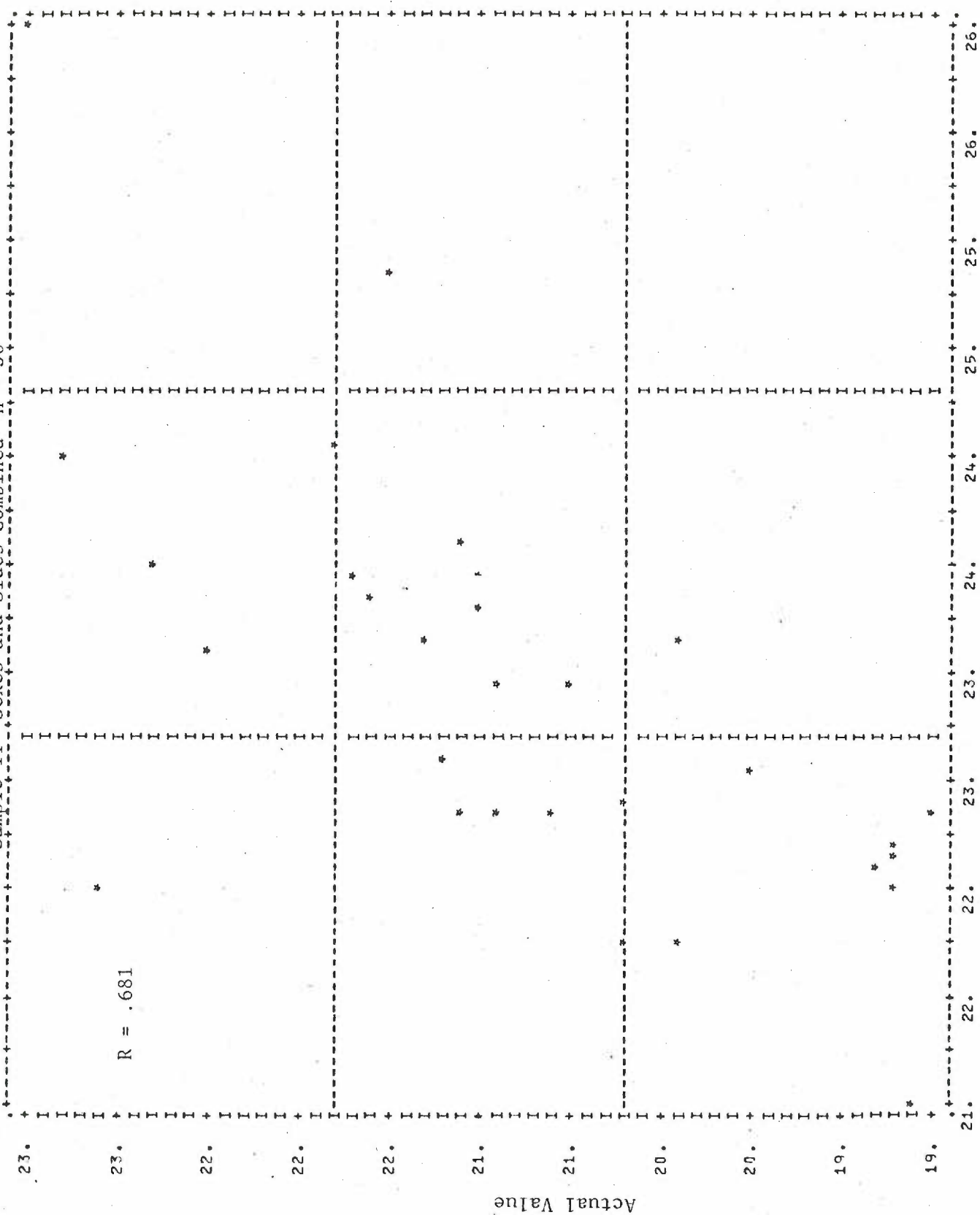


Tanaka-Johnston's Predicted Value

FIGURE 13

Sample II, Sexes and Sides Combined n = 30

FIGURE 145

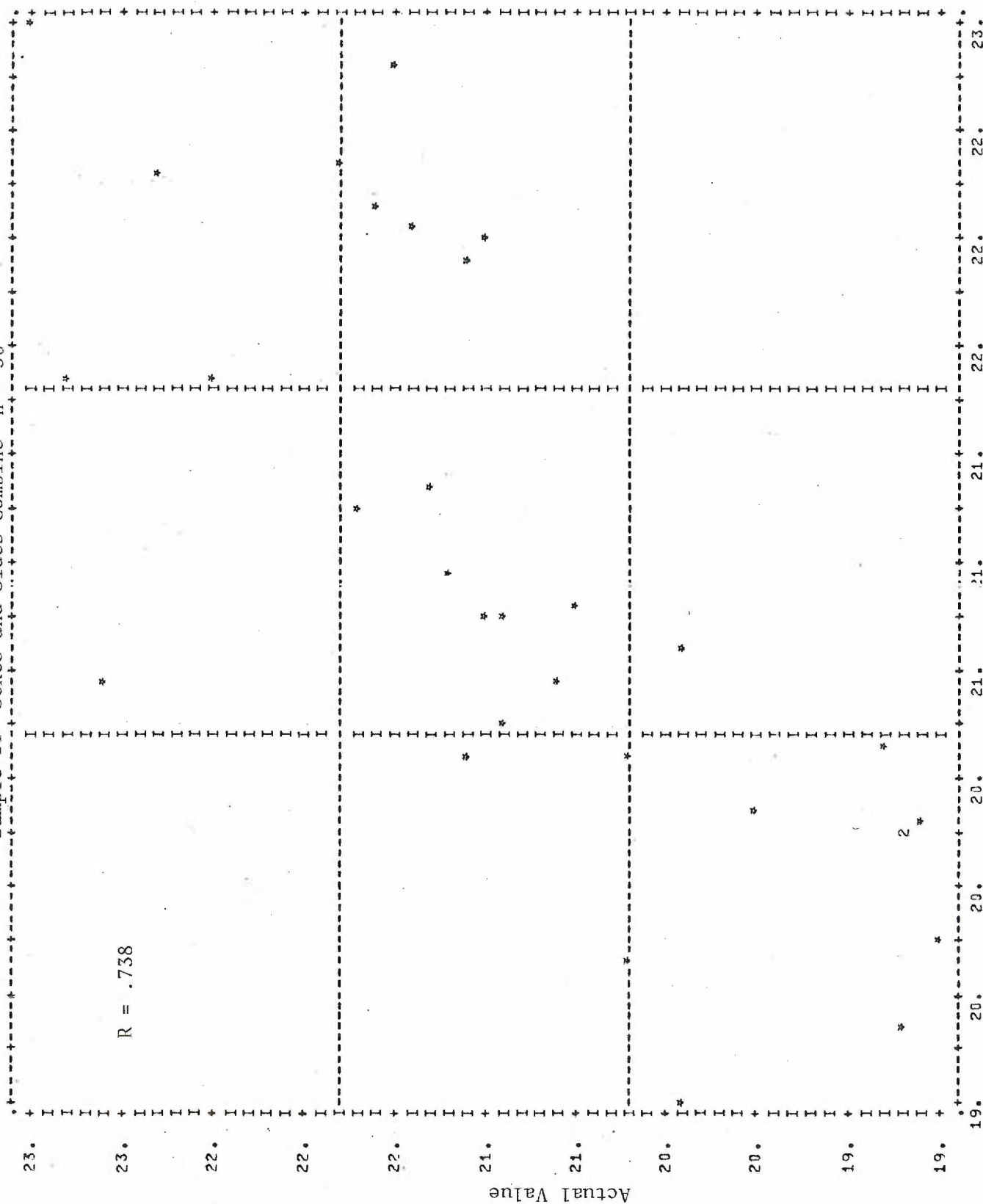


Moyers' 95% Predicted Value

FIGURE 16

Sample II Sexes and Sides Combine n = 30

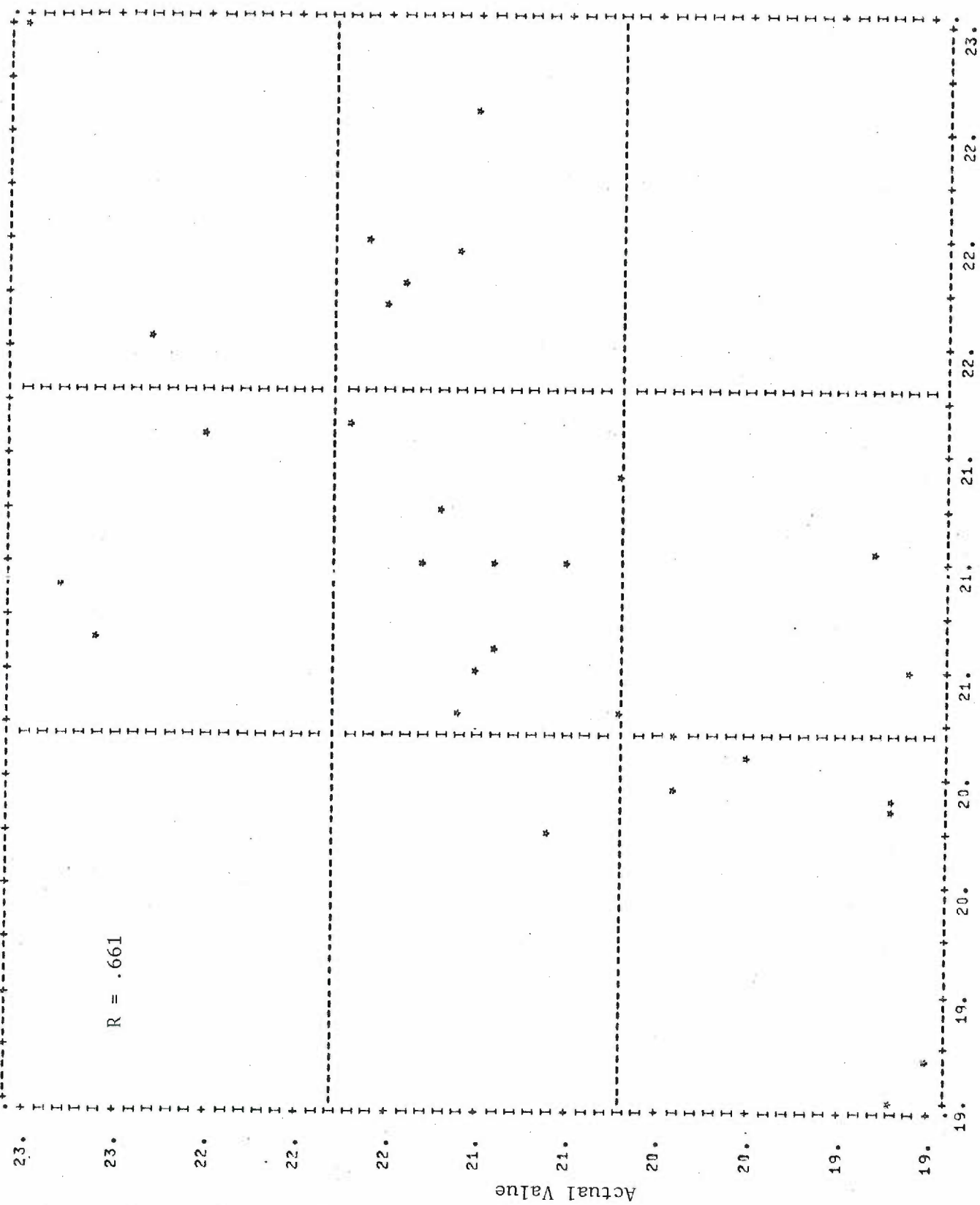
FIGURE 16



Multiple Regression's Predicted Value

Sample II Sexes and Sides Combined n = 30

FIGURE 17



Single Regression's Predicted Value

TABLE I

Standard Error of Measure for Different Groups of Measurements

MEASUREMENT	STANDARD ERROR OF MEASURE
(a) X-rays	
- first and second premolars	0.09 mm
- first and second primary molars	0.13 mm
(b) Casts	
- central and lateral incisors	0.09 mm
- canines, first and second premolars	0.10 mm
- first and second primary molars	0.12 mm
(c) Casts - anterior crowding	
- space available for central and lateral incisors during mixed dentition	0.26 mm
- space available for central and lateral incisors during permanent dentition	0.15 mm
- space occupied by primary canine, primary first and second molars	0.15 mm

TABLE II

Correlations of actual values of sum of permanent canine, first and second premolars with their predicted values by three methods.

Sample I	Hixon-Oldfather			Moyers			Tanaka-Johnston		
Subsample	n	Pearson's r	Sig	n	Pearson's r	Sig	n	Pearson's r	Sig
females	right	.899	***	46	.634	***	47	.678	***
	left	.865	***	44	.563	***	44	.522	***
	right	.885	***	49	.659	***	49	.659	***
	left	.877	***	39	.633	***	39	.608	***
males	right	.879	***	95	.626	***	96	.631	***
	left	.883	***	83	.618	***	83	.596	***
sexes combined	right								
Sample II Subsample females	right	.595	*	13	.843	***	13	.822	***
	left	.799	***	16	.807	***	16	.831	***
	right	.595	*	13	.290	NS	13	.292	NS
	left	.821	***	13	.547	NS	13	.523	NS
males	right	.583	***	26	.637	***	26	.625	***
	left	.811	***	29	.742	***	29	.754	***
sexes combined	right								
sexes combined	right								
	left								

* $p < .05$, ** $p < .01$, *** $p < .001$, NS not significant

TABLE III

SAMPLE I				HIXON OLDFATHER				MOYERS								
Sub-sample	Sides	n	$\bar{X}_d$	SD	t	Sig	65%			75%		85%				
							n	$\bar{X}_d$	t	$\bar{X}_d$	t	$\bar{X}_d$	t			
Females	right	43	-0.185	.428	-2.84	**	46	-1.184	-10.93	-1.486	-13.7	-1.884	-1			
	left	36	+0.089	.559	.95	NS	44	-1.080	-8.58	-1.380	-10.96	-1.780	-1			
Males	right	47	+0.368	.627	4.02	***	49	-0.431	-3.14	-.731	-.534	-1.131	-			
	left	33	+0.309	.678	2.62	*	39	-0.431	-2.53	-.731	-4.29	-1.131	-			
Sexes Combined	right	90	+0.104	.606	1.63	NS	95	-.795	-8.31	-1.098	-11.44	-1.495	-1			
	left	69	+0.194	.624	2.58	*	83	-.775	-7.07	-1.075	-9.81	-1.475	-1			
SAMPLE II																
Females	right	12	-1.996	1.187	-5.83	***	13	-.877	-3.75	-1.177	-5.04	-1.577	-			
	left	16	-1.722	1.010	-6.85	***	16	-1.086	-4.39	-1.388	-5.61	-1.788	-			
Males	right	12	-1.442	.919	-5.43	***	13	-.904	-3.07	-1.204	-4.09	-1.604	-			
	left	13	-1.499	.651	-8.31	***	13	-.639	-2.41	-.939	-3.55	-1.339	-			
Sexes Combined	right	24	-1.719	1.076	-2.82	***	26	-.890	-4.84	-1.19	-6.47	-1.59	-			
	left	29	-1.622	.857	-10.19	***	29	-.886	-4.85	-1.186	-6.50	-1.586	-8.64	-2.186	-11.98	.985

TABLE IV

Unpaired t-test of Sample I subsamples differences between actual values of permanent canine, first and second premolars and their predicted values by Hixon-Oldfather method.

Sample I		n	$\bar{X}_d$	Differences of $\bar{X}_d$	t values	Sig
Subsamples						
females	right	43	-0.1849	0.274	2.46	*
	left	36	+0.0889			
males	right	47	+0.3681	0.059	0.602	NS
	left	33	+0.3091			
females	right	43	-0.1849	0.553	4.84	***
vs. males	right	47	+0.3681			
females	left	36	+0.0889	0.220	1.480	NS
vs. males	left	33	+0.3091			
sexes combined	right	90	+0.1039	-0.09	.9231	NS
	left	69	+0.1942			

*p $\leq$.05, **p $\leq$.01, ***p $\leq$.001, NS not significant

TABLE V
LIST OF VARIABLES

Variable Abbreviations	Variables Entered for Multiple Regression
Dependent	
CC12	Cast measurements of permanent canine, first and second premolars
CRC12	CC12 on right side
CLC12	CC12 on left side
Independent	
CCI	Cast measurement of central incisor
CRCI	CCI on right side
CLCI	CCI on left side
CLI	Cast measurement of lateral incisor
CRLI	CLI for right side
CLLI	CLI for left side
XFP	X-ray measurement of first premolar
XRFP	XFP for right side
XLFP	XFP for left side
XSP	X-ray measurement of second premolar
XRSP	XSP for right side
XLSP	XSP for left side
Hxol Sum	Hixon-Oldfather sum of CCI, CLI, XFP and XSP
Hxol Sum R	Hxol Sum for right side
Hxol Sum L	Hxol Sum for left side
HKFP	Huckaba's corrected value for XFP
HKRFP	HKFP for the right side
HKLFP	HKFP for the left side
HKSP	Huckaba's corrected value for XSP
HKRSP	HKSP for the right side
HKLSP	HKSP for the left side
HK Sum	Sum of CCI, CLI, HKFP and HKSP
HK Sum R	HK Sum for right side
HK Sum L	HK Sum for left side

TABLE VI

Multiple and Single Regressions: Individuals with all variables on both sides

Sample I	Variables Entered	Significant Variables	Multiple R	Mean Square Residual	F	Sig
Subsamples	Side					
	N					
Sexes Combined	Right	All variables entered	.964	.104	154.720	***
	39	Hxol Sum R Hxol Sum L	.933	.183	246.670	***
	39	HK Sum R HK Sum L	.908	.246	174.726	***
Left	39	All variables entered	.962	.121	104.94	***
	39	Hxol Sum R Hxol Sum L	.900	.282	158.19	***
	39	HK Sum R HK Sum L	.894	.308	112.966	***

*** $P < .001$

TABLE VIII

Multiple and Single Regressions: Independent variables from Table V excluding Huckaba's modification variables

Sample I	Variables Entered	Significant Variables	Multiple R	Mean Square Residual	F	Sig
Subsamples						
	Sides	N				
	All Right Sides	90				
	All Left Sides	69				
Sexes Combined	All right side variables		.897	.289	117.41	***
	Hxol Sum R		.879	.326	299.94	***
	All left side variables		.921	.245	27.56	***
	Hxol Sum L		.883	.347	236.42	***

*** $p < .001$

TABLE IX

Multiple and Single Regressions: Combined sexes and sides: Right sides from individuals with measurements only on right side, left sides from individuals with measurements only on left side and for individuals with both sides one side was randomly selected.

Sample I	Variables Entered	Significant Variables	Multiple R	Mean Square Residual	F	Sig	Regression Formulae
Subsamples	N						
	93	All variables (except Huckaba)	.904	.280	98.32	***	(A)
	93	Hxol Sum	.889	.312	341.01	***	(B)

Sexes and sides combined

*** $p \leq .001$

$$(A) Y = 1.345 + (1.71)XSP + (.967)XFP + (.533)CCI + (.489)CLI.$$

$$(B) Y = -1.803 + .850 (HXOL \text{ Sum})$$

TABLE X

Multiple and Single Regressions: Independent variables from Table V excluding Huckaba's modification variables

Sample II		Variables Entered	Significant Variables	Multiple R	Mean Square Residual	F	Sig
Females	Side	N					
	Rights	12	All variables from right side Hxol Sum R	.783 .593	.798 1.34	15.80 5.4	** **
	Lefts	16	All variables from left side Hxol Sum L	.856 .800	.771 1.04	38.34 24.82	*** ***
Males	Rights	12	All variables from right side Hxol Sum R	.605 .591	.692 .710	5.7 5.3	* *
	Lefts	13	All variables from left side Hxol Sum L	.819 .819	.510 .466	7.48 22.40	** ***

* $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$

TABLE XI
Multiple and Single Regressions: Independent variables from Table V excluding
Huckaba's modification variables

Sample I	Variables Entered	Significant Variables	Multiple R	Mean Square Residual	F	Sig
Subsamples						
Sides	N					
Sexes Combined						
All right sides	24	All right side variables	.581	1.03	11.20	**
		Hxol Sum R	.580	1.029	11.17	**
All left sides	29	All left side variables	.831	.697	27.56	***
		Hxol Sum L	.811	.746	51.926	***

*** $p \leq .001$

** $p \leq .01$

TABLE XII

Multiple and Single Regressions: Combined sexes and sides: Right sides from individuals with measurements only on right side, left sides from individuals with measurements only on left side and for individuals with both sides one side was randomly selected.

Sample II	Variables Entered	Significant Variables	Multiple R	Mean Square Residual	F	Sig
Subsamples	N					
	30	All Variables	.738	.853	15.88	***
	Sexes and sides combined					
30	Hxol Sum	Hxol Sum	.661	1.01	21.78	***

*** $p < .001$