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Craniofacial Secular Change in Recent Mexican Migrants

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Title: Craniofacial Secular Change in Recent Mexican Migrants

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Abstract: Research by economists suggests that recent Mexican migrants are better educated and have higher socio-economic status (SES) than previous migrants. Because factors associated with higher SES and improved education can lead to positive secular changes in overall body form, secular changes in the craniofacial complex were analyzed within a recent migrant group from Mexico. The Mexican group represents individuals in the act of migration, not yet influenced by the American environment and as such can serve as a starting point for future studies of secular change in this population group. The excavation of a historic Hispanic cemetery in Tucson, Arizona also allows for a comparison of historic Hispanics to recent migrants for the purpose of exploring craniofacial trends over a broad time period as both groups originate from Mexico.

The present research addresses two main questions: 1) Are cranial secular changes evident in recent Mexican migrants? and 2) Are historic Hispanics and recent Mexican migrants similar? By studying secular changes within a migrant population group, secular trends may be detected, which will be important for understanding the human biology of the migrants themselves as well as serve as a preliminary investigation of secular change within Mexican migrants. The comparison of recent Mexican migrants to a historic Hispanic sample, predominantly of Mexican origin allows for the exploration of morphological similarities and differences between early and recent Mexicans within the US.

A total of 82 craniofacial inter-landmark distances (ILDs) and vault and face size were used to explore secular changes within the recent Mexican migrants (females = 38, males = 178) and to explore the morphological similarities between historic Hispanics (females = 54, males = 58) and recent migrants. Sexes were separated and multivariate adaptive regression splines and basis splines (quadratic with one knot) were used to assess the direction and magnitude of secular trends for the recent Mexican migrants. Because dates of birth were unavailable for the historic sample, partial least squares discriminant analysis (PLS-DA) was used to evaluate morphological differences between historic and recent Mexican Migrants. The data was separated into a training and a testing dataset to ensure realistic results.

Males presented with eight variables (four positive and four negative) and females presented with six variables (two positive and four negative) that demonstrated significant differences over time. In the PLS-DA, three components were identified as important in model creation and resulted in a classification accuracy of 87% when applied to a held out sample. The high classification accuracy demonstrates significant morphological differences between the two groups with the historic Hispanic sample displaying overall larger craniofacial dimensions.

While differences in cranial morphology are evident between historic Hispanics and recent Mexican migrants, no clear pattern of secular change is detected within the recent Mexican migrant sample.

Studies of secular change typically focus on quantitative traits in a particular population group, or groups, and explore the change of selected traits over time. Studies include comparisons of native versus foreign-born groups to ascertain the impact of genes and/or the environment for the particular traits at hand. Previous studies of secular change have provided valuable information on the changing nature of the American population (Angel 1976; Boas 1940; Jantz 2001; Jantz and Logan 2010; Jantz and Meadows Jantz 2000; Jantz and Willey 1983; Meadows Jantz and Jantz 1999; Roche 1986; Sparks and Jantz 2003; Spradley 2013a; Steckel 1994; Weisensee and Jantz 2011; Wescott and Jantz 2005). The majority of research on skeletal secular change primarily focused on American Blacks and Whites and found significant changes in cranial and postcranial morphology over time, likely due to a combination of factors including gene flow, selection, and changes in the environment.

In a study of colonial to modern change, Angel (1976) found that facial height increased from colonial to modern times for both American Blacks and Whites. More recent studies of secular change in American Blacks and Whites found that the most significant changes are in the cranial vault, which is positively and significantly correlated with birth-year cohorts (Jantz 2001; Jantz and Meadows Jantz 2000; Wescott and Jantz 2005). Meadows Jantz and Jantz (1999), using postcranial metric data, found that secular changes occurred in the upper and lower limbs, although the magnitude was greater for lower limbs. Moreover, Jantz and Meadows Jantz (2000) found that cranial vault height parallels stature and can be used as a proxy to assess the overall health of a population. Historically, no skeletal data has been available for studies of secular change in the US that has paralleled that of American Blacks and Whites.

Studies of secular change in Hispanics in the US typically focus on individuals from Mexico who have experienced secular changes because of exposure to a new environment during growth and development (Dewey et al. 1983; Malina et al. 1987a; Malina et al. 1987b). Some have argued that physical changes do not occur until after the act of migration (Malina et al. 1982), although migration from Mexico to the US is not a singular event, rather a continuous and ongoing process. Furthermore, upon arrival in the US migrants from various areas in Mexico, Central America, and South America are lumped into the single category of Hispanic. Hispanics are the second largest population group in the United States, with the majority of Hispanics (64.1%) having origins within Mexico and 36.2% being foreign born (Stepler and Brown 2015). It is estimated that undocumented Mexican migrants make up 51% of the total number of Mexican immigrants residing in the US (Passel and Cohn 2014) and that the majority of Mexican migrants originate from central and southern Mexico (Stepler and Brown 2015). Areas in southern Mexico are now undergoing demographic transitions including a reduction in infant mortality, better nutrition, and an increase in life expectancy (Malina et al. 2008).

The demographic structure of migrants is also thought to be changing to include more migrants from urban rather than rural areas that exhibit higher socio-economic status (SES), are better educated, and more likely to reside in the US than return home (Marcelli and Cornelius 2001; Rodriguez 2002). However, skeletal analysis of presumed migrants brought to the Pima County Office of the Medical Examiner (PCOME) located in Tucson, Arizona suggests that migrants are of low SES (Birkby et al. 2008). These skeletal findings suggesting low SES are based on the presence of enamel hypoplasias, poor oral health, and short stature. These contradictory findings warrant further investigation.

As several economists have suggested that Mexican migrants may be better educated and higher SES than previously reported (Marcelli and Cornelius 2001; Rodriguez 2002), secular changes may be apparent within Mexican migrants over time. Due to large scale data collection efforts between the Pima County Office of the Medical Examiner (PCOME) in Tucson, Arizona and Texas State University (Spradley 2013b), metric data from migrants primarily of Mexican origin are now available for study. These data allow for the analysis of secular changes in a continuous sample of migrants over time. Additionally, the excavation and analysis of a historic cemetery in Tucson, Arizona permits a comparison of historic Hispanics to recent migrants for the purpose of exploring craniofacial trends over a broad time period. This research addresses two main questions: 1) Are cranial secular changes evident in recent Mexican migrants? 2) Are historic Hispanics and recent Mexican migrants similar?

By studying secular changes within a migrant population group, secular trends may be detected, which is important for understanding the biological variation of the migrants themselves and provides a starting point for future studies of secular change in Mexican migrants. The comparison of recent Mexican migrants to a historic Hispanic sample, predominantly of Mexican origin (Stepler and Brown 2015) allows for the exploration of morphological similarities and differences between early and recent Mexicans within the US.

Materials and Methods

For the purpose of this research, the term Hispanic is references individuals of Mexican origin. Samples for analyses are from two sources; the historic Hispanic sample (*n* = 112) is from a cemetery in Tucson, Arizona and the recent migrant sample is comprised of decedents along the U.S. Mexican border (*n* = 216) (Table 1). All crania were digitized using a Microscribe® digitizer and the program 3Skull (Ousley, nd). The program 3Skull calculates Howells (1973) craniometric variables (aka inter-landmark distances, ILDs). For the present study, 82 ILDs were used (Table 2) to ascertain if secular trends are present within the recent Migrants and between the historic Hispanics and recent migrants. Two additional variables, vault size and face size, were created following Darroch and Mosimann (1985) and Jantz and Meadows Jantz (2000). Vault size is the geometric mean of cranial length, cranial height, and cranial breadth; face size is the geometric mean of upper facial height and bi-zygomatic breadth. These variables were used as they previously demonstrated secular trends in the craniofacial complex of American Blacks and Whites.

Recent Mexican Migrants

Of the 2,000 miles of shared border between the U.S. and Mexico, 281 miles are located in what the U.S. Border Patrol (USBP) refers to as the Tucson Sector (Anderson 2008). All border-crossing fatalities in the Tucson Sector are sent to the PCOME. The USBP reported in 2004 that 43% of all undocumented border crossers were apprehended in the Tucson Sector, and the majority of border crossers are from Mexico (Anderson 2008). During the course of a large scale data collection project between Texas State University and the PCOME, migrant skeletal remains were measured. A total of 154 positively identified individuals, with known age-at-death, date-of-birth (DOB), and country of origin, are used in the present analyses. Additionally, 62 non-positively identified individuals were used in the analyses to increase sample size. A DOB was estimated by subtracting the mid-point of the age-at-death estimation from the year the individual was found. A total of 216 individuals (*females* = 38, *males* = 178) from the PCOME are used in the subsequent analyses. Although the present research includes individuals that are not positively identified, the majority of positively identified individuals from the PCOME are from Central and South Mexico, with fewer individuals from North Mexico. The DOBs for the recent Mexican Migrants span from 1940 – 1999 (Table 3). The majority of migrant fatalities at the PCOME are males under the age of 40 and most deaths are due to hyperthermia (Anderson 2008), thus the deaths are largely random and should not influence the sample composition.

Historic Hispanics

The historic Hispanic sample is from a cemetery excavation conducted between 2006 and 2008, by Statistical Research, Inc. (SRI) in Tucson, AZ under a contract to Pima County, Arizona. The burials were associated with a former cemetery located at the corner of Stone Avenue and Alameda Street in downtown Tucson, Arizona (now known formally as the Alameda-Stone Cemetery). SRI identified two distinct areas within the cemetery—a military section and a civilian section. The military section was identified in the southwest corner of the project area. The civilian section was used by nearly every other member of the Tucson community—Mexican, Anglo-American, Native American—during the 1860s and 1870s (Heilen 2012).

SRI excavated over 1200 individuals. In compliance with the *Agreement on Treatment and Disposition of Burial Discoveries Dating After 1775* (ARS §41-844, Case 06-14), SRI made every effort to assess the cultural affiliation (ancestry) of the individuals recovered during these excavations. For each individual, an assessment of cultural affiliation relied on multiple lines of evidence and included: context (i.e., where a set of remains was discovered within the cemetery and the grave good/mortuary items found in association with that individual); osteological indicators (i.e., basic biological profile, pathology); and, historical evidence (i.e., how the cemetery was used, the identities of the people buried there, and the cultural traditions of the communities in and around Tucson during this period). After these lines of evidence were evaluated, a likelihood statement of cultural affiliation based on the strength of each assessment (highly likely, multiple affinities, or culturally indeterminate) was prepared.

Of the 1,090 individuals removed from the civilian section and feasibly analyzed, one was African American, one was Apache, 99 were Euroamerican, 230 were Hispanic, three were Yaqui, 181 had multiple cultural affinities, and 575 were indeterminate. These results correspond to what is known about nineteenth-century Tucson: it was a mostly Hispanic community that also included African Americans, Euroamericans, and Native Americans among its members. Certainly, the large number of individuals with multiple affinities reflects the diverse history of Tucson, where many people from many backgrounds exchanged cultural traditions. Based on this analysis, the authors implemented the individuals of Hispanic ancestry (*females = 54, males =58*) in the following analyses to assess morphological change among historic and recent Mexican migrants (Heilen 2012).

Data Imputation

Some statistical methodologies require complete datasets, which is unlikely when dealing with skeletal material that has been exposed to the environment. In an attempt to maximize the use of the data, missing values were addressed in the dataset. Recent literature has suggested that the *k* nearest-neighbor approach presents with the least differences to the actual data as well as has the least impact on biodistance studies (Kenyhercz and Passalacqua 2015). A robust sequential nearest neighbor imputation was utilized that sequentially estimated the missing values by using statistical measures of distance, such as mean and covariance. Concurrently, the influence of outliers was decreased through robust estimates of location and scatter (Todorov 2012). Because craniometrics and genetics are linked, basing imputations off the most similar complete specimens provides a more realistic imputation than imputing values based on the variation of all specimens.

Secular Change within Recent Mexican Migrants

While grouping individuals per decade of birth is a generally accepted approach for secular change analyses, there were drastically different sample sizes between some of the decades (Table 3). The different sample sizes directly affected the variances for each category, which could violate some assumptions inherent to statistical analyses, such as analysis of variance.

All variables were utilized in a regression analysis to explore when (in terms of DOB) secular changes occurred and the degree of change over time. Multivariate adaptive regression splines (MARS) were employed, as the craniofacial and DOB data are nonlinear and require nonparametric modeling. MARS subdivides the *x-axis* (DOB) into sub-regions and finds the basis function, f(*X*), for each (Friedman, 1991; Sekulic and Kowalski, 1992). Linear basis functions are conducted for each predictor variable and every possible value of *t*, or the knot, which forms a reflected pair and indicates a change in slope (Friedman, 1991; Sekulic and Kowalski, 1992; Muñoz and Felicísimo, 2004; Hastie et al., 2009; Butte et al., 2010). The presence of a secular trend is inferred when a knot is identified in the model, thus indicating a change in slope of the measurement. MARS is built through k-fold cross-validation (K = 10); models were built with *K*-1 parts and the prediction error is calculated from the out-of-fold data (*k*th part) that is averaged across all folds (Friedman, 1991; Efron and Tibshirani, 1993; Kohavi, 1995; Hastie et al., 2009). More details regarding MARS can be found in Friedman (1991), Hastie et al. (2009), and Stull et al. (2014).

While MARS determines an exact point where there is a difference in slope, secular trends generally occur as a continuous process and a specific point in time may be overly optimistic. Therefore, basis splines were also used to assess the trends. Basis splines are considered adaptable because the fit is constructed piecewise from a different polynomial function in each contiguous interval of *X*, which presents as one parametric curve (Hastie and Tibshirani, 1990; Eilers and Marx, 1996; Wood, 2006; Racine, 2012). In additive models, the scalar (*B*) is replaced by a function rather than multiplied by the *X* variable as in linear models (Wright and London, 2009). Piecewise-polynomials are considered superior to polynomial transformations because polynomial transformations tend to be erratic at the boundaries when the coefficients are adjusted (Hastie et al., 2009).

The order (*m*) and number of knots (*N*) defines a basis spline. Fundamentally, two knots are always at the endpoints making the total number of knots $N + 2$. The *m* specified is associated with the type and complexity of the spline and corresponds to different types of regression (Wright and London, 2009). For example, a 0-degree polynomial is analogous to the constant ($\beta0$), a second-degree polynomial is a quadratic regression, and a 3rd-degree polynomial is considered a cubic regression. Each curve requires only one additional knot, such that increasing the number of knots does not greatly increase the complexity of the model in terms of degrees of freedom (Wright and London, 2009). For the current study, a second-degree polynomial with one knot was used in all models.

Secular Trends between Historic Hispanics and Recent Mexican Migrants

Regression analyses could not be conducted because there are no known DOBs associated with the Alameda-Stone Cemetery data, only a general time period. Thus, the authors chose to explore differences between the two datasets through discriminant analysis. The data was combined and a partial least squares discriminant analysis (PLS-DA) was conducted. The methodology – though not predominant in the anthropological literature – was applied because the craniometric data provides a moderately large number of predictor variables but the reference samples are fairly small (Pérez-Enciso and Tenenhaus 2003), a situation where PLS is recognized to work fairly well (Boulesteix and Strimmer, 2007). Similar to PCA, PLS constructs a set of linear combinations of the predictor variables. In contrast to PCA, the components identified by PLS are chosen in respect to the response variable(s) (Boulesteix and Strimmer, 2007; Hastie et al., 2009). PCA is only capable of capturing total sample variability and not any type of among and/or within group variability (Barker and Rayens, 2003). Therefore, when discrimination is the goal and a dimension reduction is necessary, it has been stated that performing a PLS is preferred to PCA (Barker and Rayens 2003; Pérez-Enciso and Tenenhaus 2003).

Males and females were pooled for the PLS-DA analyses and all predictor variables were centered and scaled prior to employing PLS-DA. The data was split into a training (75%) and testing set (25%). The Receiver Operator Curve (ROC) was used to measure performance and choose the number of components to use in the final model. Once the model was created, the testing data was used to obtain a realistic classification accuracy. The contribution of each variable to the model is based on the Variable Importance of Projection (VIP) statistic of Wold (1994). The VIP provides a means to quantify the contribution of each measurement in the final model. It is generally accepted that a value less than 1 is "small" for the VIP; the larger the VIP, the greater the contribution to the model

(Mehmood et al., 2012).

Results

Recent Mexican Migrants

Males

Eight out of the 84 (ILDs, vault size, and face size) variables (BPL, SSS, FRF, FOB, BAA, OCA, BBA, SSA) displayed a change in slope, as recognized by a hinge function in the MARS model. Both positive and negative trends were observed. Quadratic basis spline models were also created for all measurements that presented with a change in slope in order to further assess the trends; as expected all models presented with significant p-values ($p < 0.05$). The basis spline models followed a similar trajectory as the MARS models (Figure 1). As expected, the tails tend to be a bit more variable. The direction of change and the magnitude of mean change in size for each measurement in the male sub-sample is:

- *Basion-prosthion length (BPL) increased in mean size from 92mm in 1952 to 98mm in 1963 and then remained constant to 1993.*
- *Zygomaxially subtense (SSS) remained constant from 1952 until 1981 and then increased in mean size from 26mm in 1981 to 29mm in 1993.*
- *Foramen magnum breadth (FOB) increased in mean size from 29mm in 1994 to 31mm in 1990 and then remained constant to 1993.*

- *Occipital angle (OCA) increased in mean size from 113mm in 1944 to 119mm in 1969 and then remained constant to 1993.*
- *Zygomaxillary angel (SSA) remained constant from 1952 until 1984 and then decreased in mean size from 122mm in 1984 to 117mm in 1993.*
- *Basion angle (nasio- prosthion)(BAA) decreased in mean size from 46mm to 41mm from 1947 until 1967 and then remained constant to 1993.*
- *Basion angle (nasion-bregma) (BBA) decreased in mean size from 57mm in 1944 to 52mm in 1967 and then remained constant to 1993.*
- *Frontal fraction (FRF) decreased in mean size from 62mm 1944 to 52mm in 1960 and then remained constant to 1993.*

Females

Six out of the 84 variables (BBH, FRC, FRS, DKR, BAA, RFA) displayed a change in slope, as recognized by a hinge function in the MARS model; Five out of six variables display negative trends. In accord with the male analyses, quadratic basis spline models were also created for all measurements that presented with a change in slope in order to further assess the trends in the female sub-sample. The six models were all significant ($p < 0.05$) and a visual comparison between secular trends identified by MARS and basis spline models is provided in Figure 2. The direction of change and the magnitude of mean change in size for each measurement in the female sub-sample is:

- *Dacryon radius (DKR) remained constant from 1955 to 1983 and then increased in mean size from 78mm in 1983 to 81mm in 1990.*
- *Basion- bregma height (BBH) remained constant from 1955 until 1969 and then decreased in mean size from 132mm in 1969 to 126mm in 1996.*
- *Basion angle (nasion-bregma)(BBA) decreased in mean size from 57mm in 1955 to 57mm in 1978 and then remained constant from 1978 to 1996*
- *Frontal chord (FRC) decreased in mean size from 113mm in 1955 to 104mm in 1978 and then remained constant to 1996.*
- *Frontal subtense (FRS) decreased in mean size from 28mm in 1955 to 23mm in 1978 and then remained constant to 1996.*
- *Radio-frontal angle (RFA) decreased in mean size from 65mm in 1955 to 60mm in 1979 and then remained constant from 1979 to 1996.*

Historic Hispanics and Recent Mexican Migrants

Three components were identified as important in the PLS-DA model using the training data (Figure 3). A VIP is provided for each ILD and each PLS component and then an overall model VIP. The ILDS with the largest overall model VIP, and thus influence on discrimination, were MLS, FRS, FRA, FOB, and PRA (Figure 4). The classification accuracy, when the created model was applied to the held-out dataset (*n* = 82), was 87% (Table 4). Visualization of the discriminant function scores illustrates that the two groups can be separated

(Figure 5). The 95% confidence interval associated with the classification accuracy of the held out sample was 77% to 93%. The positive predictive value was 77% and the negative predictive value was 92%. The discriminant loading separated the historic Hispanics from the recent Mexican Migrants based on larger values for MLS, PRA, FRS, FOB and FMR (Figure 5).

Discussion

In order to detect secular change, the study sample must come from the same origin or source (Roche et al. 1977). In the present study, the migrants are viewed as originating from one source, Mexico. However, regional differences in anthropometric dimensions and admixture estimates within Mexico may influence the detection of secular change in this study.

Based on the regression analyses for the PCOME data, eight variables for males and six variables for females show significant change over time, these changes are both positive and negative and are mostly include angles, fractions, subtenses, radii, and chords. Most notably, the males show an increase in prognathism over time (BPL and SSS) and a decrease in basion, occipital, and basion angles. Basion-bregma height (BBH), which has been shown to correlate with stature (Jantz and Meadows Jantz 2000), decreased over time in females.

While significant changes over time were identified in both the male and female sub-samples, it is necessary to make note of the different sample sizes across the predictor variable (DOB). The fewer individuals in the oldest years and the smaller female sub-sample overall could have an effect on the trends identified. It is possible that the differential sample sizes throughout the DOB resulted in influential observations that may have skewed the data in some cases. As expected, the influential observations were located with the oldest DOB, which reflects the smaller sample sizes associated with the oldest cases. Because there is not an equal sample size per DOB, the authors chose not to remove these observations, as it is unknown whether the observations were actually outliers or reflect normal variation. A larger sample size is required for further evaluation.

Several other factors need to be discussed that could have affected the regression analyses. Specifically, the sample may not have enough time-depth and regional differences within Mexico may obscure detection of secular changes. Previous research within rural areas of Mexico, Oaxaca in particular, suggests that the birth-years represented in this research have experienced secular changes in anthropometric measurements of the cranium (Little et al. 2006). However, these identified secular changes include a narrower face and an overall shorter head length, rather than an increase in linear dimensions (Little et al. 2006).

Although several studies by economists have suggested that migrants from Mexico are more affluent in recent years (Marcelli and Cornelius 2001; Rodriguez 2002), if positive secular change is taken as an indicator of overall economic improvement, the present research does not support this conclusion.

Although few variables exhibit secular change, the majority of variables do not, especially the variables (cranial height, cranial length) that have previously demonstrated positive changes in American Blacks and Whites (Jantz 2001; Jantz and Meadows Jantz 2000; Wescott and Jantz 2005). In the present research, cranial height (basion-bregma height or BBH) demonstrates a negative secular change. While it could be argued that migrants that die crossing the border may not be representative of the migrants that survive the crossing and arrive at their final destination within the US, the cause of death for most migrants from the PCOME is due to exposure (e.g. hypothermia, hyperthermia, dehydration), not selective pressures that would affect different SES and age groups differently (Pima County Office of the Medical Examiner 2014).

Although relatively few variables exhibit secular change within the recent Mexican Migrants, they are morphologically different from historic Hispanics, as demonstrated by the PLS-DA. Because DOBs are not available to perform analogous analyses between and within the historic Hispanic and recent Mexican Migrant samples, the PLS-DA allowed the authors to look at overall differences in the cranial complexes of both samples. The morphological differences are found in the facial region (MLS, PRA), frontal region (FRS, FRA) and in the basicranial region (FOB). Further, the results suggest that the recent Mexican Migrants exhibit smaller values for these particular variables indicating that the historic Hispanics had overall larger dimensions. As mentioned previously, Little et al. (2006) found that anthropometric dimensions of the craniofacial complex within Oaxaca, Mexico became reduced over time resulting in a shorter cranial vault and narrower face.

The apparent reduction in size of craniofacial variables for the historic to recent samples is likely due to both genetic and temporal differences between the samples. The historic Hispanic sample represents individuals from North Mexico that eventually became US residents (Heilen et al. 2012). Recent genetic research suggests that both historic and recent Mexicans in the North exhibit genetic differentiation from Central and Southern Mexicans (Rubi-Castellanos et al. 2009), the latter two being the primary origin of the majority of the recent Mexican migrant group.

Secular changes are evident in relatively few cranial variables and differences in cranial morphology are evident between historic Hispanics and recent Mexican migrants. Previous studies of secular change in Mexico focus on particular communities (Malina et al., 2010), and in the US, they focus on populations that have already experienced a new environment and potential gene flow (Malina et al. 1987, Dewey et al., 1982). The sample presented here, representative of recent migrants predominantly from Mexico, has not yet been exposed to the US environment during growth and development and thus can serve as a starting point for future studies of secular change.

Perspectives

The majority of secular change literature on Mexican migrants has focused on the anthropometry of Mexican American children; see Malina et al. (1986) for a comprehensive review. Today, the term Hispanic is more often used than Mexican American, as Mexican American can refer to individuals born in the US or who migrated after birth, or second, third, or fourth generations born in the US (Malina et al. 1986; Malina et al. 1987a; Malina et al. 1987b). The term Hispanic is not without its own terminological issues as it erases cultural identity, geographic origin (Melville 1988), and differences in genetic population structure (Bryc et al. 2010). The present research found significant differences in cranial morphology between historic Hispanics and recent Mexican migrants.

Although recent Mexican Migrants would be considered Hispanic for bureaucratic purposes (e.g. US Census) within the US, they are morphologically different from historic Hispanics likely because of specific geographic origins within Mexico and temporal differences. Thus, if the term *Hispanic* is used within a research context, it should be clearly defined as to the origin and the temporal period of the group.

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Table 1: Groups, and their associated abbreviations, and their associated sample sizes grouped by sex that were used in analyses

Group	Female	Male
Historic Hispanic (Alameda-Stone)	54	58
Recent Mexican Migrant (PCOME)	38	178

Table 2: Variables used in analyses *(following Howells 1973, Key 1983*, and defined in Moore-Jansen et al. 1994**)*

Abbreviation	**Measurement**	**Abbreviation**	**Measurement**
GOL	glabella-occipital	PAF	parietal fraction
NOL	nasion-occipital	OCC	occipital chord
BNL	basion-nasion	OCS	occipital subtense
BBH	basion-bregma	OCF	occipital fraction
WFB*	minimum frontal breadth	FOL	foramen magnum length
XCB	max cran br	FOB	foramen magnum breadth**
XFB	max frontal br	NAR	nasion radius
ZYB	byzygomatic breadth	SSR	subspinale radius
AUB	biauricular breadth	PRR	prosthion radius
ASB	biasterionic breadth	DKR	dacryon radius
BPL	basion-prosthion length	ZOR	zygoorbitale radius
NPH	nasion-prosthion height	FMR	frontomalare radius
NLH	nasal height	EKR	ectoconchion radius
JUB	bijugal breadth	ZMR	zygomaxillare radius
NLB	nasal breadth	AVR	M1 alveolar radius
MAB	external palate breadth	BRR	bregma radius
MAL*	external palate length	VRR	vertex radius
MDH	mastoid height	LAR	lambda radius
OBH	orbital height	OSR	opisthion radius
OBB	orbital breadth	BAR	basion radius
DKB	interorbital br	NAA	nasion angle
NDS	nasion-dacryon subtense	PRA	prosthion angle
WNB	simotic chord	BAA	basion angle, nasion-prosthion
SIS	simotic subtense	NBA	nasion angle
ZMB	bimaxillary br	BBA	basion angle, nasion-bregma
SSS	zygo-maxillary subtense	BRA	Bregma angle
FMB	bifrontal breadth	SSA	zygomaxillary angle
NAS	nasio-frontal subtense	NFA	nasion-frontal angle
EKB	bi-orbital breadth	DKA	dacryal angle
DKS	dacryon subtense	NDA	nasion-dacryon angle
IML	inferior malar length	SIA	simiotic angle
XML	maximum malar length	FRA	frontal angle
MLS	malar subtense	PAA	parietal angle
WMH	minimum malar height	OCA	occipital angle
GLS	glabella projection	RFA	radio-frontal angle
STB	bistephanic breadth	RPA	radio-parietal angle
FRC	frontal chord	ROA	radio-occipital angle, lambda-opisthion
FRS	frontal subtense	BSA	basal angle, prosthion-opishtion
FRF	frontal fraction	SBA	sub-bregma angle
PAC	parietal chord	SLA	sub-lambda angle
PAS	parietal subtense	CBA*	Cranial base angle

Table 3: DOB and sample size

Birth Year	Sex	Sample Size
1944	M	2
	F	-
1945	M	2
	F	-
1947	M	1
	F	-
1952	M	1
	F	-
1953	M	1
	F	-
1954	M	1
	F	-
1955	M	1
	F	1
1956	M	1
	F	-
1957	M	-
	F	1
1958	M	2
	F	1
1959	M	4
	F	-
1960	M	2
	F	-
1961	M	3
	F	-
1963	M	7
	F	-
1964	M	3
	F	-
1965	M	5
	F	2
1966	M	3
	F	1
1967	M	1
	F	5
1968	M	4
	F	1
1969	M	14
	F	3
1970	M	7
	F	-
1971	M	2
	F	-
1972	M	7
	F	-
1973	M	8
	F	-
1974	M	9
	F	-
1975	M	7
	F	-
1976	M	7
	F	2
1977	M	5
	F	1
1978	M	10
	F	3
1979	M	3
	F	1
1980	M	3
	F	-
1981	M	8
	F	-
1982	M	3
	F	3
1983	M	12
	F	4
1984	M	4
	F	3
1985	M	3
	F	-
1986	M	4
	F	3
1987	M	3
	F	4
1988	M	2
	F	-
1989	M	1
	F	1
1990	M	6
	F	2
1991	M	2
	F	-
1992	M	1
	F	-
1993	M	2
	F	-
1996	M	-
	F	1

Table 4: Classification matrices for the training sample and the testing (held-out) sample.

	Reference Groups			
	Training Sample		**Testing Sample**	
Predicted Group	*Alameda-Stone*	*PCOME*	*Alameda-Stone*	*PCOME*
Alameda-Stone	61	12	24	7
PCOME	23	150	4	47

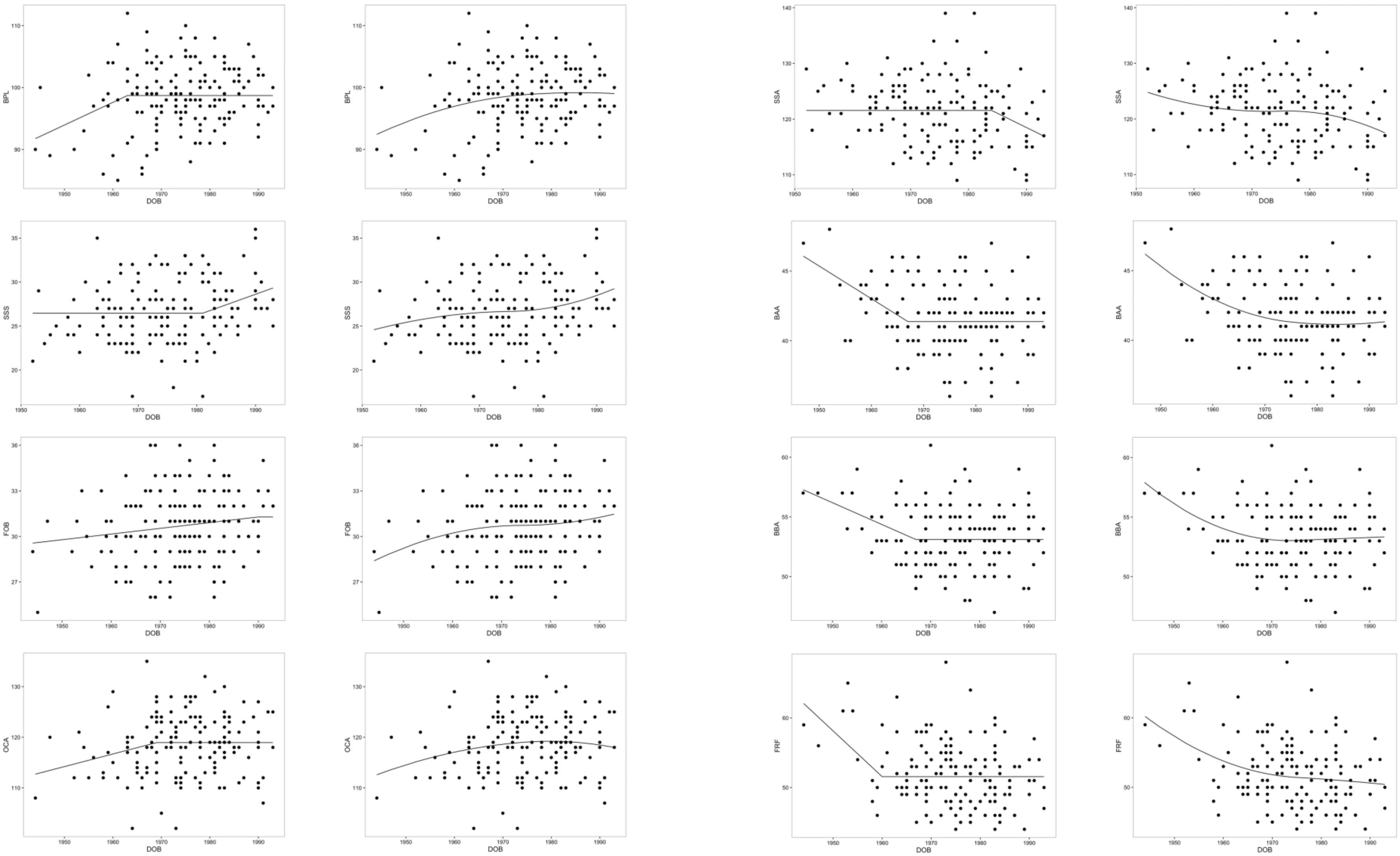
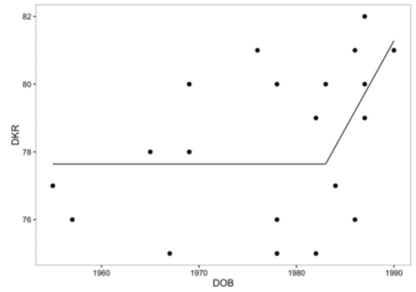
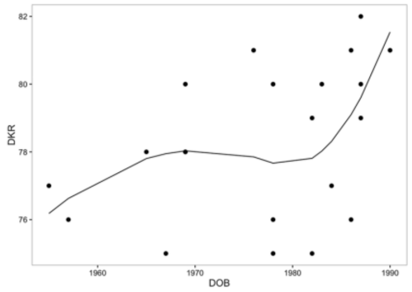


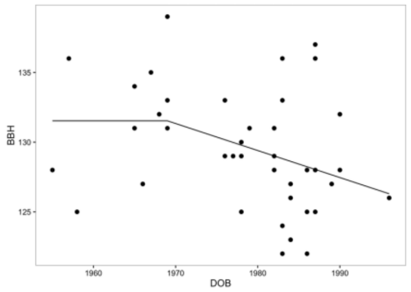
Figure 1: Variables regressed on DOB for Recent Mexican Migrants males. Left column MARS right column quadratic basis spline.



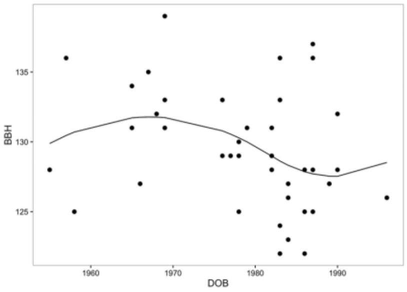
DKR
76
78
80
82
DOB
1960
1970
1980
1990



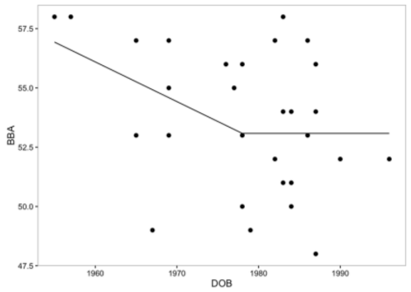
DKR
76
78
80
82
DOB
1960
1970
1980
1990



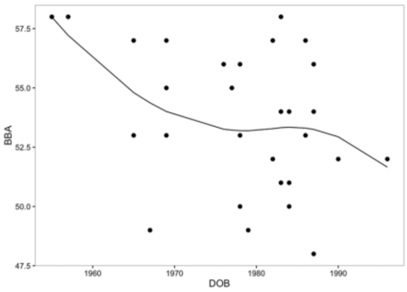
BBH
125
130
135
DOB
1960
1970
1980
1990



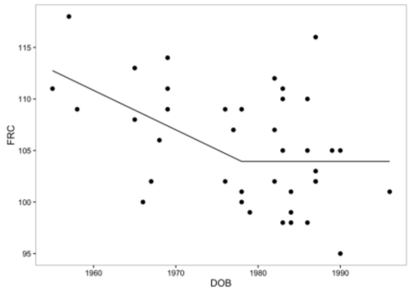
BBH
125
130
135
DOB
1960
1970
1980
1990



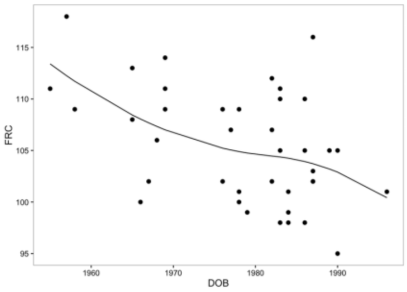
BBA
47.5
50.0
52.5
55.0
57.5
DOB
1960
1970
1980
1990



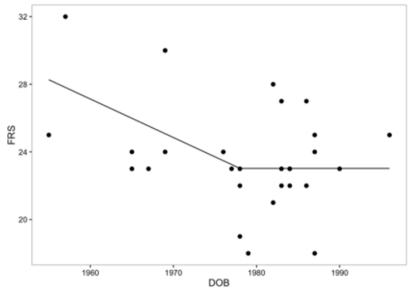
BBA
47.5
50.0
52.5
55.0
57.5
DOB
1960
1970
1980
1990



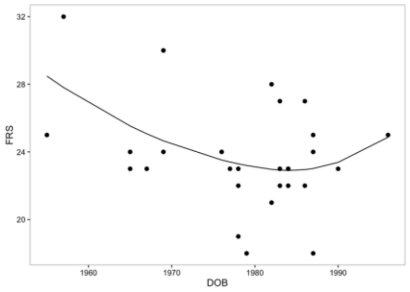
FRC
95
100
105
110
115
DOB
1960
1970
1980
1990



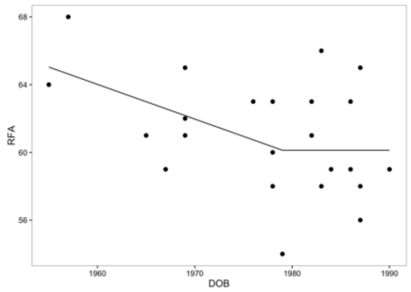
FRC
95
100
105
110
115
DOB
1960
1970
1980
1990



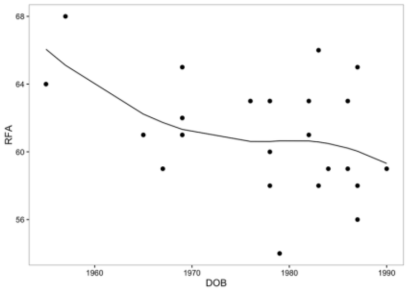
FRS
20
24
28
32
DOB
1960
1970
1980
1990



FRS
20
24
28
32
DOB
1960
1970
1980
1990



RFA
56
60
64
68
DOB
1960
1970
1980
1990



RFA
56
60
64
68
DOB
1960
1970
1980
1990

Figure 2: Variables regressed on DOB for Recent Mexican Migrants females. Left column MARS right column quadratic basis spline.

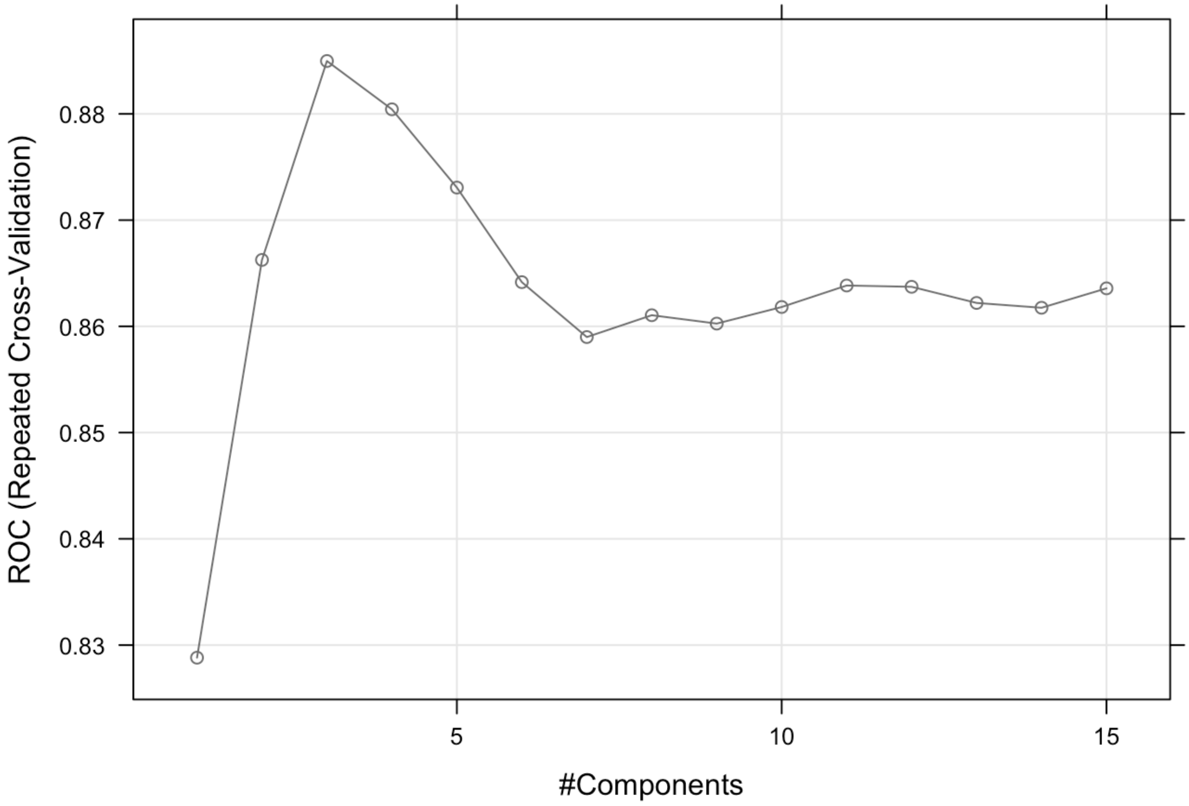


Figure 3. Visualization of the relationship between the number of PLS components and the resampled estimate of the area under the ROC curve.

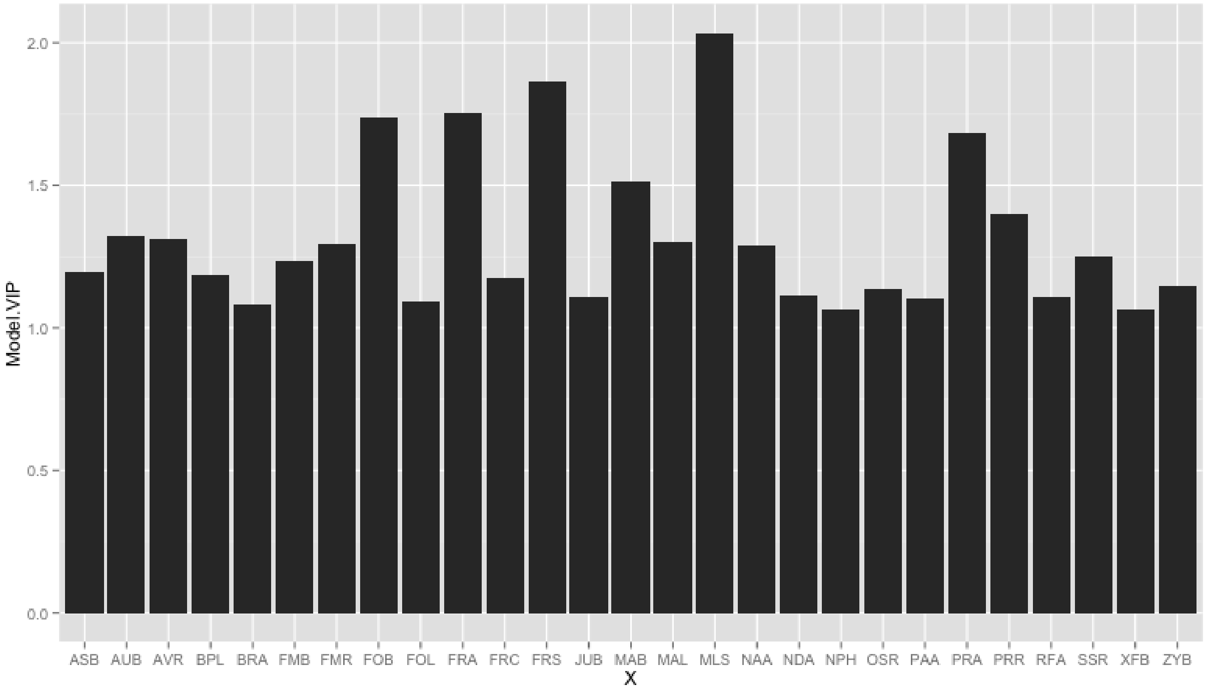


Figure 4. ILDs whose variation is important in differentiating between modern and historic Mexican migrants, based on the variable importance criterion (VIP). All measurements depicted had a VIP > 1; MLS, FRS, FRA, FMR, and PRA all contributed the most to the final model.

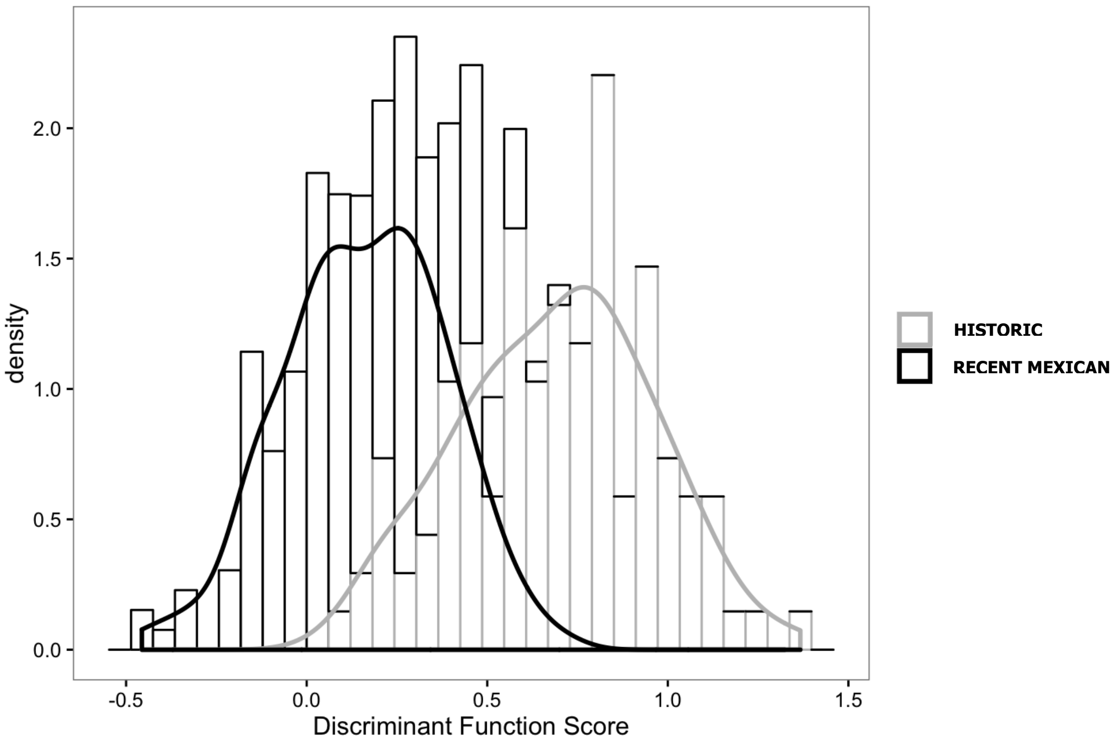


Figure 5: Histogram of discriminant function score showing separation of Historic Hispanics and Recent Mexican Migrants.