MARTA REGINA PINHEIRO FLORES

Discriminatory power of photo-anthropometric facial measures

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Discriminatory power of photo-anthropometric facial measures

(Poder discriminatório de medidas faciais fotoantropométricas)

Corrected Version

Thesis presented to the Dentistry College of the University of São Paulo, post-graduation program in Dentistry Sciences to obtain the title of PhD in Dental Sciences.

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I dedicate this work

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“Strength doesn't come from what you can do. It comes from overcoming the things you once thought you couldn't.”

(Rikki Rogers)

RESUMO

Flores MRP. Poder discriminatório de medidas faciais fotoantropométricas [tese]. São Paulo: Universidade de São Paulo, Faculdade de Odontologia; 2019. Versão Corrigida.

Distinguir indivíduos por sua aparência facial é uma tarefa desafiadora para as ciências forenses, particularmente nos exames de Identificação Facial Forense (FFI). A fim de fundamentar conclusões nesses casos, esta tese tem como objetivo avaliar a freqüência e o poder discriminatório de medidas faciais fotoantropométricas obtidas de indivíduos não relacionados e de gêmeos idênticos (monozigóticos, univitelinos ou MZT). Para tanto, esta tese foi estruturada na forma de três capítulos. O primeiro capítulo tem como objetivo avaliar a frequência de 211 distâncias Euclidianas (ED) na população brasileira, de ambos os sexos e de grupos etários distintos (20, 30, 40, 50 e acima de 60 anos), utilizando uma metodologia métrica de avaliação das estruturas faciais em imagens frontais bidimensionais (2D) (fotoantropometria facial – FPA). No intuito de selecionar medidas com maior potencial de discriminação, um método de regressão logística foi aplicado assim como a avaliação de erro interexaminadores. De forma geral, potencial discriminatório foi observado para 16 EDs. Essas medidas foram utilizadas para o estabelecimento de 20 índices (IN) e 21 ângulos (AN) faciais e seu poder discriminatório foi verificado no segundo estudo por meio da análise de 920 imagens de indivíduos de ambos os sexos e de oito faixas etárias distintas (5, 15, 20, 30, 40, 50, 60 e acima de 70 anos de idade). A análise consistiu em achar valores duplicados considerando três fontes de variabilidade: interindivíduo (ER), intraindivíduo (RA) quando analisado pelo mesmo examinador (RAA), e intraindivíduo quando analisado por diferentes examinadores (RAE). Como resultado, pode-se observar que 15 ED ou 20 IN foram necessários para alcançar uma probabilidade de menos de um indivíduo com medidas duplicadas em uma população de um milhão (10^6). A mesma probabilidade foi alcançada quando 18 ANs foram utilizados somente nas idades de 5, 15, 50, 60 e 70 anos. O último capítulo consistiu em avaliar a capacidade dessas medidas em distinguir um grupo populacional cujas características faciais são extremamente similares, ou seja, MZT. Para isso, análise de duplicadas foram realizadas entre e dentre pares de MZT

considerando intervalos de confiança intraindivíduo. Como resultado, pode-se observar padrões diferentes de discriminação das medidas faciais quando MZT foram comparados com indivíduos não correlatos. Podendo-se concluir que medidas faciais fotoantropométricas são capazes de discriminar indivíduos, inclusive MZT.

Palavras-chave: Antropologia Forense. Odontologia Legal. Gêmeos Monozigóticos. Identificação Humana. Fotoantropometria. Comparação Facial.

ABSTRACT

Flores MRP. Discriminatory power of photo-anthropometric facial measures [thesis]. São Paulo: Universidade de São Paulo, Faculdade de Odontologia; 2019. Corrected Version.

Distinguishing individuals by their facial appearance is a challenging task in forensic science, particularly in Forensic Facial Identification (FFI) examinations. In order to substantiate match decisions in such cases, this thesis aims to assess and compare the frequency and discriminatory power of photo-anthropometric facial measures taken from both unrelated individuals and identical twins (i.e., monozygotic, univiteline or MZT). This thesis is organized in three chapters. Chapter I aims to evaluate the frequencies of 211 Euclidean distances (ED) of Brazilian adults, of both sexes and within five age groups (20, 30, 40, 50 and over 60 years old), by applying a metric approach to the assessment of facial structures in 2D frontal view images (i.e., facial photo-anthropometry - FPA). In order to select measures with the greatest potential for facial discrimination, a logistic regression method was used, together with interexaminer error analysis. In general, results indicate 16 EDs as having great discriminatory potential. These measures were used to establish 20 indices (IN) and 21 facial angles (AN) and their discriminatory powers were assessed in the second study through the analysis of 920 facial images of individuals of both sexes and within eight age groups (5, 15, 20, 30, 40, 50, 60 and over 70 years old). This analysis consisted of finding duplicate measures considering three sources of variability: interindividual (ER), intraindividual (RA) when analyzed by the same examiner (RAA) and intraindividual when analyzed by different examiners (RAE). As a result, 15 ED or 20 IN were required to achieve a probability of finding less than one individual in a population of one million (10^6) with duplicate measures. The same probability was achieved using 18 ANs only in age groups of 5, 15, 50, 60 and 70 years old. The last chapter discusses whether such measures can be used to distinguish a group whose facial characteristics are extremely similar, i.e. MZT. For this purpose, duplicate analyses were performed between, and within, MZT pairs considering intraindividual variability intervals. As a result, it was observed that measures performed differently when comparing MZT with unrelated individuals and

it was concluded that FPA measures can potentially discriminate individuals, including even MZT.

Keywords: Forensic anthropology. Forensic odontology. Monozygotic twins. Human identification. Photo-anthropometry. Facial comparison.

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LIST OF ABBREVIATIONS AND ACRONYMS

%	Percentage
2D	Bidimensional
3D	Three-dimensional
AN	Angle
BM	Bilateral measure
BSV	Between-source variability
CCTV	Closed-circuit television
CG	Control group
CI	Confidence interval
CM	Cross-side measure
CV	Coefficient of variation
DNA	Deoxyribonucleic acid
DP	Discriminatory power
ED	Euclidean distance
ES	Effect size
FISWG	Facial Identification Scientific Working Group
FFI	Forensic Facial Identification
FR	Facial Recognition
FPA	Facial Photo-anthropometry
HM	Horizontal measure

HVID	Horizontal Visible Iris Diameter
ICAO	International Civil Aviation Organization
ICC	Intra-class correlation coefficient
IN	Indice
LASSO	Least Absolute Shrinkage and Selection Operator
PM	Probability of match
MZT	Monozygotic twins
px	Pixel
RAA	Intraindividual variability (intraexaminer)
RAE	Intraindividual variability (interexaminer)
RE	Interindividual
SAFF-2D®	Two-dimensional Forensic Facial Analysis System, Federal Police, Brazil
SD	Standard deviation
SG	Sample group
VM	Vertical measure
VSP	Variability percentage
WSV	Within-source variability
YO	Years old

SUMMARY

1 INTRODUCTION

Distinguishing individuals by their facial appearance is a challenging task in forensic science. Both the widespread use of digital imaging devices and the large-scale implementation of CCTV (closed-circuit television) surveillance systems are increasing the demand among law enforcement agencies worldwide for non-automated facial comparisons of offenders/suspects depicted on images for human individualization purposes; a process known as Forensic Facial Identification (FFI) (1). This procedure of evaluating whether two bidimensional (2D) facial images come from the same person is based on the assumption of human face uniqueness, even though it is an unproven and gradually more outdated concept (2, 3). What is acknowledged, however, is that every individual has facial characteristics that are potentially useful for human individualization, even identical twins (monozygotic, univiteline or MZT) (4).

The identical nature of their genetic codes (DNA) results, naturally, in huge similarities between their anatomical structures, hindering not only the automated process of facial recognition but also the examiner-dependent individualization one (FFI) (5-7). Studies have shown, however, that even MZT have facial singularities that can be verified and used in order to differentiate them. This discrimination procedure is notably better performed by humans than biometric systems (6-9). Although the development of verification systems (i.e., one-to-many, facial recognition - FR) is of great importance for monitoring and surveillance security issues, what is seen in everyday forensic practice is a large increase in requests for manual examinations of images (computer-assisted or not), specifically, that is facial mapping or one-to-one comparisons (FFI) (10, 11). Despite its relevance, little is known about the rarity and variation of facial features to better support source attributions in facial imaging comparison evaluations.

Frequency and occurrence studies of population-specific features are of extreme importance for the evaluative process of facial evidence (5). Understanding which features contribute to the application of probabilistic models, as well as to what extent they influence human variability and facial differentiation, especially when

individuals are theoretically identical, as MZT, is vital (4). Finding measures that are capable of distinguishing individuals, even within this particular group, may raise new understanding of human face variation and support practical FFI examinations.

Scientifically, facial features can be described using morphological and metric approaches. The first involves subjectively classifying facial features into categories, such as ‘wide’ and ‘rounded’. Despite not being considered a reproducible method of facial classification, it is the most reliable one for FFI examinations (4, 12). The metric approach (i.e., facial photo-anthropometry – FPA) traditionally involves measuring and comparing distances and proportions taken from specific points on the face (namely, landmarks). Theoretically, any morphological feature can be converted into metrics by measuring its category descriptors (such as width, height, curvature, angle). This concept forms the understanding of morphometric constitution of the human face and emphasizes the relevance of developing FPA studies.

The trustworthy application of this inherently objective and anthropometry-grounded method for analyzing human faces through images mostly relies on its sensitivity towards detecting facial differences. Many factors can affect the variability of absolute metric values (e.g., lighting, camera angle and lenses, facial pose/expression). As a result, even measurements taken from the same individual will rarely be the same. Because of this, the use of facial proportions and relations (such as indices, ratios, and angles) seems to reduce the effect of those factors in facial morphometry. Recent studies have appointed horizontal visible iris diameter (HVID) as an important FPA reference, as a magnification factor for image scaling or even as a common denominator in the determination of ratios or proportionality indices (PIs). Such designations are justified by its low variability and long-term stability, along with the fact that it is the most isometric measure of the human face (13-15). In addition, this reference measure has been shown to be particularly sensitive for detecting facial growth, with applications in age estimation (11). Nonetheless, no study to fate has attempted to use HVID to verify human differences.

In this sense, the present work aims to widen understanding about the rarity of human facial traits and to assess the metric features that have the greatest relevance and influence in distinguishing unrelated and MZT individuals, therefore contributing to FFI evaluation decisions. Far from fruitlessly trying to establish the uniqueness of metric facial features (a concept that is gradually becoming more

obsolete and irrelevant) (16-18), this thesis aims to describe how likely duplicate measures are to be found within both assessed populations. Throughout this thesis, the term *discriminatory potential* refers to the promising capacity of measures in differentiating individuals, whereas *discriminatory power* is applied after capacity validation results. Therefore, this term is not in accordance with statistical fundamentals since distinct statistical tests were performed to achieve discriminatory results.

This thesis is organized in three chapters. Initially, a frequency study applying a logistic regression method was carried out to assess which FPA measures are least common among Brazilian adults, thus having great potential to distinguish unrelated adult individuals. Under ethical committee approval (APPENDIX A), 211 Euclidean distances were calculated from the positioning of 23 landmarks on 600 standardized frontal view facial images (APPENDIX B). All measures were divided by the HVID to generate facial ratios (i.e., iris ratios) and scored according to their reliability, frequency and relative consistency considering sex and age groups (20, 30, 40, 50 and over 60 years old). At the end of this study, 16 general measures were identified, according to established criteria, as having superior discriminatory potential, indicating their importance for facial evidence evaluation.

From these results, the measures with greatest discrimination potential were selected to establish morphometric relations (20 indices and 21 angles) and their performance in human individualization was evaluated. The discriminatory capacity of these facial measures was verified among unrelated individuals of both sexes and within different ages groups (5, 15, 20, 30, 40, 50, 60, and over 70 years old). Finally, the discriminatory power of these measures (Euclidean distances, indices and angles) was tested between and within MZT pairs, in order to confirm the most relevant metric features for distinguishing individuals and revealing great applicability to FFI examinations.

2 CHAPTER I – Discriminatory potential of photo-anthropometric facial measures in Brazilian population: a logistic regression frequency study.

Abstract

Population-specific frequency studies of facial measures are essential to increase knowledge of the features that are most likely to be able to distinguish human faces. This is meaningful information for improving understanding in Forensic Facial Identification (FFI), including its metric approach, facial photo-anthropometry (FPA). Despite its use being discouraged by FFI guidelines, studies have shown promising results for the prediction of sex, ancestry, and age through use of FPA, thereby indicating that these measurements might also be useful for discriminating individuals. Recent studies have pointed out the relevance of using the iris diameter measure as a fixed reference for creating ratios (i.e., iris ratios) to enhance method sensitivity for detecting metric facial differences. Nonetheless, no study to date has applied them for discrimination purposes. In this sense, the present work aims to evaluate less frequent FPA measures (Euclidean distances divided by iris diameter), in order to better understand which of them are least likely to be found within Brazilian adult individuals and, hence, have the greatest discriminating potential. Standardized frontal view facial images of 600 individuals, equally distributed by sex and age groups of 20, 30, 40, 50, and 60 years old ± one year, were analyzed. Multinomial and binomial LASSO logistic regressions were applied to select the least frequently occurring measures between groups (namely *age*, *sex*, *male* and *female*) and Effect size (ES) was applied to quantify differences within groups. In the end, only reliable and non-frequent measures, with at least one analyzed group selected by LASSO, were classified as having the greatest potential for discriminating individuals. It was concluded that, from all 211 measures assessed, a total of 16 have the greatest potential for distinguishing between human faces.

1 Introduction

Each individual has characteristics and attributes that set them apart from others. Understanding the facial features (whether metric or morphological) that are rarest and the ones that are more likely to be found within a specific population is extremely important for human individualization processes, especially in Forensic

Facial Identification (FFI) (1). In such cases, the presence of an uncommon feature, or a combination of them, can be highly suggestive of a positive match or, indeed, lead to exclusion of a suspect, whereas the presence of more frequent characteristics on both images under comparison will be less significant (1-3).

The lack of population-specific facial feature frequencies and occurrence probabilities prevents the application of statistical models in the evaluation process of FFI evidence (4, 5). Currently, FFI evidence interpretation relies mostly on examiner expertise, in light of the lack of objective parameters for determining the information that is most relevant for a match decision. With respect to the metric approach to the assessment of facial features on images, i.e., facial photo-anthropometry (FPA), the absence of population databases and evaluative protocols contributes to quantitative comparisons being unsuitable for individualization purposes (6-8) and not being recommended as evidence in a court of law, especially when dealing with low-quality and non-standardized images (2, 4, 6-10).

Nevertheless, FPA studies have reported its potential for the construction of biological profiles in forensic anthropology casework, by distinguishing populations according to their age, sex, and ancestry, thereby emphasizing that facial features might also be useful for personal individualization (1, 11-16). FPA measures have also already proven to be valuable in successfully matching the identities of suspects in several law enforcement cases, through the analysis of images from identity documents and passports (17). Furthermore, it is an objective and reproducible tool for the extraction, interpretation, and classification of human facial information, especially within large populations, and has promising potential for automation (18). With regards to the discriminatory power of specific measures, angles and indices, however, studies have shown that the variability between facial measures of the same individual can be as great as their variability between different individuals, mainly due to the influence of image acquisition factors (e.g., variations in camera angle, lenses and resolution) (6-8, 10). Moreover, high correlation between measures limits practical application in face discrimination, even with high-quality frontal view standardized images, essentially supporting the use of FPA measures for exclusion purposes only (7, 8, 10).

One particular reason may be that commonly used methodologies for assessment of discriminatory potential are not sensitive enough to detect facial differences. A recent study used horizontal visible iris diameter (HVID) as a more sensitive tool for detecting facial growth and for estimating child and sub-adult ages

(14). Apart from this, HVID has been shown to be an important FPA reference as a magnification factor for image scaling or even as a common denominator in the determination of facial ratios and proportions (14, 19, 20). Such uses are justified by its low variability and long-term stability, along with the fact that is the most isometric distance of the human face (14, 18).

In this sense, the present study aims to assess which FPA measures (Euclidean distances divided by the iris diameter) are least frequent, and therefore potentially most discriminant, within a population of unrelated Brazilian individuals of both sexes and within five age groups (20, 30, 40, 50, and 60 years old ± one year). Descriptive analysis was performed to determine the least frequent measures. LASSO logistic regression was performed to indicate the least frequent measures between groups (namely *age*, *sex*, *male* and *female*). Each analysis resulted in a list of potentially discriminant FPA-measures. Apart from introducing a novelty in analyzing and presenting FPA frequency data by using iris ratios, this study is a preliminary step of great importance for further discriminatory studies.

2 Material and methods

2.1 Reference facial images

Standardized frontal view facial images of 600 individuals of both sexes and from five age groups (20, 30, 40, 50, and 60 years old ± one year) were randomly selected from a Brazilian civilian database. Each age group consisted of 120 images homogeneously divided by sex. All images underwent a pre-selection process with the following inclusion criteria: all facial landmarks visible, faces aligned with the Frankfurt plane, neutral facial expression, absence of beard, mustache, and makeup. Images were acquired at resolutions of 640 x 480 pixels.

2.2 Metric analysis

A manual-form approach of FPA landmark-positioning proposed by Flores et al. (21) was used for metric assessment. Facial landmarks with lack of short-term stability (i.e. those that rapidly change) (e.g., *Psg*, *Ps*, *Pi*, *Me*, *Se*, *Le*, *Spn*, *Ln*) (5), low reproducibility (e.g., *Lm*) and/or are poorly referenced in FFI scientific works (e.g., Mid)

were excluded (1, 2, 13, 18, 22). Ear landmarks (*Sa*, *Pa*, *Sba*, *Slb*) were not analyzed as they are frequently obstructed by hair, especially in female images. Despite the exclusion of eyebrow landmarks, the positioning of *Laterale Eyebrow* landmark (*Le*) was required to determine the *Frontotemporale* landmark (*Ft*), according to the referenced methodology (p. 23) (21). The following 23 landmarks were considered: Alare (*Al*); Chelion (*Ch*); Crista Philtre (*Cph*); Ectocanthion (*Ec*); Endocanthion (*En*); Frontotemporale (*Ft*); Glabella (*G*); Gnathion (*Gn*); Gonion (*Go*); Iridion Laterale (*Il*); Iridion Mediale (*Im*); Labiale Inferius (*Li)*; Labiale Superius (*Ls*); Nasion (*N*); Superius Nostril (*Spn*); Laterale Nostril (*Ln)*; Pronasale (*Prn*); Pupil (*Pu*); Subalare (*Sbal*); Subnasale (*Sn*); Stomion (*Sto*); Trichion (*Tr*); and, Zygion (*Zy*) (APPENDIX B).

The FPA analysis was carried out by a single examiner and interexaminer analysis was performed to confirm its reliability. For this purpose, 65 standardized frontal view images of 40-year-old individuals were analyzed by four examiners and results were compared solely with the same age group from the sample.

For face mapping, a non-commercial software package for two-dimensional facial analysis (SAFF-2D®, Forensic Facial Analysis System, Department of Federal Police, Brazil) was used. The software allows examiners to locate the facial landmarks on images and to automatically register them through Cartesian coordinates (X, Y).

2.3 Data treatment

Initially, 211 Euclidean distances (ED) were calculated from the Cartesian coordinates (X, Y) by applying the Pythagorean Theorem. Of all measures, 14 were horizontal (HM), 19 vertical (VM), 160 bilateral (BM) and 18 included both sides (R-right and L-left) at the same distance, namely cross-side measure (CM). The latter two were presented as duplicate distances that correspond to each facial side, e.g., *PuL-ChL (BM)*, *PuR-ChR (BM), ChL-Li (BM), ChR-Li (BM)*, *PuL-ChR (CM)*, *PuR-ChL (CM)*.

To reduce the influence of imaging acquisition factors and to make measures comparable, they were all divided by the iris diameter (Euclidean distance mean between *Iridion Laterale* and *Iridion Mediale* landmarks from both sides of the face). In this sense, all Euclidean distances are reported as a fraction in relation to the iris diameter of each individual.

2.4 Results assessment

Initially, the normality of the data was assessed by the Shapiro-Wilk test. To select most relevant measures based on distinguishing potential, all of them were analyzed according to reliability, general frequency and frequency between (LASSO) groups, namely *age*, *sex*, *male* and *female*. The reliability of the measures was determined by interexaminer agreement and error analysis. The first was assessed by intra-class correlation coefficient (ICC) and calculated in two distinct ways, ICC_s-single and ICC_a-average. ICC_a represents the average agreement of the four examiners, whereas ICC_s is the estimated agreement for a single examiner. Error analysis was calculated as the percentage difference between sample (SD_s) and interexaminer (SD_e) variabilities, representing how much the sample diverged from the examiners' evaluation mean. Reliable measures were considered as those with an error ≤ 30% and excellent agreement results (ICC_s and $ICC_a \geq 0.75$).

General frequency was initially investigated through descriptive analysis (CV-coefficient of variation). Statistical differences between sex and age groups were verified by Mann-Whitney and Kruskal-Wallis tests, respectively. Effect size (ES) was used to establish the magnitude of differences within groups, in accordance with the formula: $ES_i = \frac{|\min(\bar{x}_i) - \max(\bar{x}_i)|}{s(x_i)}$, i = 1, 2, 3, …, 211 (23). After calculating the mean of all groups (x), the modulus of the difference between the lowest and highest was divided by the common standard deviation (s). LASSO (*Least Absolute Shrinkage and Selection Operator*) logistic regression was applied to select the least frequent measures between groups using the function cv.glmnet of R package. This analysis is presented in the last section, along with all analyzed groups scores. Differences between facial sides were evaluated by the Wilcoxon paired test.

Finally, only reliable and non-frequent measures, selected at least once by LASSO, were classified as having the greatest potential for discriminating individuals. FPA measures distribution of classified measures are displayed in APPENDIX C. Results of all these statistical analyses were assessed against a statistical significance level of 5% ($\alpha = 0.05$).

3 Results

Results are organized into nine sections (from 3.1 to 3.9). The first set of analyses investigated the reliability and frequency of the measures (3.2 and 3.4, respectively), as well as facial side differences (3.3). Frequency within groups (ES) is reported in sections 3.5 to 3.8. Finally, compiled results from each analysis were considered together with the frequency between groups results (LASSO), in order to classify and score the most potentially discriminatory measures.

3.1 General statistical analysis

The Shapiro-Wilk test indicated that the data were not normally distributed and, thus, a non-parametric statistical analysis was subsequently conducted.

3.2 Reliability analysis

Of all 211 measures, 105 showed excellent interexaminer agreement results (ICC_s and $ICC_a \geq 0.75$), revealing desirable levels of concordance for almost half of the measures (Table 2.1). All measures composed of *Tr* and *ZyL/R* landmarks showed poor-agreement ($ICC_s < 0.50$) and unacceptable error results (error > 30%). Similarly, none of the measures composed of *LnL/R* and *SbalL/R* landmarks were classified according to reliability criteria, indicating that their variability is more consistent with methodological error than innate population variability.

On the contrary, almost all measures composed of landmarks containing *ImL/R* (except for *ImR-Gn* and *ImL-GoR*), *Li* (except for *Li-Sto* and *Li-Gn*) and *PuL/R* (except for *PuL-Tr*, *PuR-Tr*, and *PuR-Gn*) were classified with acceptable reliability results. Indeed, lower variability differences (error) were observed for *EnL-Li* (0.03), *PuR-ChL* (0.03), and *EnL-G* (0.10), demonstrating superior consistency between examiners. Iris diameter (i.e., *IlL-ImL* and *IlR-ImR*) was found to be the most reliable measure, even when analysed by different examiners. Indeed, it displayed the lowest interexaminer deviations ($SD_i = 0.01$), highest average agreement results ($ICC_a = 0.98$) and low error (1.02). In general, landmarks from the eye region (e.g., *EnL/R*, *ImL/R, PuL/R*, *IlL/R*) appeared most frequently among the most reliable measures. All these results are consistent with previous landmark-positioning variability studies, which suggested

greater reproducibility for landmarks located in the mouth and eye region, as well as lower reproducibility for the *ZyR/L* landmark (2, 18, 24-26).

Contrary to these studies, measures including landmarks from the nose region, particularly from the nostrils (e.g., *Ln* and *Spn*), showed poor agreement. Indeed, high errors > 90% were observed for *LnL-Sn*, *LnR-SbalR*, *AlL-SbalL*, *SpnL-SbalL*, *SpnR-SbalR*, and *AlR-SbalR*. This statement does not apply to *Spn-Spn* or to measures composed of *AlR/L* landmarks, which generally showed the opposite results (e.g., *Al-Al*, *AlR-Sto*, *AlR-ChR*, and *AlL-Sn*). The poor reliabilities of nasal measures can be explained by the fact that even slight variations in lighting and facial pose (particularly from vertical and transverse axes rotations) can affect the way nasal structures are perceived by the examiner, leading to improper positioning of landmarks and thus increasing intra- and interexaminer errors.

As a result of the reliability analysis, a total of 96 measures were considered as reliable for discriminatory purposes (72 BM, 11 CM, 6 VM, and 7 HM, corresponding to 45%, 61%, 31% and 50% of the total measures, respectively).

Table 2.1 **-** Reliability classification (Rc) of all measures sorted in ascending order according to error values (%). Measures within desirable values are presented in bold (ICC_s and $ICC_a \geq 0.75$; error < 30%) and marked with an asterix in the last colum (*). Reference number of each measure in alphabetical order is displayed in the first column (#). (R: right side; L: left side)

#	Type	Measure	ICCa	ICCs	SDi	%	Rc	#	Type	Measure	ICCa	ICCs	SDi	%	Rc
167	CM	PuR-ChL	**0.94**	**0.80**	0.20	**0.03**	*	119	CM	IlR-FtL	0.72	0.39	0.26	**21.46**	
77	BM	EnL-Li	**0.95**	**0.84**	0.20	**0.03**	*	162	BM	PuL-Ls	**0.95**	**0.81**	0.17	**21.48**	*
75	BM	EnL-G	**0.96**	**0.84**	0.06	**0.10**	*	170	BM	PuR-Gn	**0.89**	0.67	0.29	**21.63**	
85	BM	EnR-G	**0.96**	**0.87**	0.06	**1.01**	*	43	BM	CphR-Ls	**0.80**	0.49	0.06	**21.94**	
122	BM	IlR-ImR	**0.98**	**0.90**	0.01	**1.02**	*	132	CM	ImL-GoR	**0.90**	0.70	0.29	**21.94**	
114	BM	IlL-ImL	**0.98**	**0.90**	0.01	**1.02**	*	37	BM	CphL-Ls	**0.82**	0.54	0.07	**22.48**	
135	CM	ImR-ChL	**0.94**	**0.80**	0.20	**1.26**	*	92	HM	Ft-Ft	0.65	0.32	0.32	**22.53**	
6	BM	AlL-N	**0.93**	**0.76**	0.17	**1.43**	*	19	BM	AlR-Sn	**0.95**	**0.83**	0.07	**22.68**	*
163	BM	PuL-Prn	**0.97**	**0.88**	0.11	**1.56**	*	104	BM	GoR-G	**0.92**	**0.75**	0.24	**22.72**	*
109	VM	G-Sn	**0.95**	**0.83**	0.16	**1.77**	*	138	BM	ImR-Gn	**0.90**	0.68	0.29	**22.83**	
60	CM	EcR-ChL	**0.92**	**0.75**	0.23	**1.78**	*	88	BM	EnR-Ls	**0.92**	0.73	0.17	**23.20**	
55	BM	EcL-N	**0.88**	0.64	0.15	**1.82**		97	VM	G-Gn	**0.91**	0.73	0.31	**23.90**	
152	VM	Ls-Li	**0.93**	**0.78**	0.08	**1.86**	*	13	BM	AlR-ChR	**0.97**	**0.87**	0.06	**23.96**	*
130	BM	ImL-G	**0.93**	**0.78**	0.10	**1.93**	*	44	BM	CphR-Sn	**0.94**	**0.79**	0.07	**25.06**	*
87	BM	EnR-Li	**0.96**	**0.85**	0.19	**1.98**	*	154	VM	N-Gn	**0.90**	0.69	0.31	**25.17**	
172	BM	PuR-Prn	**0.96**	**0.87**	0.11	**2.18**	*	106	BM	GoR-Ls	**0.96**	**0.87**	0.15	**25.55**	*
160	BM	PuL-G	**0.93**	**0.78**	0.10	**2.39**	*	188	BM	SpnL-Sn	**0.92**	0.74	0.06	**25.57**	
3	CM	AlL-ChR	**0.94**	**0.79**	0.13	**2.53**	*	191	BM	SpnR-Sn	**0.92**	0.74	0.06	**25.57**	
155	VM	N-Prn	**0.97**	**0.89**	0.12	**2.54**	*	20	BM	AlR-Sto	**0.97**	**0.88**	0.08	**25.61**	*
42	BM	CphR-Li	**0.97**	**0.90**	0.07	**2.90**	*	78	BM	EnL-Ls	**0.93**	**0.77**	0.17	**25.90**	*
51	BM	EcL-G	**0.89**	0.68	0.15	**2.90**		86	BM	EnR-Gn	**0.90**	0.69	0.29	**26.03**	
144	HM	Ln-Ln	**0.90**	0.68	0.13	**2.90**		107	BM	GoR-Prn	**0.95**	**0.82**	0.18	**26.18**	*
16	BM	AlR-N	**0.93**	**0.77**	0.17	**3.19**	*	28	BM	ChR-Gn	**0.89**	0.67	0.13	**26.20**	
72	BM	EnL-AlL	**0.94**	**0.80**	0.14	**3.89**	*	143	VM	Li-Sto	**0.76**	0.44	0.08	**26.23**	
69	BM	EcR-Sto	**0.94**	**0.78**	0.21	**3.96**	*	52	BM	EcL-Gn	**0.92**	0.74	0.29	**27.05**	
164	BM	PuL-Sn	**0.95**	**0.84**	0.14	**4.18**	*	112	BM	IlL-Gn	**0.93**	**0.76**	0.28	**27.42**	*

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31	BM	ChR-Sn	**0.92**	0.74	0.11	**4.18**		161	BM	PuL-Gn	**0.93**	**0.76**	0.28	**27.44**	*
74	BM	EnL-EcL	**0.85**	0.59	0.11	**4.22**		131	BM	ImL-Gn	**0.93**	**0.76**	0.28	**27.45**	*
117	BM	IlL-Sn	**0.95**	**0.84**	0.14	**4.26**	*	23	BM	ChL-Gn	**0.89**	0.68	0.12	**27.59**	
134	BM	ImL-Sn	**0.96**	**0.84**	0.14	**4.27**	*	101	BM	GoL-Ls	**0.95**	**0.81**	0.16	**28.40**	*
46	HM	Ec-Ec	**0.90**	0.68	0.28	**4.51**		102	BM	GoL-Prn	**0.95**	**0.81**	0.18	**28.76**	*
68	BM	EcR-Sn	**0.93**	**0.76**	0.18	**4.58**	*	15	BM	AlR-Ls	**0.91**	0.71	0.08	**29.36**	
49	CM	EcL-ChR	**0.91**	0.72	0.24	**4.90**		192	HM	Spn-Spn	**0.97**	**0.90**	0.06	**29.76**	*
159	CM	PuL-ChR	**0.93**	**0.77**	0.21	**5.32**	*	76	BM	EnL-Gn	**0.92**	0.74	0.28	30.04	
54	CM	EcL-IlR	**0.93**	**0.76**	0.22	**5.41**	*	142	VM	Li-Gn	**0.91**	0.71	0.12	30.87	
116	BM	IlL-N	**0.93**	**0.77**	0.09	**5.43**	*	105	BM	GoR-Gn	**0.88**	0.64	0.20	31.55	
59	BM	EcR-AlR	**0.93**	**0.76**	0.16	**5.45**	*	151	VM	Ls-Gn	**0.94**	**0.81**	0.13	31.57	
17	BM	AlR-Prn	**0.95**	**0.83**	0.08	**5.77**	*	100	BM	GoL-Gn	**0.86**	0.60	0.21	32.68	
82	BM	EnR-AlR	**0.94**	**0.79**	0.13	**5.79**	*	38	BM	CphL-Sn	**0.94**	**0.78**	0.07	33.00	
121	BM	IlR-GoR	**0.85**	0.58	0.20	**5.79**		5	BM	AlL-Ls	**0.96**	**0.86**	0.07	33.27	
25	BM	ChL-Ls	**0.95**	**0.83**	0.07	**5.88**	*	41	BM	CphR-Gn	**0.94**	**0.81**	0.14	33.37	
7	BM	AlL-Prn	**0.96**	**0.86**	0.06	**5.95**	*	183	VM	Sn-Ls	**0.94**	**0.80**	0.07	34.20	
79	BM	EnL-Sn	**0.95**	**0.82**	0.13	**6.02**	*	35	BM	CphL-Gn	**0.95**	**0.84**	0.13	35.39	
129	CM	ImL-ChR	**0.93**	**0.77**	0.21	**6.04**	*	14	BM	AlR-Gn	**0.91**	0.71	0.18	36.91	
156	VM	N-Sn	**0.94**	**0.81**	0.16	**6.04**	*	45	BM	CphR-Sto	0.73	0.41	0.07	37.38	
184	VM	Sn-Prn	**0.90**	0.69	0.08	**6.49**		4	BM	AlL-Gn	**0.95**	**0.81**	0.16	38.70	
36	BM	CphL-Li	**0.97**	**0.89**	0.08	**6.65**	*	200	CM	ZyL-GoR	0.40	0.14	0.79	40.13	
125	BM	IlR-Sn	**0.95**	**0.81**	0.14	**6.70**	*	182	VM	Sn-Gn	**0.95**	**0.83**	0.16	41.27	
137	BM	ImR-G	**0.96**	**0.85**	0.09	**6.71**	*	193	VM	Sto-Gn	**0.93**	**0.78**	0.12	41.73	
56	BM	EcL-Sn	**0.94**	**0.78**	0.17	**6.73**	*	111	CM	IlL-FtR	0.53	0.22	0.30	42.31	
65	BM	EcR-GoR	**0.84**	0.57	0.20	**6.84**		210	BM	ZyR-Tr	**0.80**	0.49	1.00	54.40	
169	BM	PuR-G	**0.96**	**0.85**	0.09	**6.85**	*	108	BM	GoR-Tr	**0.87**	0.63	0.74	54.77	
39	BM	CphL-Sto	**0.86**	0.61	0.08	**6.85**		195	VM	Tr-Gn	**0.87**	0.63	0.95	56.42	
66	CM	EcR-IlL	**0.92**	0.74	0.23	**7.31**		211	HM	Zy-Zy	0.12	0.03	1.03	56.66	
173	BM	PuR-Sn	**0.95**	**0.82**	0.14	**7.46**	*	93	BM	FtL-N	0.19	0.06	0.22	59.60	
30	BM	ChR-Ls	**0.93**	**0.78**	0.09	**7.68**	*	95	BM	FtR-N	0.28	0.09	0.22	59.98	
133	CM	ImL-IlR	**0.95**	**0.83**	0.17	**7.75**	*	206	CM	ZyR-GoL	0.24	0.07	1.09	62.26	
40	BM	CphR-ChR	**0.94**	**0.80**	0.08	**7.81**	*	32	BM	ChR-Tr	**0.87**	0.63	0.83	65.23	
166	HM	Pu-Pu	**0.95**	**0.83**	0.16	**7.88**	*	62	BM	EcR-FtR	0.24	0.07	0.16	65.36	
110	HM	Il-Il	**0.95**	**0.83**	0.16	**7.88**	*	204	BM	ZyR-G	0.19	0.06	0.87	66.74	
127	HM	Im-Im	**0.95**	**0.83**	0.16	**7.89**	*	197	BM	ZyL-G	0.22	0.07	0.88	68.38	
24	BM	ChL-Li	**0.97**	**0.89**	0.07	**7.90**	*	198	BM	ZyL-Gn	0.15	0.04	1.21	69.97	
29	BM	ChR-Li	**0.97**	**0.89**	0.07	**7.90**	*	27	BM	ChL-Tr	**0.86**	0.61	0.95	71.36	
140	CM	ImR-IlL	**0.95**	**0.83**	0.16	**8.00**	*	21	BM	AlR-Tr	**0.86**	0.61	0.83	71.67	
67	BM	EcR-N	**0.89**	0.67	0.16	**8.06**		70	BM	EcR-Tr	**0.86**	0.61	0.67	71.84	
157	VM	N-Sto	**0.94**	**0.78**	0.20	**8.08**	*	205	BM	ZyR-Gn	0.08	0.02	1.27	71.89	
63	BM	EcR-G	**0.91**	0.71	0.15	**8.17**		103	BM	GoL-Tr	**0.86**	0.61	1.02	71.90	
141	BM	ImR-Sn	**0.95**	**0.82**	0.14	**8.23**	*	196	VM	Tr-Sn	**0.86**	0.61	0.86	73.66	
34	BM	CphL-ChL	**0.86**	0.61	0.09	**8.56**		96	BM	FtR-Tr	**0.86**	0.60	0.62	74.26	
47	BM	EcL-AlL	**0.93**	**0.78**	0.15	**8.72**	*	126	BM	IlR-Tr	**0.86**	0.60	0.68	74.33	
124	BM	IlR-N	**0.95**	**0.83**	0.09	**8.75**	*	174	BM	PuR-Tr	**0.86**	0.60	0.71	75.22	
12	CM	AlR-ChL	**0.94**	**0.80**	0.12	**8.90**	*	11	BM	AlL-Tr	**0.86**	0.60	0.93	75.91	
89	BM	EnR-Sn	**0.94**	**0.80**	0.14	**9.10**	*	50	BM	EcL-FtL	0.13	0.04	0.21	76.00	
90	BM	EnR-Sto	**0.94**	**0.81**	0.17	**9.37**	*	202	BM	ZyL-Sn	0.18	0.05	1.00	76.07	
57	BM	EcL-Sto	**0.92**	0.73	0.22	**9.45**		201	BM	ZyL-Prn	0.19	0.06	0.94	76.33	
84	BM	EnR-EcR	**0.88**	0.65	0.11	**9.84**		203	BM	ZyL-Tr	**0.82**	0.54	1.42	76.42	
98	HM	Go-Go	**0.84**	0.57	0.36	**10.25**		207	BM	ZyR-GoR	0.05	0.01	1.27	76.77	
10	BM	AlL-Sto	**0.92**	0.73	0.09	**10.82**		209	BM	ZyR-Sn	0.07	0.02	1.03	77.59	
26	BM	ChL-Sn	**0.91**	0.73	0.09	**11.35**		91	BM	EnR-Tr	**0.85**	0.60	0.76	77.80	
1	HM	Al-Al	**0.97**	**0.89**	0.10	**11.86**	*	208	BM	ZyR-Prn	0.09	0.02	0.97	78.15	
80	BM	EnL-Sto	**0.93**	**0.77**	0.19	**11.87**	*	148	BM	LnR-Prn	0.05	0.01	0.22	81.11	
181	HM	Sbal-Sbal	**0.75**	0.43	0.20	**12.75**		194	VM	Tr-G	**0.85**	0.58	0.84	81.34	
153	VM	Ls-Sto	**0.85**	0.58	0.05	**13.80**		81	BM	EnL-Tr	**0.85**	0.59	0.86	81.47	
9	BM	AlL-Sn	**0.96**	**0.86**	0.06	**14.02**	*	165	BM	PuL-Tr	**0.85**	0.58	0.92	82.13	
33	HM	Cph-Cph	**0.93**	**0.77**	0.09	**14.09**	*	199	BM	ZyL-GoL	0.05	0.01	1.56	82.20	
53	BM	EcL-GoL	**0.96**	**0.84**	0.16	**14.16**	*	145	BM	LnL-Prn	0.05	0.01	0.20	82.30	
128	BM	ImL-ChL	**0.94**	**0.81**	0.17	**15.19**	*	58	BM	EcL-Tr	**0.85**	0.58	0.95	82.46	
158	BM	PuL-ChL	**0.94**	**0.80**	0.17	**15.62**	*	146	BM	LnL-SbalL	0.48	0.19	0.67	82.52	
73	BM	EnL-ChL	**0.93**	**0.77**	0.17	**15.79**	*	118	BM	IlL-Tr	**0.85**	0.58	0.93	82.61	
185	VM	Sn-Sto	**0.94**	**0.81**	0.08	**16.32**	*	150	BM	LnR-Sn	0.04	0.01	0.21	82.75	
22	HM	Ch-Ch	**0.90**	0.69	0.14	**16.41**		94	BM	FtL-Tr	**0.85**	0.58	0.94	86.02	
123	BM	IlR-Ls	**0.93**	**0.76**	0.18	**16.78**	*	189	BM	SpnR-LnR	0.00	0.00	0.19	87.46	

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113	BM	IlL-GoL	**0.95**	**0.82**	0.17	**16.83**	*	178	BM	SbalR-Ls	0.38	0.13	0.64	87.79
99	BM	GoL-G	**0.93**	**0.76**	0.25	**16.84**	*	186	BM	SpnL-LnL	0.09	0.03	0.19	87.82
48	BM	EcL-ChL	**0.93**	**0.77**	0.19	**17.18**	*	175	BM	SbalL-Ls	0.39	0.14	0.63	88.47
61	BM	EcR-ChR	**0.93**	**0.78**	0.16	**17.24**	*	176	BM	SbalL-Prn	0.34	0.11	0.60	89.19
83	BM	EnR-ChR	**0.93**	**0.78**	0.16	**17.24**	*	179	BM	SbalR-Prn	0.33	0.11	0.62	89.45
64	BM	EcR-Gn	**0.87**	0.62	0.31	**17.33**		177	BM	SbalL-Sn	0.37	0.13	0.64	89.66
168	BM	PuR-ChR	**0.94**	**0.81**	0.16	**17.45**	*	180	BM	SbalR-Sn	0.36	0.12	0.66	89.99
139	CM	ImR-GoL	**0.93**	**0.76**	0.28	**17.62**	*	18	BM	AlR-SbalR	0.34	0.11	0.60	91.87
136	BM	ImR-ChR	**0.94**	**0.81**	0.16	**17.71**	*	190	BM	SpnR-SbalR	0.33	0.11	0.59	92.63
71	HM	En-En	**0.96**	**0.85**	0.11	**18.13**	*	187	BM	SpnL-SbalL	0.34	0.11	0.62	92.98
171	BM	PuR-Ls	**0.93**	**0.76**	0.18	**18.27**	*	8	BM	AlL-SbalL	0.33	0.11	0.64	93.62
2	BM	AlL-ChL	**0.96**	**0.86**	0.07	**20.11**	*	149	BM	LnR-SbalR	0.48	0.19	0.63	94.88
120	BM	IlR-Gn	**0.89**	0.66	0.29	**20.40**		147	BM	LnL-Sn	0.00	0.00	0.20	95.24
115	BM	IlL-Ls	**0.95**	**0.81**	0.17	**21.25**	*							

Source: prepared by the author.

*ICC_a: average intra-class correlation coefficient; ICC_s: single intra-class correlation coefficient; SD_i: standard deviation between examiners; Rc: Reliability classification; % (error): Percentage difference between sample and examiner deviations (SD_s and SD_e).

3.3 Facial side analysis

Results showed significant differences between facial sides, hence facial asymmetry, for 37% of all BM and CM measures (66 in a total of 178) (Appendix A). Higher significant differences were observed for BM *Ec-Ch* (0.29), *Ec-G* (0.06) and *Cph-Ch* (0.06). As the mouth is essentially supported by soft tissues, great changeability is seen in its components, which respond differently to facial changing factors (e.g., expressions, musculoskeletal dysfunctions and the aging process). This can explain why mouth landmarks, such as *Ch* and *Cph,* were more frequently found among the measures with significant differences.

Identical averages were observed for *Ch-Li*, *Al-Sn* and *Spn-Sn*, revealing facial symmetry in distances that correspond to both the upper part of the nostril and the ala of the nose (nasal wing) to the midpoint of the nasal base (*Al-Sn* and *Spn-Sn*). *Ch-Li* results can be explained by the methodology adopted, in which the *Li* landmark is positioned over a vertical line defined as the mean of the X coordinate distance between both sides *Ch*. Although the methodology intended to reduce landmarking positioning variability, bringing the *Li* landmark to a mean point limited its usefulness in detecting anatomical differences. Despite most measures showing no significant difference between facial sides in the present study, results will be presented separately hereafter in order to better assist future works.

3.4 General Frequency Analysis

Frequency results by descriptive analysis (CV) are displayed in Table 2.2. High CV values indicate great measure variability in relation to its mean, thus suggesting its low frequency. The highest CVs were observed for *SpnL-LnL* (66.68), *SpnR-LnR* (61.34) and *EcL-FtL* (41.10), showing variations above 50% relative to their mean. Despite indicating low frequency, preceding low-reliability results indicate the deviations are more consistent with methodological error for these particular measures.

On the contrary, a low CV indicates very close deviation, thus high correlation between measures, which may render them inappropriate for discriminatory purposes. Measures with lowest CVs were *IlL-ImL* (0.01), *IlR-ImR* (0.01), *Il-Il* (5.56), *EcL-ChR* (5.79) *and EcR-ChL* (5.81). The first two results are justified by the imaging normalization process. The *Zy-Zy* (HM) was also within the least variable measures (7.76), contrary to other measures composed of the *Zy* landmark, such as *ZyL-Tr* (23.51) and *ZyL-GoL* (16.28), confirming results of previous studies that concluded that this landmark is only reliable in horizontal measures (2, 18).

Therefore, it was possible to observe that HM were more frequently seen among the measures with lower variation, whereas VM were more often among those with higher variations, confirming previous studies that found greater distortion in vertical axis measures (17). Nonetheless, considering that the sample is composed of different age groups, these results were already expected, due to the predominantly vertical nature of both facial development and the aging process (14, 27). Indeed, vertical facial measures, such as *Tr* and *Gn,* displayed greater variations.

From this analysis, 142 measures were classified for final selection (CV ≥ 8.00). This threshold was chosen with the view of withdrawing nearly 30% of measures with lowest CV. LASSO selection is presented hereafter in a specific section along with all analyzed groups.

Table 2.2 - Descriptive analysis of all measures sorted in ascending order according to coefficient of variation (CV). Reference number of each measure in alphabetical order is displayed in the first column (#) as well as their type classification in the second column. Measures within desirable values are presented in bold (CV ≥ 8.00). (R: right side; L: left side)

#	Type	Measure	Mean	SD	CV	CI - 95%[1]	#	Type	Measure	Mean	SD	CV	CI - 95%[1]
114	BM	IIL-ImL	1.00	0.01	0.01	[1.00; 1.00]	107	BM	GoR-Prn	6.06	0.58	**9.60**	[6.02; 6.11]
122	BM	IIR-ImR	1.00	0.01	0.01	[1.00; 1.00]	82	BM	EnR-AlR	3.02	0.30	**9.79**	[2.99; 3.04]
110	HM	Il-Il	6.48	0.36	5.56	[6.45; 6.50]	31	BM	ChR-Sn	3.00	0.30	**9.82**	[2.98; 3.02]
49	CM	EcL-ChR	8.35	0.48	5.79	[8.31; 8.38]	30	BM	ChR-Ls	2.17	0.21	**9.87**	[2.15; 2.19]
60	CM	EcR-ChL	8.33	0.48	5.81	[8.29; 8.37]	24	BM	ChL-Li	2.22	0.22	**9.92**	[2.21; 2.24]
54	CM	EcL-IIR	7.08	0.41	5.83	[7.05; 7.12]	29	BM	ChR-Li	2.22	0.22	**9.92**	[2.21; 2.24]
66	CM	EcR-IIL	7.11	0.41	5.83	[7.07; 7.14]	25	BM	ChL-Ls	2.14	0.21	**9.94**	[2.12; 2.16]
167	CM	PuR-ChL	7.73	0.47	6.05	[7.69; 7.76]	71	HM	En-En	2.77	0.28	**10.06**	[2.75; 2.79]
159	CM	PuL-ChR	7.75	0.47	6.06	[7.72; 7.79]	72	BM	EnL-AlL	3.03	0.31	**10.06**	[3.00; 3.05]
46	HM	Ec-Ec	7.71	0.48	6.22	[7.67; 7.74]	26	BM	ChL-Sn	2.96	0.30	**10.10**	[2.94; 2.99]
135	CM	ImR-ChL	7.42	0.47	6.33	[7.39; 7.46]	182	VM	Sn-Gn	6.06	0.62	**10.19**	[6.01; 6.11]
129	CM	ImL-ChR	7.45	0.47	6.35	[7.42; 7.49]	2	BM	AlL-ChL	2.77	0.28	**10.23**	[2.75; 2.79]
99	BM	GoL-G	9.07	0.59	6.53	[9.02; 9.11]	105	BM	GoR-Gn	6.55	0.67	**10.25**	[6.50; 6.61]
140	CM	ImR-IIL	5.48	0.36	6.57	[5.45; 5.51]	101	BM	GoL-Ls	5.26	0.54	**10.33**	[5.21; 5.30]
166	HM	Pu-Pu	5.48	0.36	6.57	[5.45; 5.51]	13	BM	AlR-ChR	2.81	0.29	**10.42**	[2.79; 2.83]
133	CM	ImL-IIR	5.48	0.36	6.58	[5.45; 5.50]	108	BM	GoR-Tr	13.61	1.44	**10.55**	[13.49; 13.73]
104	BM	GoR-G	9.08	0.60	6.60	[9.03; 9.12]	5	BM	AlL-Ls	2.77	0.30	**10.70**	[2.74; 2.79]
57	BM	EcL-Sto	6.98	0.46	6.65	[6.95; 7.01]	15	BM	AlR-Ls	2.79	0.30	**10.78**	[2.77; 2.81]
119	CM	IIR-FtL	7.83	0.52	6.65	[7.79; 7.87]	106	BM	GoR-Ls	5.23	0.56	**10.78**	[5.18; 5.27]
69	BM	EcR-Sto	6.99	0.47	6.71	[6.95; 7.02]	41	BM	CphR-Gn	4.67	0.50	**10.79**	[4.63; 4.71]
51	BM	EcL-G	4.14	0.28	6.85	[4.12; 4.16]	35	BM	CphL-Gn	4.68	0.51	**10.90**	[4.64; 4.72]
132	CM	ImL-GoR	9.57	0.66	6.90	[9.52; 9.63]	1	HM	Al-Al	3.26	0.36	**10.91**	[3.23; 3.29]
52	BM	EcL-Gn	10.53	0.73	6.92	[10.47; 10.59]	151	VM	Ls-Gn	4.45	0.50	**11.15**	[4.41; 4.49]
97	VM	G-Gn	11.38	0.79	6.96	[11.32; 11.44]	193	VM	Sto-Gn	3.98	0.45	**11.35**	[3.94; 4.01]
112	BM	IIL-Gn	10.51	0.74	7.00	[10.45; 10.57]	9	BM	AlL-Sn	1.74	0.20	**11.50**	[1.73; 1.76]
160	BM	PuL-G	3.06	0.22	7.03	[3.04; 3.07]	17	BM	AlR-Prn	1.68	0.20	**11.86**	[1.67; 1.70]
198	BM	ZyL-Gn	10.41	0.73	7.05	[10.36; 10.47]	195	VM	Tr-Gn	16.61	1.99	**11.98**	[16.45; 16.77]
64	BM	EcR-Gn	10.53	0.74	7.06	[10.47; 10.58]	19	BM	AlR-Sn	1.76	0.21	**12.07**	[1.75; 1.78]
205	BM	ZyR-Gn	10.41	0.74	7.08	[10.35; 10.47]	7	BM	AlL-Prn	1.70	0.21	**12.16**	[1.68; 1.72]
120	BM	IIR-Gn	10.50	0.75	7.11	[10.44; 10.56]	210	BM	ZyR-Tr	9.92	1.23	**12.37**	[9.83; 10.02]
139	CM	ImR-GoL	9.59	0.68	7.13	[9.53; 9.64]	40	BM	CphR-ChR	1.70	0.22	**12.65**	[1.68; 1.72]
161	BM	PuL-Gn	10.37	0.74	7.14	[10.30; 10.43]	185	VM	Sn-Sto	2.09	0.27	**12.92**	[2.07; 2.11]
206	CM	ZyR-GoL	12.04	0.86	7.16	[11.97; 12.11]	34	BM	CphL-ChL	1.64	0.22	**13.14**	[1.63; 1.66]
170	BM	PuR-Gn	10.36	0.75	7.22	[10.30; 10.42]	32	BM	ChR-Tr	12.83	1.73	**13.48**	[12.70; 12.97]
75	BM	EnL-G	2.18	0.16	7.25	[2.17; 2.19]	148	BM	LnR-Prn	1.30	0.18	**13.78**	[1.28; 1.31]
131	BM	ImL-Gn	10.25	0.74	7.25	[10.19; 10.30]	154	VM	N-Gn	10.48	1.48	**14.11**	[10.38; 10.62]
63	BM	EcR-G	4.20	0.31	7.29	[4.17; 4.22]	145	BM	LnL-Prn	1.32	0.19	**14.13**	[1.31; 1.34]
138	BM	ImR-Gn	10.24	0.75	7.31	[10.18; 10.30]	207	BM	ZyR-GoR	4.67	0.67	**14.33**	[4.61; 4.72]
74	BM	EnL-EcL	2.45	0.18	7.32	[2.44; 2.47]	175	BM	SbalL-Ls	1.87	0.28	**14.85**	[1.84; 1.89]
84	BM	EnR-EcR	2.49	0.18	7.33	[2.48; 2.51]	147	BM	LnL-Sn	1.22	0.19	**15.18**	[1.21; 1.24]
136	BM	ImR-ChR	6.07	0.45	7.33	[6.03; 6.10]	178	BM	SbalR-Ls	1.88	0.29	**15.33**	[1.85; 1.90]
200	CM	ZyL-GoR	12.00	0.88	7.34	[11.93; 12.07]	144	HM	Ln-Ln	2.28	0.35	**15.37**	[2.25; 2.31]
168	BM	PuR-ChR	6.10	0.45	7.36	[6.07; 6.14]	150	BM	LnR-Sn	1.23	0.19	**15.52**	[1.21; 1.24]
61	BM	EcR-ChR	5.81	0.43	7.39	[5.78; 5.85]	142	VM	Li-Gn	3.24	0.50	**15.56**	[3.20; 3.28]
83	BM	EnR-ChR	5.81	0.43	7.39	[5.78; 5.85]	176	BM	SbalL-Prn	1.45	0.23	**15.81**	[1.43; 1.47]
92	HM	Ft-Ft	8.85	0.65	7.39	[8.80; 8.90]	179	BM	SbalR-Prn	1.43	0.23	**15.99**	[1.41; 1.45]
117	BM	IIL-Sn	5.10	0.38	7.39	[5.07; 5.13]	27	BM	ChL-Tr	12.87	2.08	**16.19**	[12.71; 13.04]
123	BM	IIR-Ls	6.43	0.48	7.41	[6.39; 6.47]	199	BM	ZyL-GoL	4.68	0.76	**16.28**	[4.62; 4.74]
115	BM	IIL-Ls	6.42	0.48	7.42	[6.39; 6.46]	184	VM	Sn-Prn	1.03	0.17	**16.45**	[1.02; 1.05]
128	BM	ImL-ChL	6.04	0.45	7.42	[6.00; 6.08]	103	BM	GoL-Tr	13.79	2.29	**16.61**	[13.61; 13.97]
56	BM	EcL-Sn	5.36	0.40	7.43	[5.33; 5.39]	38	BM	CphL-Sn	1.56	0.27	**17.25**	[1.53; 1.58]
158	BM	PuL-ChL	6.07	0.45	7.45	[6.04; 6.11]	44	BM	CphR-Sn	1.55	0.27	**17.31**	[1.52; 1.57]
90	BM	EnR-Sto	5.88	0.44	7.46	[5.85; 5.92]	188	BM	SpnL-Sn	1.08	0.19	**17.37**	[1.06; 1.09]
48	BM	EcL-ChL	6.10	0.46	7.47	[6.07; 6.14]	191	BM	SpnR-Sn	1.08	0.19	**17.37**	[1.06; 1.09]
80	BM	EnL-Sto	5.89	0.44	7.49	[5.86; 5.93]	21	BM	AlR-Tr	10.05	1.76	**17.53**	[9.92; 10.21]
73	BM	EnL-ChL	5.78	0.43	7.51	[5.75; 5.82]	8	BM	AlL-SbalL	0.94	0.17	**17.71**	[0.92; 0.95]
76	BM	EnL-Gn	9.80	0.74	7.55	[9.74; 9.86]	183	VM	Sn-Ls	1.62	0.29	**17.97**	[1.60; 1.64]
86	BM	EnR-Gn	9.79	0.74	7.55	[9.73; 9.85]	70	BM	EcR-Tr	7.83	1.42	**18.12**	[7.74; 7.96]

to be continued

concluded

77	BM	EnL-Li	6.61	0.50	7.60	[6.58; 6.66]	192	HM	Spn-Spn	1.79	0.33	**18.15**	[1.77; 1.82]
87	BM	EnR-Li	6.61	0.50	7.61	[6.57; 6.65]	39	BM	CphL-Sto	0.90	0.17	**18.40**	[0.89; 0.91]
125	BM	IlR-Sn	5.11	0.39	7.63	[5.08; 5.14]	196	VM	Tr-Sn	10.58	1.95	**18.42**	[10.42; 10.75]
68	BM	EcR-Sn	5.39	0.41	7.67	[5.36; 5.42]	33	HM	Cph-Cph	1.15	0.22	**18.75**	[1.13; 1.16]
3	CM	AlL-ChR	4.63	0.36	7.72	[4.60; 4.66]	96	BM	FtR-Tr	6.76	1.28	**18.97**	[6.66; 6.87]
211	HM	Zy-Zy	11.76	0.91	7.76	[11.68; 11.83]	45	BM	CphR-Sto	0.87	0.17	**19.04**	[0.85; 0.88]
171	BM	PuR-Ls	6.19	0.48	7.80	[6.16; 6.24]	95	BM	FtR-N	4.69	0.90	**19.29**	[4.62; 4.77]
162	BM	PuL-Ls	6.19	0.48	7.82	[6.15; 6.22]	37	BM	CphL-Ls	0.62	0.12	**19.72**	[0.61; 0.63]
12	CM	AlR-ChL	4.62	0.36	7.89	[4.59; 4.64]	181	HM	Sbal-Sbal	1.92	0.39	**20.15**	[1.89; 1.95]
130	BM	ImL-G	2.62	0.21	7.93	[2.60; 2.64]	18	BM	AlR-SbalR	0.95	0.19	**20.38**	[0.94; 0.97]
197	BM	ZyL-G	6.52	0.52	7.95	[6.48; 6.56]	126	BM	IlR-Tr	7.37	1.52	**20.56**	[7.25; 7.50]
111	CM	IlL-FtR	7.85	0.63	**8.00**	[7.80; 7.90]	11	BM	AlL-Tr	10.12	2.09	**20.64**	[9.96; 10.29]
201	BM	ZyL-Prn	6.12	0.49	**8.01**	[6.08; 6.16]	43	BM	CphR-Ls	0.59	0.12	**20.78**	[0.58; 0.60]
127	HM	Im-Im	4.48	0.36	**8.04**	[4.45; 4.51]	157	VM	N-Sto	6.51	1.37	**21.01**	[6.42; 6.63]
164	BM	PuL-Sn	4.80	0.39	**8.04**	[4.76; 4.83]	177	BM	SbalL-Sn	0.97	0.22	**22.18**	[0.96; 0.99]
202	BM	ZyL-Sn	6.42	0.52	**8.04**	[6.38; 6.46]	36	BM	CphL-Li	1.53	0.34	**22.22**	[1.51; 1.56]
169	BM	PuR-G	3.09	0.25	**8.17**	[3.07; 3.11]	180	BM	SbalR-Sn	0.98	0.22	**22.32**	[0.96; 1.00]
173	BM	PuR-Sn	4.80	0.40	**8.26**	[4.77; 4.83]	174	BM	PuR-Tr	7.18	1.60	**22.35**	[7.06; 7.31]
204	BM	ZyR-G	6.56	0.54	**8.28**	[6.52; 6.61]	42	BM	CphR-Li	1.51	0.34	**22.42**	[1.48; 1.54]
113	BM	IlL-GoL	6.37	0.53	**8.31**	[6.33; 6.41]	203	BM	ZyL-Tr	10.15	2.39	**23.51**	[9.97; 10.36]
208	BM	ZyR-Prn	6.10	0.51	**8.31**	[6.06; 6.14]	67	BM	EcR-N	4.01	0.95	**23.63**	[3.94; 4.09]
209	BM	ZyR-Sn	6.44	0.54	**8.32**	[6.39; 6.48]	91	BM	EnR-Tr	7.08	1.81	**25.50**	[6.95; 7.23]
109	VM	G-Sn	5.33	0.45	**8.36**	[5.29; 5.36]	93	BM	FtL-N	4.67	1.32	**28.30**	[4.58; 4.78]
121	BM	IlR-GoR	6.36	0.54	**8.41**	[6.32; 6.41]	58	BM	EcL-Tr	7.98	2.29	**28.66**	[7.80; 8.15]
22	HM	Ch-Ch	4.17	0.36	**8.51**	[4.14; 4.20]	152	VM	Ls-Li	1.22	0.36	**29.26**	[1.19; 1.25]
88	BM	EnR-Ls	5.43	0.47	**8.59**	[5.39; 5.47]	124	BM	IlR-N	3.36	0.99	**29.49**	[3.29; 3.45]
78	BM	EnL-Ls	5.43	0.47	**8.63**	[5.40; 5.47]	190	BM	SpnR-SbalR	0.63	0.19	**29.51**	[0.61; 0.64]
134	BM	ImL-Sn	4.53	0.39	**8.70**	[4.50; 4.56]	81	BM	EnL-Tr	7.14	2.12	**29.70**	[6.99; 7.31]
163	BM	PuL-Prn	4.01	0.35	**8.70**	[3.98; 4.04]	118	BM	IlL-Tr	7.51	2.26	**30.11**	[7.34; 7.70]
10	BM	AlL-Sto	3.17	0.28	**8.72**	[3.15; 3.19]	16	BM	AlR-N	4.15	1.27	**30.52**	[4.06; 4.25]
4	BM	AlL-Gn	6.89	0.61	**8.87**	[6.84; 6.93]	165	BM	PuL-Tr	7.29	2.24	**30.66**	[7.13; 7.49]
141	BM	ImR-Sn	4.54	0.40	**8.89**	[4.50; 4.57]	146	BM	LnL-SbalL	0.51	0.16	**30.72**	[0.50; 0.52]
20	BM	AlR-Sto	3.18	0.28	**8.93**	[3.15; 3.20]	62	BM	EcR-FtR	1.84	0.57	**30.74**	[1.80; 1.88]
28	BM	ChR-Gn	4.45	0.40	**8.97**	[4.43; 4.49]	156	VM	N-Sn	4.43	1.39	**31.40**	[4.34; 4.55]
65	BM	EcR-GoR	6.01	0.54	**8.97**	[5.97; 6.05]	153	VM	Ls-Sto	0.48	0.16	**32.30**	[0.47; 0.50]
53	BM	EcL-GoL	6.02	0.54	**9.01**	[5.97; 6.06]	143	VM	Li-Sto	0.74	0.24	**32.65**	[0.72; 0.76]
14	BM	AlR-Gn	6.89	0.62	**9.02**	[6.84; 6.94]	187	BM	SpnL-SbalL	0.63	0.21	**32.65**	[0.61; 0.64]
172	BM	PuR-Prn	4.00	0.36	**9.02**	[3.97; 4.02]	94	BM	FtL-Tr	6.93	2.33	**33.55**	[6.75; 7.13]
47	BM	EcL-AlL	3.83	0.35	**9.19**	[3.80; 3.86]	55	BM	EcL-N	3.97	1.34	**33.64**	[3.88; 4.10]
100	BM	GoL-Gn	6.58	0.61	**9.24**	[6.53; 6.63]	6	BM	AlL-N	4.15	1.41	**33.99**	[4.05; 4.28]
79	BM	EnL-Sn	3.90	0.36	**9.26**	[3.87; 3.93]	149	BM	LnR-SbalR	0.52	0.19	**36.98**	[0.50; 0.53]
59	BM	EcR-AlR	3.83	0.36	**9.28**	[3.80; 3.86]	194	VM	Tr-G	5.30	2.07	**38.93**	[5.15; 5.47]
85	BM	EnR-G	2.20	0.20	**9.29**	[2.18; 2.21]	116	BM	IlL-N	3.35	1.32	**39.41**	[3.26; 3.47]
102	BM	GoL-Prn	6.11	0.57	**9.35**	[6.06; 6.15]	155	VM	N-Prn	3.41	1.40	**41.06**	[3.30; 3.54]
98	HM	Go-Go	10.43	0.98	**9.43**	[10.35; 10.51]	50	BM	EcL-FtL	1.85	0.76	**41.10**	[1.80; 1.91]
137	BM	ImR-G	2.66	0.25	**9.43**	[2.64; 2.68]	189	BM	SpnR-LnR	0.30	0.18	**61.34**	[0.28; 0.31]
89	BM	EnR-Sn	3.89	0.37	**9.50**	[3.87; 3.93]	186	BM	SpnL-LnL	0.31	0.20	**66.68**	[0.29; 0.32]
23	BM	ChL-Gn	4.49	0.43	**9.53**	[4.45; 4.52]							

Source: prepared by the author.
SD: standard deviation; CV: coefficient of variation; CI[1]: Bootstrap confidence interval. Measures type: VM (vertical measure); HM (horizontal measure); BM (bilateral measure), and CM (cross-side measure).

3.5 Age group analysis

It is possible to observe that, of all 211 measures, 70 showed significant differences between age groups, indicating greater potential in distinguishing adult individuals (Table 2.3). The largest effect sizes were observed for *Li-Sto* (1.572) and *Ls-Li* (1.526), both measures related to the mouth region, in agreement with previous works that correlate large differences overtime of measures from mouth and nasal

regions (14, 25, 28). Indeed, the fifteen most different measures between age groups are located in these facial regions (*Li-Sto*, *Ls-Li*, *CphL-Li*, *CphR-Li*, *SbalL-Ls*, *SbalR-Ls*, *CphL-Sn*, *CphR-Sn*, *Ls-Sto*, *Sn-Ls*, *AlL-Ls*, *CphL-Sto*, *AlR-Ls*, *SbalL-Sn*, and *Sbal-Sbal*).

On the contrary, measures with the smallest effect sizes were *EcL-N* (0.140), *EcL-FtL* (0.400) and *GoR-Gn* (0.431), indicating high frequency between adult age groups. As expected, *IlL-ImL* (0.211) and *IlR-ImR* (0.211) results showed no significant difference over time, confirming their high correlation and low discriminating potencial.

Table 2.3 - Mean values of each measure by age group. Measures are sorted in descending order according to effect size analysis (ES). Reference number of each measure in alphabetical order is displayed in the first column (#) and type classification in the second. (R: right side; L: left side)

#	Type	Measure	Age groups					Significance	
			20	30	40	50	60	ES	p-value
143	VM	Li-Sto	0.94	0.82	0.76	0.62	0.56	1.572	**< 0.001***
152	VM	Ls-Li	1.49	1.34	1.25	1.07	0.95	1.526	**< 0.001***
36	BM	CphL-Li	1.79	1.63	1.57	1.39	1.28	1.515	**< 0.001***
42	BM	CphR-Li	1.76	1.61	1.54	1.38	1.26	1.461	**< 0.001***
175	BM	SbalL-Ls	1.67	1.76	1.88	1.96	2.05	1.366	**< 0.001***
178	BM	SbalR-Ls	1.69	1.75	1.88	2.00	2.06	1.277	**< 0.001***
38	BM	CphL-Sn	1.41	1.45	1.56	1.68	1.68	1.036	**< 0.001***
44	BM	CphR-Sn	1.39	1.45	1.56	1.67	1.67	1.027	**< 0.001***
153	VM	Ls-Sto	0.56	0.52	0.50	0.45	0.40	0.999	**< 0.001***
183	VM	Sn-Ls	1.46	1.52	1.63	1.74	1.75	0.995	**< 0.001***
5	BM	AlL-Ls	2.64	2.65	2.75	2.88	2.92	0.934	**< 0.001***
39	BM	CphL-Sto	0.98	0.91	0.92	0.88	0.82	0.924	**< 0.001***
15	BM	AlR-Ls	2.67	2.67	2.78	2.89	2.93	0.870	**< 0.001***
177	BM	SbalL-Sn	0.88	0.94	0.99	1.00	1.06	0.855	**< 0.001***
181	HM	Sbal-Sbal	1.76	1.83	1.96	1.96	2.08	0.838	**< 0.001***
142	VM	Li-Gn	3.03	3.13	3.26	3.41	3.39	0.754	**< 0.001***
102	BM	GoL-Prn	5.87	5.96	6.18	6.30	6.24	0.751	**< 0.001***
2	BM	AlL-ChL	2.69	2.69	2.76	2.88	2.83	0.703	**< 0.001***
26	BM	ChL-Sn	2.85	2.91	2.98	3.06	3.01	0.694	**< 0.001***
94	BM	FtL-Tr	6.37	6.54	6.68	7.12	7.95	0.679	**< 0.001***
10	BM	AlL-Sto	3.11	3.07	3.16	3.26	3.23	0.666	**< 0.001***
185	VM	Sn-Sto	2.00	2.02	2.12	2.18	2.13	0.665	**< 0.001***
13	BM	AlR-ChR	2.73	2.73	2.81	2.92	2.87	0.659	**< 0.001***
180	BM	SbalR-Sn	0.91	0.92	1.00	1.01	1.05	0.658	**< 0.001***
103	BM	GoL-Tr	13.27	13.30	13.61	13.98	14.77	0.654	**< 0.001***
96	BM	FtR-Tr	6.43	6.52	6.71	6.87	7.26	0.653	0.004
84	BM	EnR-EcR	2.53	2.48	2.54	2.49	2.43	0.649	**< 0.001***
203	BM	ZyL-Tr	9.64	9.63	9.92	10.40	11.17	0.648	**< 0.001***
210	BM	ZyR-Tr	9.55	9.64	9.97	10.10	10.34	0.645	**< 0.001***
45	BM	CphR-Sto	0.91	0.88	0.88	0.85	0.81	0.643	**< 0.001***
27	BM	ChL-Tr	12.42	12.43	12.72	13.04	13.75	0.638	**< 0.001***
78	BM	EnL-Ls	5.29	5.29	5.47	5.53	5.59	0.638	**< 0.001***
8	BM	AlL-SbalL	1.01	0.92	0.91	0.95	0.90	0.637	**< 0.001***
32	BM	ChR-Tr	12.44	12.45	12.75	12.99	13.54	0.633	0.001
194	VM	Tr-G	4.92	4.97	5.06	5.37	6.20	0.623	0.038
101	BM	GoL-Ls	5.05	5.15	5.32	5.38	5.38	0.622	**< 0.001***
74	BM	EnL-EcL	2.49	2.44	2.50	2.46	2.39	0.621	**< 0.001***
174	BM	PuR-Tr	6.85	6.88	7.04	7.25	7.85	0.620	0.009
126	BM	IlR-Tr	7.07	7.09	7.26	7.45	8.00	0.618	0.008
108	BM	GoR-Tr	13.26	13.25	13.63	13.76	14.13	0.615	**< 0.001***

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91	BM	EnR-Tr	6.73	6.78	6.91	7.15	7.83	0.609	0.028
165	BM	PuL-Tr	6.88	6.90	7.03	7.41	8.24	0.607	0.019
118	BM	IlL-Tr	7.10	7.11	7.24	7.63	8.47	0.606	0.019
81	BM	EnL-Tr	6.76	6.79	6.91	7.23	8.03	0.598	0.061
176	BM	SbalL-Prn	1.38	1.39	1.49	1.52	1.48	0.598	**< 0.001***
88	BM	EnR-Ls	5.32	5.29	5.46	5.52	5.56	0.594	**< 0.001***
24	BM	ChL-Li	2.28	2.26	2.24	2.19	2.15	0.592	**< 0.001***
29	BM	ChR-Li	2.28	2.26	2.24	2.19	2.15	0.592	**< 0.001***
98	HM	Go-Go	10.06	10.21	10.60	10.64	10.64	0.590	**< 0.001***
58	BM	EcL-Tr	7.59	7.57	7.71	8.10	8.92	0.588	0.039
11	BM	AlL-Tr	9.74	9.75	9.97	10.18	10.97	0.587	0.026
196	VM	Tr-Sn	10.25	10.23	10.43	10.62	11.37	0.584	0.086
18	BM	AlR-SbalR	1.02	0.95	0.93	0.94	0.91	0.582	**< 0.001***
21	BM	AlR-Tr	9.73	9.73	9.95	10.10	10.75	0.582	0.026
20	BM	AlR-Sto	3.11	3.09	3.17	3.25	3.26	0.580	**< 0.001***
31	BM	ChR-Sn	2.93	2.95	3.03	3.10	3.00	0.580	**< 0.001***
70	BM	EcR-Tr	7.57	7.57	7.74	7.90	8.38	0.571	0.035
9	BM	AlL-Sn	1.72	1.70	1.73	1.77	1.81	0.558	**< 0.001***
3	CM	AlL-ChR	4.56	4.54	4.64	4.74	4.68	0.556	**< 0.001***
195	VM	Tr-Gn	16.21	16.19	16.55	16.79	17.28	0.550	0.009
87	BM	EnR-Li	6.75	6.58	6.67	6.55	6.48	0.544	0.001
46	HM	Ec-Ec	7.80	7.66	7.81	7.72	7.55	0.538	**< 0.001***
162	BM	PuL-Ls	6.06	6.06	6.22	6.28	6.31	0.518	**< 0.001***
139	CM	ImR-GoL	9.40	9.44	9.71	9.75	9.64	0.514	**< 0.001***
115	BM	IlL-Ls	6.30	6.30	6.46	6.52	6.54	0.512	**< 0.001***
7	BM	AlL-Prn	1.65	1.64	1.71	1.75	1.75	0.511	**< 0.001***
1	HM	Al-Al	3.23	3.17	3.26	3.30	3.35	0.507	**< 0.001***
61	BM	EcR-ChR	5.74	5.69	5.85	5.91	5.88	0.501	**< 0.001***
83	BM	EnR-ChR	5.74	5.69	5.85	5.91	5.88	0.501	**< 0.001***
99	BM	GoL-G	8.91	8.91	9.17	9.20	9.13	0.497	**< 0.001***
100	BM	GoL-Gn	6.42	6.48	6.66	6.72	6.61	0.497	**< 0.001***
197	BM	ZyL-G	6.44	6.39	6.61	6.65	6.54	0.494	**< 0.001***
12	CM	AlR-ChL	4.53	4.53	4.62	4.71	4.69	0.492	**< 0.001***
179	BM	SbalR-Prn	1.37	1.37	1.46	1.48	1.46	0.485	**< 0.001***
77	BM	EnL-Li	6.74	6.59	6.68	6.56	6.50	0.484	0.004
73	BM	EnL-ChL	5.69	5.66	5.83	5.87	5.86	0.483	**< 0.001***
107	BM	GoR-Prn	5.91	5.91	6.19	6.18	6.13	0.478	**< 0.001***
51	BM	EcL-G	4.19	4.09	4.20	4.17	4.06	0.476	**< 0.001***
184	VM	Sn-Prn	1.02	0.99	1.06	1.07	1.03	0.465	0.001
59	BM	EcR-AlR	3.89	3.83	3.90	3.78	3.74	0.463	0.001
192	HM	Spn-Spn	1.75	1.78	1.79	1.77	1.90	0.459	**< 0.001***
132	CM	ImL-GoR	9.43	9.40	9.70	9.70	9.62	0.454	**< 0.001***
160	BM	PuL-G	3.05	3.01	3.08	3.11	3.02	0.453	0.003
171	BM	PuR-Ls	6.09	6.07	6.24	6.28	6.29	0.451	**< 0.001***
113	BM	IlL-GoL	6.28	6.24	6.41	6.42	6.48	0.444	**< 0.001***
53	BM	EcL-GoL	5.93	5.90	6.05	6.06	6.14	0.438	**< 0.001***
123	BM	IlR-Ls	6.34	6.31	6.48	6.51	6.52	0.438	**< 0.001***
145	BM	LnL-Prn	1.32	1.27	1.33	1.34	1.36	0.438	0.008
63	BM	EcR-G	4.23	4.20	4.25	4.20	4.12	0.436	0.002
130	BM	ImL-G	2.62	2.58	2.65	2.67	2.59	0.435	0.002
54	CM	EcL-IlR	7.13	7.03	7.16	7.11	6.98	0.431	0.004
104	BM	GoR-G	8.95	8.93	9.19	9.18	9.14	0.431	**< 0.001***
159	CM	PuL-ChR	7.68	7.66	7.80	7.86	7.78	0.427	0.006
129	CM	ImL-ChR	7.38	7.35	7.50	7.55	7.48	0.425	0.005
190	BM	SpnR-SbalR	0.60	0.61	0.65	0.68	0.60	0.425	0.006
119	CM	IlR-FtL	7.93	7.79	7.88	7.81	7.71	0.424	0.026
206	CM	ZyR-GoL	11.83	11.91	12.20	12.14	12.12	0.420	0.004
40	BM	CphR-ChR	1.73	1.72	1.72	1.70	1.64	0.419	0.006
65	BM	EcR-GoR	5.94	5.88	6.06	6.06	6.10	0.419	0.001
66	CM	EcR-IlL	7.15	7.06	7.18	7.15	7.00	0.419	0.003
106	BM	GoR-Ls	5.10	5.11	5.34	5.30	5.29	0.418	0.001
41	BM	CphR-Gn	4.73	4.67	4.72	4.69	4.52	0.417	0.012
136	BM	ImR-ChR	6.01	5.96	6.11	6.15	6.11	0.417	0.006
158	BM	PuL-ChL	6.00	5.97	6.12	6.15	6.13	0.415	0.003
4	BM	AlL-Gn	6.81	6.77	6.91	7.02	6.91	0.414	0.018
188	BM	SpnL-Sn	1.04	1.06	1.08	1.09	1.12	0.414	0.003

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191	BM	SpnR-Sn	1.04	1.06	1.08	1.09	1.12	0.414	0.003
207	BM	ZyR-GoR	4.83	4.64	4.66	4.55	4.64	0.414	0.050
168	BM	PuR-ChR	6.04	6.00	6.14	6.18	6.15	0.411	0.007
128	BM	ImL-ChL	5.96	5.94	6.09	6.12	6.10	0.408	0.003
111	CM	IlL-FtR	7.99	7.80	7.90	7.84	7.73	0.407	0.021
204	BM	ZyR-G	6.45	6.51	6.67	6.64	6.54	0.405	0.007
47	BM	EcL-AlL	3.86	3.84	3.90	3.78	3.76	0.401	0.020
50	BM	EcL-FtL	2.05	1.85	1.80	1.75	1.78	0.400	**< 0.001***
17	BM	AlR-Prn	1.67	1.63	1.69	1.70	1.71	0.399	0.023
151	VM	Ls-Gn	4.51	4.46	4.50	4.47	4.32	0.395	0.017
35	BM	CphL-Gn	4.74	4.68	4.73	4.69	4.54	0.394	0.014
92	HM	Ft-Ft	8.91	8.85	8.96	8.83	8.71	0.393	0.002
121	BM	IlR-GoR	6.29	6.23	6.42	6.43	6.44	0.393	0.001
182	VM	Sn-Gn	5.97	5.97	6.13	6.21	6.04	0.393	0.013
19	BM	AlR-Sn	1.77	1.72	1.76	1.77	1.80	0.390	0.026
80	BM	EnL-Sto	5.83	5.79	5.94	5.96	5.96	0.390	0.003
75	BM	EnL-G	2.19	2.18	2.20	2.20	2.14	0.386	0.027
146	BM	LnL-SbalL	0.54	0.51	0.51	0.52	0.48	0.386	0.007
147	BM	LnL-Sn	1.21	1.20	1.22	1.21	1.27	0.386	0.029
90	BM	EnR-Sto	5.84	5.78	5.93	5.94	5.94	0.385	0.011
14	BM	AlR-Gn	6.81	6.79	6.94	7.03	6.89	0.384	0.021
135	CM	ImR-ChL	7.36	7.33	7.49	7.51	7.44	0.381	0.011
68	BM	EcR-Sn	5.47	5.36	5.45	5.35	5.31	0.380	0.019
105	BM	GoR-Gn	6.40	6.44	6.66	6.63	6.63	0.378	0.014
167	CM	PuR-ChL	7.66	7.63	7.79	7.81	7.73	0.372	0.013
62	BM	EcR-FtR	1.96	1.85	1.81	1.76	1.81	0.369	0.005
200	CM	ZyL-GoR	11.83	11.87	12.15	12.09	12.06	0.367	0.005
48	BM	EcL-ChL	6.04	6.00	6.16	6.17	6.14	0.358	0.022
187	BM	SpnL-SbalL	0.61	0.60	0.65	0.67	0.62	0.358	0.002
148	BM	LnR-Prn	1.32	1.26	1.30	1.28	1.32	0.351	0.032
86	BM	EnR-Gn	9.73	9.66	9.88	9.91	9.77	0.339	0.052
30	BM	ChR-Ls	2.18	2.17	2.19	2.19	2.12	0.337	0.032
76	BM	EnL-Gn	9.72	9.67	9.89	9.91	9.81	0.335	0.046
60	CM	EcR-ChL	8.31	8.26	8.42	8.39	8.30	0.333	0.088
140	CM	ImR-IlL	5.48	5.42	5.53	5.54	5.44	0.329	0.022
69	BM	EcR-Sto	6.98	6.91	7.06	7.02	6.98	0.327	0.229
127	HM	Im-Im	4.47	4.42	4.53	4.54	4.43	0.325	0.020
110	HM	Il-Il	6.47	6.42	6.52	6.54	6.43	0.324	0.020
166	HM	Pu-Pu	5.47	5.42	5.52	5.54	5.43	0.324	0.020
189	BM	SpnR-LnR	0.33	0.27	0.30	0.29	0.30	0.324	0.028
57	BM	EcL-Sto	6.96	6.90	7.05	7.02	6.98	0.322	0.232
49	CM	EcL-ChR	8.31	8.26	8.42	8.42	8.32	0.320	0.066
133	CM	ImL-IlR	5.47	5.42	5.52	5.53	5.43	0.318	0.019
97	VM	G-Gn	11.31	11.26	11.50	11.51	11.34	0.317	0.045
28	BM	ChR-Gn	4.45	4.44	4.51	4.49	4.38	0.316	0.243
112	BM	IlL-Gn	10.44	10.39	10.60	10.62	10.50	0.311	0.084
161	BM	PuL-Gn	10.30	10.25	10.45	10.47	10.36	0.308	0.087
95	BM	FtR-N	4.84	4.71	4.66	4.57	4.67	0.306	0.016
172	BM	PuR-Prn	4.05	4.00	4.02	3.94	3.96	0.306	0.130
131	BM	ImL-Gn	10.18	10.13	10.33	10.35	10.24	0.305	0.090
199	BM	ZyL-GoL	4.76	4.70	4.64	4.53	4.76	0.303	0.116
138	BM	ImR-Gn	10.19	10.12	10.34	10.35	10.19	0.301	0.078
34	BM	CphL-ChL	1.62	1.68	1.66	1.65	1.61	0.299	0.068
170	BM	PuR-Gn	10.31	10.25	10.46	10.47	10.31	0.299	0.080
72	BM	EnL-AlL	3.02	3.00	3.09	3.01	3.04	0.297	0.198
43	BM	CphR-Ls	0.59	0.57	0.59	0.61	0.59	0.295	0.234
120	BM	IlR-Gn	10.45	10.39	10.61	10.61	10.45	0.295	0.081
64	BM	EcR-Gn	10.50	10.42	10.64	10.62	10.45	0.293	0.145
209	BM	ZyR-Sn	6.51	6.42	6.52	6.37	6.37	0.289	0.076
208	BM	ZyR-Prn	6.15	6.09	6.19	6.04	6.04	0.288	0.171
52	BM	EcL-Gn	10.48	10.42	10.63	10.62	10.51	0.285	0.181
149	BM	LnR-SbalR	0.54	0.52	0.51	0.52	0.48	0.280	0.001
82	BM	EnR-AlR	3.03	2.97	3.06	3.00	3.03	0.278	0.228
33	HM	Cph-Cph	1.15	1.11	1.15	1.17	1.15	0.273	0.231
211	HM	Zy-Zy	11.70	11.68	11.92	11.83	11.67	0.269	0.126
85	BM	EnR-G	2.19	2.22	2.21	2.20	2.16	0.255	0.281

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89	BM	EnR-Sn	3.94	3.85	3.92	3.87	3.90	0.249	0.332
93	BM	FtL-N	4.86	4.66	4.59	4.53	4.71	0.247	0.006
155	VM	N-Prn	3.51	3.46	3.31	3.21	3.55	0.241	0.059
150	BM	LnR-Sn	1.24	1.20	1.23	1.21	1.24	0.237	0.231
79	BM	EnL-Sn	3.91	3.86	3.91	3.87	3.94	0.233	0.387
144	HM	Ln-Ln	2.31	2.23	2.29	2.26	2.31	0.230	0.057
186	BM	SpnL-LnL	0.32	0.27	0.31	0.32	0.32	0.226	0.024
22	HM	Ch-Ch	4.12	4.18	4.20	4.20	4.14	0.223	0.245
156	VM	N-Sn	4.52	4.44	4.36	4.28	4.58	0.215	0.445
169	BM	PuR-G	3.07	3.08	3.12	3.11	3.07	0.214	0.046
114	BM	IlL-ImL	1.00	1.00	1.00	1.00	1.00	0.211	0.414
122	BM	IlR-ImR	1.00	1.00	1.00	1.00	1.00	0.211	0.414
125	BM	IlR-Sn	5.15	5.07	5.15	5.08	5.07	0.210	0.230
137	BM	ImR-G	2.64	2.65	2.69	2.68	2.63	0.209	0.044
173	BM	PuR-Sn	4.85	4.77	4.85	4.78	4.77	0.207	0.271
16	BM	AlR-N	4.20	4.15	4.09	4.02	4.28	0.204	0.463
141	BM	ImR-Sn	4.58	4.50	4.58	4.51	4.51	0.203	0.330
25	BM	ChL-Ls	2.11	2.15	2.16	2.15	2.13	0.202	0.254
37	BM	CphL-Ls	0.63	0.60	0.63	0.62	0.62	0.201	0.360
71	HM	En-En	2.80	2.75	2.78	2.78	2.75	0.201	0.519
205	BM	ZyR-Gn	10.48	10.34	10.49	10.37	10.37	0.198	0.452
193	VM	Sto-Gn	3.97	3.95	4.02	4.03	3.94	0.195	0.420
6	BM	AlL-N	4.21	4.15	4.11	4.01	4.28	0.193	0.225
201	BM	ZyL-Prn	6.07	6.10	6.13	6.12	6.16	0.185	0.501
56	BM	EcL-Sn	5.40	5.33	5.40	5.34	5.34	0.174	0.642
157	VM	N-Sto	6.51	6.45	6.47	6.45	6.68	0.171	0.128
109	VM	G-Sn	5.35	5.30	5.37	5.30	5.32	0.169	0.764
116	BM	IlL-N	3.40	3.32	3.27	3.29	3.48	0.160	0.025
67	BM	EcR-N	4.08	4.02	3.98	3.93	4.02	0.159	0.002
23	BM	ChL-Gn	4.48	4.47	4.52	4.50	4.45	0.157	0.589
124	BM	IlR-N	3.39	3.38	3.31	3.30	3.45	0.155	0.161
117	BM	IlL-Sn	5.10	5.06	5.12	5.09	5.11	0.153	0.783
202	BM	ZyL-Sn	6.40	6.41	6.44	6.39	6.47	0.152	0.729
164	BM	PuL-Sn	4.81	4.76	4.82	4.79	4.81	0.150	0.762
134	BM	ImL-Sn	4.54	4.49	4.55	4.51	4.55	0.145	0.743
55	BM	EcL-N	4.07	3.95	3.92	3.88	4.05	0.140	**< 0.001***
154	VM	N-Gn	10.47	10.39	10.49	10.48	10.59	0.131	0.138
198	BM	ZyL-Gn	10.40	10.39	10.46	10.39	10.43	0.093	0.995
163	BM	PuL-Prn	4.02	4.00	4.01	4.00	4.03	0.086	0.774

Source: prepared by the author.

*Significant difference between age groups.

3.6 Sex group analysis

The majority of measures were significantly different between sex groups, except for *AlL-N, AlL-Sto, AlL-Tr, AlR-ChL, AlR-Gn, AlR-Ls, AlR-Prn, AlR-Sn, ChR-Tr, CphL-ChL, CphL-Gn, EcL-Gn, EcL-IlR, EcL-Sn, EcR-G, EnL-G, EnL-Li, EnL-Sto, EnR-AlR, Ft-Ft, G-Gn, GoR-G, GoR-Tr, IlL-FtR, ImL-IlR, ImR-ChL, LnR-SbalR, N-Sn, PuR-ChR, SbalL-Prn, Sn-Sto, SpnL-SbalL, Sto-Gn, ZyL-G, ZyL-Prn, ZyL-Sn, ZyR-Prn,* and *ZyR-Tr* that correspond to 18% of the total measures (Table 2.4). All mean values were greater for males than females, except for *CphL-Li*, *CphR-Li*, *EcR-AlR*, *EcL-AlL*, *Ls-Sto*, *Li-Sto* and *Ls-Li,* showing that, in general, males have thicker lips and larger alar distances. In the present study, sexual dimorphism accounts for up to 14% of variation between sexes.

In addition, *Ec-Ec* presented a higher effect size (1.065, p < 0.001) and *ChR-Ls* a lower effect size (0.035, p < 0.001), demonstrating greater and less potential for discriminating between faces of different sexes, respectively. Iris diameter measures (*ImL-IlL* and *ImR-IlR*) presented identical values as a result of the normalization process. In general, HMs demonstrate better ability to discriminate between sex groups, forming 50% of the 16 highest ES values (*Ec-Ec*, *En-En*, *Zy-Zy*, *Ln-Ln*, *Cph-Cph*, *Spn-Spn*, *Sbal-Sbal*, and *Ch-Ch)*. Present study results corroborate the assumption that facial width has the greatest influence in the distinction between male and female faces.

Table 2.4 - Mean values of each measure by sex group. Measures are sorted in descending order according to effect size (ES) analysis. Reference number of each measure in alphabetical order is displayed in the first column (#) and type classification in the second. (R: right side; L: left side; F: female; M: male)

#	Type	Measure	Sex group		Significance		#	Type	Measure	Sex group		Significance	
			F	M	ES	p-value				F	M	ES	p-value
46	HM	Ec-Ec	7.63	7.79	1.065	**< 0.001***	51	BM	EcL-G	4.09	4.19	0.495	**< 0.001***
71	HM	En-En	2.75	2.79	1.042	**< 0.001***	27	BM	ChL-Tr	12.51	13.24	0.493	**< 0.001***
211	HM	Zy-Zy	11.57	11.94	1.042	**< 0.001***	137	BM	ImR-G	2.60	2.72	0.488	**< 0.001***
109	VM	G-Sn	5.25	5.40	1.042	**< 0.001***	164	BM	PuL-Sn	4.74	4.86	0.480	**< 0.001***
152	VM	Ls-Li	1.27	1.17	0.969	**< 0.001***	178	BM	SbalR-Ls	1.76	2.00	0.480	**< 0.001***
69	BM	EcR-Sto	6.87	7.10	0.967	**< 0.001***	110	HM	Il-Il	6.39	6.56	0.475	**< 0.001***
136	BM	ImR-ChR	5.90	6.24	0.964	**< 0.001***	61	BM	ImR-Gn	9.90	10.57	0.474	**< 0.001***
144	HM	Ln-Ln	2.18	2.38	0.961	**< 0.001***	138	BM	EcR-ChR	5.62	6.00	0.474	**< 0.001***
88	BM	EnR-Ls	5.25	5.61	0.957	**< 0.001***	50	BM	LnL-Sn	1.17	1.28	0.473	**< 0.001***
33	HM	Cph-Cph	1.09	1.21	0.945	**< 0.001***	147	BM	EcL-FtL	1.83	1.86	0.473	**< 0.001***
192	HM	Spn-Spn	1.70	1.89	0.943	**< 0.001***	162	BM	PuL-Ls	6.02	6.35	0.466	**< 0.001***
181	HM	Sbal-Sbal	1.81	2.03	0.937	**< 0.001***	206	CM	ZyR-GoL	11.77	12.31	0.444	**< 0.001***
179	BM	SbalR-Prn	1.36	1.49	0.930	**< 0.001***	37	BM	CphL-Ls	0.59	0.65	0.430	**< 0.001***
161	BM	PuL-Gn	10.03	10.71	0.924	**< 0.001***	170	BM	PuR-Gn	10.03	10.69	0.426	**< 0.001***
8	BM	AlL-SbalL	0.90	0.98	0.923	**< 0.001***	101	BM	GoL-Ls	5.09	5.42	0.423	**< 0.001***
22	HM	Ch-Ch	4.10	4.23	0.921	**< 0.001***	31	BM	ChR-Sn	2.89	3.11	0.412	**< 0.001***
94	BM	FtL-Tr	6.66	7.20	0.921	**< 0.001***	143	VM	Li-Sto	0.77	0.72	0.407	**< 0.001***
141	BM	ImR-Sn	4.48	4.59	0.921	**< 0.001***	167	CM	PuR-ChL	7.55	7.90	0.407	**< 0.001***
199	BM	ZyL-GoL	4.62	4.74	0.918	**< 0.001***	45	BM	CphR-Sto	0.85	0.88	0.406	**< 0.001***
174	BM	PuR-Tr	6.99	7.37	0.893	**< 0.001***	200	CM	ZyL-GoR	11.74	12.27	0.406	**< 0.001***
65	BM	EcR-GoR	5.85	6.17	0.888	**< 0.001***	18	BM	AlR-SbalR	0.91	0.99	0.405	**< 0.001***
107	BM	GoR-Prn	5.84	6.29	0.882	**< 0.001***	195	VM	Tr-Gn	16.09	17.13	0.401	**< 0.001***
36	BM	CphL-Li	1.55	1.52	0.877	**< 0.001***	158	BM	PuL-ChL	5.91	6.24	0.370	**< 0.001***
76	BM	EnL-Gn	9.44	10.16	0.877	**< 0.001***	25	BM	ChL-Ls	2.11	2.17	0.361	**< 0.001***
55	BM	EcL-N	3.84	4.11	0.859	**< 0.001***	154	VM	N-Gn	10.08	10.89	0.349	**< 0.001***
29	BM	ChR-Li	2.21	2.24	0.854	**< 0.001***	183	VM	Sn-Ls	1.50	1.74	0.349	**< 0.001***
117	BM	IlL-Sn	5.04	5.16	0.850	**< 0.001***	58	BM	EcL-Tr	7.74	8.22	0.347	**< 0.001***
1	HM	Al-Al	3.11	3.41	0.843	**< 0.001***	21	BM	AlR-Tr	9.84	10.27	0.343	**< 0.001***
125	BM	IlR-Sn	5.05	5.17	0.842	**< 0.001***	67	BM	EcR-N	3.88	4.13	0.338	**< 0.001***
121	BM	IlR-GoR	6.18	6.55	0.839	**< 0.001***	116	BM	IlL-N	3.21	3.49	0.336	**< 0.001***
184	VM	Sn-Prn	1.02	1.05	0.834	**< 0.001***	79	BM	EnL-Sn	3.84	3.96	0.335	**< 0.001***
73	BM	N-Prn	3.30	3.51	0.832	**< 0.001***	159	CM	PuL-ChR	7.58	7.93	0.334	**< 0.001***
123	BM	IlR-Ls	6.27	6.59	0.832	**< 0.001***	131	BM	ImL-Gn	9.90	10.59	0.333	**< 0.001***
155	VM	EnL-ChL	5.60	5.97	0.832	**< 0.001***	191	BM	SpnR-Sn	1.03	1.13	0.326	**< 0.001***
128	BM	ImL-ChL	5.87	6.21	0.815	**< 0.001***	87	BM	EnR-Li	6.48	6.74	0.325	**< 0.001***
20	BM	AlR-Sto	3.04	3.31	0.811	**< 0.001***	100	BM	GoL-Gn	6.33	6.83	0.321	**< 0.001***
44	BM	CphR-Sn	1.44	1.66	0.809	**< 0.001***	130	BM	ImL-G	2.58	2.67	0.320	**< 0.001***
171	BM	PuR-Ls	6.03	6.36	0.798	**< 0.001***	86	BM	EnR-Gn	9.44	10.14	0.314	**< 0.001***

to be continued

continuation

4	BM	AlL-Gn	6.56	7.21	0.797	**< 0.001***	59	BM	N-Sto	6.31	6.72	0.311	**< 0.001***
7	BM	AlL-Prn	1.63	1.77	0.791	**< 0.001***	157	VM	EcR-AlR	3.85	3.81	0.311	**< 0.001***
118	BM	IlL-Tr	7.29	7.73	0.779	**< 0.001***	189	BM	SpnR-LnR	0.29	0.31	0.311	**< 0.001***
127	HM	Im-Im	4.39	4.56	0.774	**< 0.001***	96	BM	FtR-Tr	6.56	6.96	0.310	**< 0.001***
16	BM	AlR-N	4.03	4.27	0.767	**< 0.001***	145	BM	LnL-Prn	1.27	1.38	0.306	**< 0.001***
89	BM	EnR-Sn	3.83	3.96	0.758	**< 0.001***	203	BM	ZyL-Tr	9.83	10.48	0.305	**< 0.001***
70	BM	EcR-Tr	7.63	8.03	0.756	**< 0.001***	111	CM	IlL-FtR	7.75	7.96	0.303	0.001
163	BM	PuL-Prn	3.96	4.06	0.756	**< 0.001***	172	BM	PuR-Prn	3.94	4.05	0.301	**< 0.001***
112	BM	IlL-Gn	10.17	10.85	0.755	**< 0.001***	68	BM	EcR-Sn	5.35	5.43	0.300	**< 0.001***
48	BM	Tr-G	5.12	5.48	0.752	**< 0.001***	93	BM	FtL-N	4.51	4.83	0.300	**< 0.001***
160	BM	PuL-G	3.01	3.10	0.752	**< 0.001***	72	BM	EnL-AlL	2.98	3.08	0.297	**< 0.001***
194	VM	EcL-ChL	5.96	6.24	0.752	**< 0.001***	201	BM	ZyL-Prn	6.04	6.19	0.289	0.001
2	BM	AlL-ChL	2.64	2.90	0.749	**< 0.001***	82	BM	EnR-AlR	2.97	3.06	0.286	0.001
169	BM	PuR-G	3.03	3.15	0.748	**< 0.001***	175	BM	SbalL-Ls	1.75	1.98	0.285	**< 0.001***
173	BM	PuR-Sn	4.74	4.86	0.747	**< 0.001***	193	VM	Sto-Gn	3.77	4.19	0.283	0.001
142	VM	Li-Gn	3.01	3.48	0.745	**< 0.001***	64	BM	EcR-Gn	10.23	10.83	0.282	**< 0.001***
132	CM	ImL-GoR	9.31	9.84	0.743	**< 0.001***	34	BM	ZyR-Prn	6.00	6.20	0.277	0.001
62	BM	EcR-FtR	1.81	1.87	0.742	**< 0.001***	208	BM	CphL-ChL	1.63	1.66	0.277	0.003
13	BM	AlR-ChR	2.67	2.95	0.739	**< 0.001***	129	CM	ImL-ChR	7.27	7.63	0.273	**< 0.001***
198	BM	ZyL-Gn	10.15	10.67	0.735	**< 0.001***	135	CM	ImR-ChL	7.25	7.60	0.258	0.005
151	VM	Ls-Gn	4.27	4.63	0.731	**< 0.001***	39	BM	CphL-Sto	0.89	0.91	0.256	**< 0.001***
120	BM	Sn-Gn	5.77	6.36	0.728	**< 0.001***	148	BM	LnR-Prn	1.25	1.35	0.254	**< 0.001***
182	VM	IlR-Gn	10.17	10.83	0.728	**< 0.001***	150	BM	LnR-Sn	1.18	1.28	0.245	**< 0.001***
66	CM	EcR-IlL	7.02	7.19	0.708	**< 0.001***	153	VM	Ls-Sto	0.51	0.46	0.244	**< 0.001***
90	BM	EnR-Sto	5.73	6.04	0.702	**< 0.001***	197	BM	ZyL-G	6.39	6.65	0.242	0.003
134	BM	ImL-Sn	4.47	4.59	0.702	**< 0.001***	60	CM	EcR-ChL	8.18	8.48	0.241	**< 0.001***
102	BM	GoL-Prn	5.91	6.31	0.700	**< 0.001***	83	BM	EnR-ChR	5.62	6.00	0.238	**< 0.001***
85	BM	EnR-G	2.18	2.22	0.697	**< 0.001***	81	BM	EnL-Tr	6.95	7.33	0.237	**< 0.001***
146	BM	LnL-SbalL	0.49	0.54	0.697	**< 0.001***	95	BM	FtR-N	4.55	4.82	0.232	**< 0.001***
98	HM	Go-Go	10.07	10.79	0.693	**< 0.001***	166	HM	Pu-Pu	5.39	5.56	0.229	**< 0.001***
124	BM	IlR-N	3.24	3.49	0.689	**< 0.001***	41	BM	CphR-Gn	4.47	4.87	0.211	**< 0.001***
165	BM	PuL-Tr	7.07	7.51	0.688	**< 0.001***	176	BM	SbalL-Prn	1.39	1.51	0.211	0.004
40	BM	CphR-ChR	1.69	1.71	0.677	**< 0.001***	32	BM	ChR-Tr	12.49	13.18	0.210	0.013
99	BM	GoL-G	8.84	9.29	0.676	**< 0.001***	105	BM	GoR-Gn	6.27	6.84	0.209	**< 0.001***
126	BM	IlR-Tr	7.19	7.56	0.674	**< 0.001***	26	BM	ChL-Sn	2.86	3.07	0.208	**< 0.001***
53	BM	EcL-GoL	5.86	6.18	0.671	**< 0.001***	10	BM	AlL-Sto	3.03	3.30	0.205	0.005
103	BM	GoL-Tr	13.40	14.17	0.670	**< 0.001***	63	BM	EcR-G	4.13	4.27	0.204	0.013
42	BM	CphR-Li	1.53	1.49	0.623	**< 0.001***	168	BM	PuR-ChR	5.94	6.27	0.199	0.089
23	BM	ChL-Gn	4.31	4.66	0.621	**< 0.001***	47	BM	G-Gn	11.02	11.75	0.195	0.067
140	CM	ImR-IlL	5.39	5.57	0.618	**< 0.001***	97	VM	EcL-AlL	3.85	3.81	0.195	**< 0.001***
115	BM	IlL-Ls	6.26	6.58	0.617	**< 0.001***	106	BM	GoR-Ls	5.04	5.42	0.194	**< 0.001***
139	CM	ImR-GoL	9.35	9.83	0.606	**< 0.001***	92	HM	Ft-Ft	8.68	9.03	0.193	0.061
28	BM	ChR-Gn	4.29	4.62	0.602	**< 0.001***	80	BM	EnL-Sto	5.74	6.05	0.190	0.001
119	CM	IlR-FtL	7.72	7.94	0.601	**< 0.001***	149	BM	LnR-SbalR	0.49	0.54	0.182	0.060
188	BM	SpnL-Sn	1.03	1.13	0.594	**< 0.001***	77	BM	EnL-Li	6.49	6.74	0.179	0.022
9	BM	AlL-Sn	1.67	1.82	0.592	**< 0.001***	75	BM	EnL-G	2.17	2.19	0.177	0.001
177	BM	SbalL-Sn	0.91	1.03	0.589	**< 0.001***	12	CM	AlR-ChL	4.45	4.79	0.174	0.001
38	BM	CphL-Sn	1.45	1.66	0.582	**< 0.001***	210	BM	ZyR-Tr	9.65	10.19	0.171	0.316
24	BM	ChL-Li	2.21	2.24	0.581	**< 0.001***	52	BM	EcL-Gn	10.22	10.84	0.159	0.042
114	BM	IlL-ImL	1.00	1.00	0.577	**0.001[a]**	54	CM	EcL-IlR	7.00	7.17	0.158	0.171
204	BM	ZyR-G	6.40	6.73	0.570	**< 0.001***	6	BM	AlL-N	4.02	4.29	0.154	0.033
207	BM	ZyR-GoR	4.63	4.70	0.568	**< 0.001***	56	BM	EcL-Sn	5.32	5.40	0.152	0.111
180	BM	SbalR-Sn	0.92	1.04	0.565	**< 0.001***	104	BM	GoR-G	8.83	9.33	0.152	0.063
74	BM	Tr-Sn	10.34	10.81	0.557	**< 0.001***	108	BM	GoR-Tr	13.26	13.96	0.152	0.063
196	VM	EnL-EcL	2.43	2.48	0.557	**< 0.001***	202	BM	ZyL-Sn	6.36	6.49	0.151	0.736
84	BM	EnR-EcR	2.46	2.52	0.553	**< 0.001***	14	BM	AlR-Gn	6.57	7.22	0.147	0.119
122	BM	IlR-ImR	1.00	1.00	0.552	**0.001[a]**	156	VM	N-Sn	4.32	4.55	0.136	0.068
209	BM	ZyR-Sn	6.35	6.53	0.550	**< 0.001***	185	VM	Sn-Sto	2.00	2.19	0.136	0.068
113	BM	IlL-GoL	6.18	6.55	0.547	**< 0.001***	35	BM	CphL-Gn	4.47	4.88	0.126	0.087
91	BM	EnR-Tr	6.91	7.26	0.524	**< 0.001***	43	BM	CphR-Ls	0.55	0.63	0.118	**< 0.001***
3	CM	AlL-ChR	4.46	4.80	0.523	**< 0.001***	133	CM	ImL-IlR	5.39	5.56	0.114	0.282
78	BM	EnL-Ls	5.26	5.61	0.516	**< 0.001***	11	BM	AlL-Tr	9.88	10.36	0.109	0.096
57	BM	EcL-Sto	6.87	7.09	0.515	**< 0.001***	187	BM	SpnL-SbalL	0.59	0.67	0.101	0.333
205	BM	ZyR-Gn	10.14	10.68	0.514	**< 0.001***	15	BM	AlR-Ls	2.63	2.95	0.099	0.181
186	BM	SpnR-SbalR	0.60	0.66	0.508	**< 0.001***	19	BM	AlR-Sn	1.69	1.84	0.097	0.320
190	BM	SpnL-LnL	0.29	0.33	0.508	**< 0.001***	17	BM	AlR-Prn	1.61	1.76	0.065	0.457

to be continued

concluded

49	CM	EcL-ChR	8.20	8.50	0.507	**< 0.001***	30	BM	ChR-Ls	2.14	2.20	0.035	**< 0.001***
5	BM	AlL-Ls	2.62	2.92	0.506	**< 0.001***							

Source: prepared by the author.
*Significant difference between facial sides.
[a] Identical averages.

3.7 Male group analysis

In the male group, it was observed that most variables (150 measures) showed no significant difference between age groups (Table 2.5). Identical averages were observed for *IlL-ImL*, *IlR-ImR*, *Im-Im*, *GoL-Tr*, *EnL-Ls*, *IlR-Tr*, *IlR-Ls* and *ImL-Sn,* showing higher consistency over time for males. Measures with highest and lowest effect sizes, respectively, were *Sbal-Prn* (1.771, $p < 0.001$) and *IlL-Gn* (0.603, $p < 0.001$), showing opposite potentials for discriminating between males in different age groups.

Table 2.5 - Mean values of each measure by age group within male group (left columns). Measures are sorted in descending order according to effect size analysis (ES). Reference number of each measure in alphabetical order is displayed in the first column (#) and type classification in the second. (R: right side; L: left side)

#	Type	Measure	Male group					Significance	
			20	30	40	50	60	ES	p-value
176	BM	SbalL-Prn	1.44	1.46	1.56	1.57	1.53	1.771	**< 0.001***
208	BM	ZyR-Prn	6.22	6.19	6.27	6.11	6.22	1.719	**< 0.001***
15	BM	AlR-Ls	2.81	2.79	2.96	3.05	3.12	1.677	**< 0.001***
19	BM	AlR-Sn	1.84	1.79	1.85	1.82	1.91	1.655	**< 0.001***
73	BM	EnL-ChL	5.88	5.85	6.02	6.04	6.05	1.530	**< 0.001***
121	BM	IlR-GoR	6.48	6.37	6.62	6.58	6.70	1.402	**< 0.001***
71	HM	En-En	2.82	2.77	2.83	2.76	2.79	1.207	**< 0.001***
109	VM	G-Sn	5.43	5.34	5.41	5.36	5.45	1.173	**< 0.001***
20	BM	AlR-Sto	3.24	3.20	3.34	3.37	3.41	1.164	**< 0.001***
201	BM	ZyL-Prn	6.11	6.15	6.25	6.23	6.21	1.150	**< 0.001***
16	BM	AlR-N	4.38	4.29	4.11	4.03	4.55	1.137	**< 0.001***
128	BM	ImL-ChL	6.14	6.11	6.25	6.25	6.28	1.137	**< 0.001***
150	BM	LnR-Sn	1.30	1.25	1.28	1.25	1.31	1.081	**< 0.001***
83	BM	EnR-ChR	5.94	5.87	6.04	6.07	6.07	1.080	**< 0.001***
195	VM	Tr-Gn	16.40	16.61	17.13	17.03	18.45	1.077	**< 0.001***
80	BM	EnL-Sto	5.99	5.89	6.11	6.09	6.15	1.071	**< 0.001***
137	BM	ImR-G	2.69	2.74	2.74	2.72	2.70	1.071	**< 0.001***
183	VM	Sn-Ls	1.55	1.62	1.78	1.88	1.86	1.066	**< 0.001***
12	CM	AlR-ChL	4.69	4.71	4.82	4.84	4.88	1.061	**< 0.001***
116	BM	IlL-N	3.58	3.46	3.31	3.31	3.77	1.054	**< 0.001***
153	VM	Ls-Sto	0.56	0.51	0.47	0.40	0.38	1.040	**< 0.001***
75	BM	EnL-G	2.21	2.20	2.21	2.18	2.18	1.038	**< 0.001***
64	BM	EcR-Gn	10.83	10.73	10.97	10.87	10.74	1.037	**< 0.001***
6	BM	AlL-N	4.41	4.30	4.13	4.01	4.59	1.036	**< 0.001***
96	BM	FtR-Tr	6.47	6.65	6.88	6.89	7.90	1.034	**< 0.001***
47	BM	EcL-AlL	3.85	3.81	3.87	3.76	3.74	1.029	**< 0.001***
60	CM	EcR-ChL	8.48	8.41	8.56	8.49	8.48	1.024	**< 0.001***
106	BM	GoR-Ls	5.19	5.34	5.58	5.49	5.50	1.024	**< 0.001***
166	HM	Pu-Pu	5.55	5.51	5.63	5.59	5.54	1.023	**< 0.001***
206	CM	ZyR-GoL	11.95	12.19	12.53	12.46	12.41	1.019	**< 0.001***
129	CM	ImL-ChR	7.57	7.53	7.69	7.68	7.70	1.007	**< 0.001***

to be continued

continuation

95	BM	FtR-N	4.92	4.89	4.76	4.64	4.93	0.998	**< 0.001***
41	BM	CphR-Gn	4.96	4.93	4.95	4.81	4.67	0.995	**< 0.001***
124	BM	IlR-N	3.54	3.54	3.36	3.32	3.69	0.958	**< 0.001***
3	CM	AlL-ChR	4.73	4.71	4.82	4.86	4.89	0.956	**< 0.001***
114	BM	IlL-ImL	1.00	1.00	1.00	1.01	1.00	0.931	**0.001[a]**
179	BM	SbalR-Prn	1.44	1.42	1.53	1.51	1.54	0.924	**< 0.001***
74	BM	EnL-EcL	2.53	2.47	2.51	2.49	2.41	0.895	**< 0.001***
120	BM	IlR-Gn	10.81	10.72	10.97	10.88	10.77	0.881	**< 0.001***
144	HM	Ln-Ln	2.42	2.34	2.42	2.34	2.38	0.879	**< 0.001***
115	BM	IlL-Ls	6.45	6.42	6.64	6.68	6.75	0.870	**< 0.001***
70	BM	EcR-Tr	7.49	7.68	7.97	7.91	9.11	0.846	**< 0.001***
10	BM	AlL-Sto	3.24	3.18	3.31	3.37	3.40	0.823	**< 0.001***
89	BM	EnR-Sn	4.01	3.88	3.96	3.92	4.01	0.810	**< 0.001***
122	BM	IlR-ImR	1.00	1.00	1.00	1.00	1.00	0.810	**0.001[a]**
152	VM	Ls-Li	1.54	1.31	1.19	0.94	0.87	0.788	**< 0.001***
22	HM	Ch-Ch	4.19	4.24	4.26	4.22	4.24	0.725	**< 0.001***
127	HM	Im-Im	4.55	4.51	4.63	4.59	4.54	0.720	**0.001[a]**
110	HM	Il-Il	6.55	6.51	6.63	6.59	6.54	0.709	**< 0.001***
40	BM	CphR-ChR	1.74	1.75	1.72	1.67	1.66	0.704	**< 0.001***
53	BM	EcL-GoL	6.11	6.00	6.21	6.22	6.34	0.703	**< 0.001***
118	BM	IlL-Tr	6.94	7.25	7.45	7.50	9.52	0.696	**< 0.001***
99	BM	GoL-G	9.11	9.10	9.42	9.46	9.35	0.690	**< 0.001***
103	BM	GoL-Tr	13.27	13.57	14.02	14.06	15.94	0.689	**0.001[a]**
78	BM	EnL-Ls	5.45	5.41	5.66	5.72	5.80	0.683	**0.001[a]**
126	BM	IlR-Tr	6.95	7.20	7.46	7.43	8.76	0.674	**0.001[a]**
156	VM	N-Sn	4.71	4.55	4.35	4.28	4.89	0.668	0.003
185	VM	Sn-Sto	2.10	2.12	2.23	2.26	2.21	0.668	0.003
123	BM	IlR-Ls	6.49	6.42	6.64	6.67	6.74	0.661	**0.001[a]**
87	BM	EnR-Li	6.96	6.67	6.80	6.62	6.61	0.644	0.033
1	HM	Al-Al	3.36	3.31	3.45	3.42	3.52	0.634	0.002
140	CM	ImR-IlL	5.55	5.52	5.63	5.59	5.54	0.634	0.014
146	BM	LnL-SbalL	0.57	0.55	0.53	0.53	0.51	0.623	**< 0.001***
165	BM	PuL-Tr	6.71	7.03	7.24	7.29	9.28	0.623	**< 0.001***
182	VM	Sn-Gn	6.27	6.31	6.48	6.45	6.30	0.623	0.015
57	BM	EcL-Sto	7.08	6.98	7.17	7.11	7.13	0.62	0.003
171	BM	PuR-Ls	6.25	6.18	6.40	6.44	6.51	0.610	0.003
68	BM	EcR-Sn	5.53	5.38	5.46	5.36	5.42	0.607	0.037
186	BM	SpnL-LnL	0.35	0.29	0.30	0.33	0.36	0.605	0.015
190	BM	SpnR-SbalR	0.64	0.64	0.67	0.71	0.62	0.605	0.015
117	BM	IlL-Sn	5.17	5.08	5.18	5.15	5.21	0.605	0.022
112	BM	IlL-Gn	10.79	10.72	10.97	10.89	10.87	0.603	**< 0.001***
151	VM	Ls-Gn	4.72	4.69	4.71	4.58	4.47	0.603	0.014
85	BM	EnR-G	2.21	2.25	2.22	2.19	2.21	0.594	0.007
134	BM	ImL-Sn	4.61	4.51	4.61	4.57	4.65	0.586	**0.001[a]**
38	BM	CphL-Sn	1.49	1.53	1.69	1.80	1.78	0.583	0.005
192	HM	Spn-Spn	1.82	1.86	1.92	1.86	1.99	0.576	0.006
24	BM	ChL-Li	2.32	2.26	2.25	2.18	2.19	0.570	0.002
30	BM	ChR-Ls	2.22	2.21	2.21	2.18	2.18	0.570	0.017
102	BM	GoL-Prn	6.00	6.17	6.45	6.56	6.35	0.568	0.004
119	CM	IlR-FtL	7.99	7.91	8.02	7.90	7.87	0.568	0.015
7	BM	AlL-Prn	1.72	1.72	1.80	1.81	1.80	0.566	0.006
33	HM	Cph-Cph	1.24	1.17	1.21	1.21	1.21	0.564	0.006
181	HM	Sbal-Sbal	1.86	1.91	2.12	2.02	2.25	0.553	0.006
90	BM	EnR-Sto	6.00	5.89	6.09	6.08	6.12	0.543	0.021
84	BM	EnR-EcR	2.57	2.52	2.56	2.52	2.45	0.539	0.006
21	BM	AlR-Tr	9.61	9.83	10.17	10.10	11.63	0.537	0.020
143	VM	Li-Sto	0.99	0.80	0.73	0.55	0.51	0.529	0.024
142	VM	Li-Gn	3.18	3.39	3.53	3.64	3.63	0.529	0.048
207	BM	ZyR-GoR	4.88	4.60	4.66	4.59	4.79	0.528	0.007
125	BM	IlR-Sn	5.22	5.11	5.18	5.11	5.20	0.519	0.004
55	BM	EcL-N	4.27	4.09	3.96	3.90	4.35	0.507	0.010
4	BM	AlL-Gn	7.14	7.10	7.28	7.30	7.24	0.507	0.011
113	BM	IlL-GoL	6.48	6.38	6.60	6.61	6.70	0.505	0.005
36	BM	CphL-Li	1.88	1.62	1.54	1.30	1.24	0.502	0.017
76	BM	EnL-Gn	10.09	10.02	10.29	10.22	10.17	0.502	0.017
198	BM	ZyL-Gn	10.61	10.61	10.77	10.64	10.74	0.491	0.016

to be continued

continuation

98	HM	Go-Go	10.21	10.62	11.10	11.07	10.94	0.476	0.005
5	BM	AlL-Ls	2.78	2.77	2.92	3.05	3.10	0.473	0.044
14	BM	AlR-Gn	7.14	7.13	7.32	7.30	7.19	0.467	0.077
49	CM	EcL-ChR	8.47	8.41	8.57	8.52	8.50	0.464	0.070
188	BM	SpnL-Sn	1.08	1.10	1.12	1.13	1.20	0.450	0.114
91	BM	EnR-Tr	6.56	6.86	7.09	7.06	8.71	0.448	0.057
194	VM	Tr-G	4.71	5.06	5.25	5.26	7.15	0.445	0.103
43	BM	CphR-Ls	0.63	0.61	0.63	0.64	0.62	0.439	0.087
58	BM	EcL-Tr	7.46	7.73	7.93	7.98	10.00	0.439	0.165
189	BM	SpnR-LnR	0.35	0.28	0.30	0.28	0.32	0.439	0.283
173	BM	PuR-Sn	4.92	4.80	4.88	4.81	4.90	0.438	0.137
62	BM	EcR-FtR	1.91	1.88	1.90	1.78	1.90	0.431	0.135
45	BM	CphR-Sto	0.95	0.92	0.90	0.84	0.81	0.420	0.124
139	CM	ImR-GoL	9.58	9.68	10.01	10.03	9.83	0.420	0.275
184	VM	Sn-Prn	1.04	1.01	1.06	1.08	1.06	0.419	0.420
169	BM	PuR-G	3.13	3.17	3.18	3.15	3.13	0.418	0.146
13	BM	AlR-ChR	2.87	2.88	2.96	3.03	3.01	0.414	0.143
54	CM	EcL-IlR	7.22	7.13	7.25	7.16	7.09	0.410	0.161
69	BM	EcR-Sto	7.12	6.99	7.17	7.11	7.14	0.401	0.276
18	BM	AlR-SbalR	1.05	0.99	0.97	1.00	0.94	0.400	0.211
27	BM	ChL-Tr	12.43	12.70	13.09	13.10	14.87	0.399	0.413
25	BM	ChL-Ls	2.15	2.20	2.19	2.16	2.16	0.398	0.059
63	BM	EcR-G	4.30	4.29	4.31	4.25	4.18	0.398	0.263
35	BM	CphL-Gn	4.98	4.93	4.96	4.81	4.72	0.393	0.258
149	BM	LnR-SbalR	0.56	0.54	0.53	0.56	0.52	0.392	0.228
31	BM	ChR-Sn	3.04	3.08	3.14	3.17	3.13	0.388	0.209
133	CM	ImL-IlR	5.55	5.51	5.62	5.58	5.54	0.387	0.129
17	BM	AlR-Prn	1.74	1.71	1.78	1.74	1.81	0.385	0.054
88	BM	EnR-Ls	5.48	5.41	5.65	5.72	5.78	0.383	0.306
51	BM	EcL-G	4.25	4.13	4.25	4.20	4.13	0.379	0.318
82	BM	EnR-AlR	3.08	3.00	3.10	3.06	3.08	0.378	0.248
136	BM	ImR-ChR	6.19	6.12	6.27	6.28	6.31	0.375	0.237
160	BM	PuL-G	3.10	3.05	3.14	3.14	3.08	0.373	0.219
191	BM	SpnR-Sn	1.08	1.10	1.12	1.13	1.20	0.369	0.029
170	BM	PuR-Gn	10.66	10.58	10.83	10.74	10.64	0.366	0.226
37	BM	CphL-Ls	0.68	0.63	0.65	0.63	0.65	0.364	0.108
2	BM	AlL-ChL	2.82	2.83	2.89	3.00	2.96	0.363	0.230
131	BM	ImL-Gn	10.54	10.46	10.71	10.63	10.60	0.362	0.262
46	HM	Ec-Ec	7.90	7.75	7.89	7.76	7.64	0.361	0.266
163	BM	PuL-Prn	4.07	4.02	4.07	4.04	4.10	0.360	0.314
67	BM	EcR-N	4.24	4.18	4.02	3.95	4.24	0.360	0.358
141	BM	ImR-Sn	4.65	4.53	4.61	4.54	4.64	0.359	0.446
8	BM	AlL-SbalL	1.05	0.96	0.93	0.99	0.94	0.357	0.464
200	CM	ZyL-GoR	11.97	12.16	12.52	12.39	12.29	0.355	0.638
48	BM	EcL-ChL	6.18	6.14	6.30	6.28	6.28	0.354	0.337
161	BM	PuL-Gn	10.65	10.58	10.83	10.75	10.72	0.353	0.480
174	BM	PuR-Tr	6.73	6.99	7.25	7.23	8.64	0.351	0.427
29	BM	ChR-Li	2.32	2.26	2.25	2.18	2.19	0.349	0.551
204	BM	ZyR-G	6.61	6.73	6.84	6.76	6.71	0.347	0.245
79	BM	EnL-Sn	3.98	3.87	3.98	3.94	4.04	0.347	0.281
11	BM	AlL-Tr	9.62	9.88	10.21	10.12	11.99	0.347	0.325
94	BM	FtL-Tr	6.42	6.71	6.86	6.99	9.03	0.347	0.417
65	BM	EcR-GoR	6.10	5.99	6.21	6.19	6.34	0.347	0.440
28	BM	ChR-Gn	4.62	4.61	4.71	4.62	4.55	0.344	0.366
107	BM	GoR-Prn	6.06	6.17	6.46	6.39	6.38	0.343	0.445
196	VM	Tr-Sn	10.14	10.32	10.65	10.60	12.35	0.340	0.297
205	BM	ZyR-Gn	10.71	10.60	10.77	10.60	10.75	0.336	0.260
23	BM	ChL-Gn	4.66	4.63	4.72	4.64	4.66	0.336	0.598
211	HM	Zy-Zy	11.87	11.91	12.15	12.01	11.78	0.332	0.346
101	BM	GoL-Ls	5.13	5.34	5.56	5.62	5.48	0.331	0.313
177	BM	SbalL-Sn	0.93	0.97	1.09	1.05	1.12	0.331	0.423
202	BM	ZyL-Sn	6.43	6.44	6.55	6.50	6.53	0.329	0.174
44	BM	CphR-Sn	1.48	1.54	1.69	1.79	1.79	0.328	0.495
172	BM	PuR-Prn	4.11	4.02	4.06	3.97	4.08	0.325	0.470
178	BM	SbalR-Ls	1.80	1.84	2.03	2.11	2.21	0.322	0.439
59	BM	EcR-AlR	3.89	3.80	3.84	3.76	3.74	0.322	0.506

to be continued

concluded

210	BM	ZyR-Tr	9.62	9.87	10.29	10.22	10.97	0.318	0.357
147	BM	LnL-Sn	1.27	1.24	1.29	1.26	1.32	0.318	0.475
61	BM	EcR-ChR	5.94	5.87	6.04	6.07	6.07	0.318	0.478
42	BM	CphR-Li	1.83	1.62	1.52	1.29	1.21	0.318	0.687
138	BM	ImR-Gn	10.54	10.46	10.71	10.62	10.52	0.317	0.477
100	BM	GoL-Gn	6.61	6.77	7.00	7.01	6.78	0.316	0.566
167	CM	PuR-ChL	7.85	7.81	7.97	7.93	7.95	0.316	0.818
162	BM	PuL-Ls	6.21	6.18	6.40	6.45	6.52	0.313	0.535
187	BM	SpnL-SbalL	0.65	0.65	0.67	0.69	0.67	0.304	0.090
86	BM	EnR-Gn	10.10	10.01	10.28	10.21	10.11	0.303	0.458
175	BM	SbalL-Ls	1.76	1.84	2.03	2.09	2.19	0.300	0.357
72	BM	EnL-AlL	3.08	3.03	3.14	3.05	3.09	0.298	0.335
92	HM	Ft-Ft	9.14	9.01	9.12	8.96	8.90	0.297	0.462
145	BM	LnL-Prn	1.38	1.34	1.39	1.39	1.40	0.296	0.336
97	VM	G-Gn	11.69	11.63	11.89	11.81	11.71	0.296	0.562
203	BM	ZyL-Tr	9.63	9.91	10.23	10.34	12.29	0.294	0.234
199	BM	ZyL-GoL	4.83	4.65	4.67	4.59	4.96	0.292	0.689
104	BM	GoR-G	9.16	9.19	9.47	9.41	9.43	0.287	0.569
108	BM	GoR-Tr	13.33	13.48	14.05	13.95	14.98	0.287	0.569
159	CM	PuL-ChR	7.87	7.83	7.99	7.98	7.99	0.281	0.742
93	BM	FtL-N	4.97	4.82	4.69	4.60	5.06	0.279	0.139
168	BM	PuR-ChR	6.23	6.15	6.30	6.32	6.34	0.271	0.166
148	BM	LnR-Prn	1.37	1.32	1.36	1.31	1.37	0.271	0.835
111	CM	IlL-FtR	8.02	7.93	8.05	7.92	7.88	0.265	0.635
81	BM	EnL-Tr	6.56	6.88	7.09	7.10	9.02	0.264	0.207
77	BM	EnL-Li	6.95	6.68	6.82	6.63	6.64	0.261	0.960
105	BM	GoR-Gn	6.59	6.78	7.00	6.90	6.93	0.252	0.452
32	BM	ChR-Tr	12.48	12.69	13.12	13.10	14.51	0.244	0.683
157	VM	N-Sto	6.80	6.64	6.57	6.53	7.08	0.241	0.446
180	BM	SbalR-Sn	0.97	0.97	1.07	1.04	1.15	0.240	0.213
26	BM	ChL-Sn	2.96	3.04	3.12	3.15	3.09	0.237	0.062
130	BM	ImL-G	2.66	2.63	2.70	2.70	2.64	0.236	0.724
132	CM	ImL-GoR	9.63	9.68	10.03	9.94	9.90	0.233	0.574
39	BM	CphL-Sto	1.02	0.93	0.92	0.85	0.85	0.226	0.075
52	BM	EcL-Gn	10.80	10.73	10.97	10.87	10.84	0.226	0.800
34	BM	CphL-ChL	1.63	1.72	1.68	1.65	1.62	0.223	0.743
209	BM	ZyR-Sn	6.57	6.50	6.58	6.42	6.56	0.212	0.557
66	CM	EcR-IlL	7.25	7.15	7.27	7.20	7.10	0.212	0.865
9	BM	AlL-Sn	1.79	1.75	1.83	1.84	1.89	0.210	0.604
135	CM	ImR-ChL	7.54	7.51	7.67	7.64	7.65	0.210	0.785
158	BM	PuL-ChL	6.17	6.14	6.29	6.29	6.31	0.203	0.385
155	VM	N-Prn	3.68	3.55	3.29	3.20	3.84	0.203	0.799
56	BM	EcL-Sn	5.45	5.35	5.45	5.38	5.40	0.199	0.853
154	VM	N-Gn	10.95	10.82	10.82	10.72	11.13	0.195	0.897
193	VM	Sto-Gn	4.17	4.19	4.26	4.20	4.13	0.192	0.627
197	BM	ZyL-G	6.58	6.52	6.76	6.77	6.64	0.186	0.038
164	BM	PuL-Sn	4.87	4.78	4.88	4.84	4.91	0.175	0.608
50	BM	EcL-FtL	1.93	1.87	1.87	1.77	1.85	0.170	0.654

Source: prepared by the author.
*Significant difference between age groups within male group.
[a] Identical averages.

3.8 Female group analysis

Compared with the male group, it was observed that even more variables (176 measures) displayed no significant difference between females within different age groups (Table 2.6). Identical averages were observed for *IlL-ImL*, *IlR-ImR*, *EnR-Li*, *Sbal-Sbal*, *IlL-Ls*, *IlR-Gn*, *IlL-GoL* and *PuL-ChL,* showing higher consistency over time for females. As in the male group, the first two measures *(i.e., IlL-ImL* and *IlR-ImR*)

were identical due to the imaging normalization process. Measures with highest and lowest effect sizes were, respectively, *EnL-ChL* (1.498, $p < 0.001$) and *ChR-Ls* (0.441, $p < 0.001$), showing opposite potentials for discriminating between females in different age groups.

Table 2.6 - Mean values of each measure by age group within female group (left columns). Measures are sorted in descending order according to effect size analysis (ES). Reference number of each measure in alphabetical order is displayed in the first column (#) and type classification in the second. (R: right side; L: left side)

#	Type	Measure	Female Group					ES analysis	
			20	30	40	50	60	ES	p-value
73	BM	EnL-ChL	5.49	5.48	5.64	5.71	5.66	1.498	**< 0.001***
121	BM	IlR-GoR	6.11	6.09	6.23	6.27	6.18	1.437	**< 0.001***
176	BM	SbalL-Prn	1.32	1.31	1.41	1.46	1.43	1.364	**< 0.001***
208	BM	ZyR-Prn	6.08	5.98	6.10	5.97	5.85	1.335	**< 0.001***
15	BM	AlR-Ls	2.54	2.55	2.59	2.74	2.75	1.329	**< 0.001***
19	BM	AlR-Sn	1.70	1.65	1.67	1.72	1.69	1.243	**< 0.001***
16	BM	AlR-N	4.02	4.01	4.08	4.01	4.01	1.183	**< 0.001***
128	BM	ImL-ChL	5.78	5.77	5.92	5.98	5.91	1.117	**< 0.001***
20	BM	AlR-Sto	2.97	2.98	3.01	3.13	3.10	1.088	**< 0.001***
71	HM	En-En	2.79	2.74	2.72	2.80	2.70	0.989	**< 0.001***
192	HM	Spn-Spn	1.68	1.70	1.66	1.68	1.80	0.933	**< 0.001***
109	VM	G-Sn	5.26	5.25	5.33	5.24	5.19	0.915	**< 0.001***
182	VM	Sn-Gn	5.67	5.64	5.78	5.96	5.79	0.889	**< 0.001***
74	BM	EnL-EcL	2.45	2.40	2.49	2.43	2.36	0.884	**< 0.001***
22	HM	Ch-Ch	4.06	4.11	4.13	4.19	4.03	0.878	**< 0.001***
201	BM	ZyL-Prn	6.03	6.04	6.01	6.02	6.11	0.860	**< 0.001***
194	VM	Tr-G	5.13	4.88	4.87	5.49	5.26	0.836	**< 0.001***
114	BM	IlL-ImL	1.00	1.00	1.00	1.00	1.00	0.818	**0.001[a]**
6	BM	AlL-N	4.00	3.99	4.09	4.01	3.97	0.815	**< 0.001***
146	BM	LnL-SbalL	0.51	0.47	0.49	0.51	0.45	0.801	**< 0.001***
124	BM	IlR-N	3.23	3.21	3.27	3.27	3.21	0.799	**< 0.001***
179	BM	SbalR-Prn	1.31	1.31	1.39	1.44	1.37	0.786	**< 0.001***
33	HM	Cph-Cph	1.06	1.06	1.10	1.13	1.08	0.783	0.005
122	BM	IlR-ImR	1.00	1.00	1.00	1.00	1.00	0.765	**0.001[a]**
144	HM	Ln-Ln	2.19	2.13	2.16	2.17	2.25	0.751	0.003
68	BM	EcR-Sn	5.41	5.34	5.44	5.33	5.21	0.749	**< 0.001***
87	BM	EnR-Li	6.54	6.48	6.54	6.48	6.34	0.746	**0.001[a]**
84	BM	EnR-EcR	2.48	2.45	2.53	2.46	2.40	0.743	**< 0.001***
152	VM	Ls-Li	1.44	1.36	1.31	1.19	1.03	0.725	**< 0.001***
143	VM	Li-Sto	0.89	0.84	0.79	0.69	0.61	0.703	**< 0.001***
181	HM	Sbal-Sbal	1.66	1.76	1.79	1.91	1.92	0.693	**0.001[a]**
193	VM	Sto-Gn	3.76	3.71	3.78	3.86	3.75	0.692	0.002
35	BM	CphL-Gn	4.51	4.43	4.51	4.57	4.36	0.689	0.005
98	HM	Go-Go	9.91	9.80	10.11	10.21	10.34	0.681	**< 0.001***
115	BM	IlL-Ls	6.15	6.19	6.28	6.36	6.34	0.675	**0.001[a]**
110	HM	Il-Il	6.40	6.33	6.42	6.49	6.33	0.663	0.002
120	BM	IlR-Gn	10.10	10.06	10.24	10.34	10.12	0.660	**0.001[a]**
136	BM	ImR-ChR	5.82	5.81	5.95	6.02	5.92	0.659	0.003
156	VM	N-Sn	4.33	4.33	4.38	4.28	4.26	0.659	0.003
185	VM	Sn-Sto	1.91	1.93	2.00	2.11	2.04	0.659	0.003
211	HM	Zy-Zy	11.53	11.45	11.68	11.65	11.56	0.651	0.005
118	BM	IlL-Tr	7.26	6.98	7.03	7.76	7.42	0.649	0.003
56	BM	EcL-Sn	5.35	5.32	5.36	5.29	5.28	0.648	0.004
113	BM	IlL-GoL	6.08	6.11	6.23	6.24	6.25	0.642	**0.001[a]**
46	HM	Ec-Ec	7.70	7.57	7.72	7.67	7.45	0.64	0.013
158	BM	PuL-ChL	5.82	5.80	5.95	6.02	5.94	0.628	**0.001[a]**
70	BM	EcR-Tr	7.64	7.46	7.52	7.90	7.65	0.618	0.003
36	BM	CphL-Li	1.71	1.64	1.60	1.49	1.31	0.617	0.004

to be continued

continuation

76	BM	EnL-Gn	9.35	9.32	9.48	9.61	9.45	0.617	0.004
171	BM	PuR-Ls	5.94	5.96	6.08	6.12	6.06	0.614	0.005
17	BM	AlR-Prn	1.61	1.56	1.60	1.65	1.62	0.597	0.015
55	BM	EcL-N	3.88	3.80	3.88	3.87	3.75	0.596	0.002
177	BM	SbalL-Sn	0.83	0.90	0.89	0.94	1.00	0.593	0.014
2	BM	AlL-ChL	2.55	2.55	2.63	2.77	2.70	0.593	0.023
21	BM	AlR-Tr	9.85	9.63	9.72	10.11	9.88	0.592	0.005
149	BM	LnR-SbalR	0.52	0.51	0.50	0.49	0.45	0.590	0.002
160	BM	PuL-G	3.01	2.97	3.03	3.08	2.97	0.590	0.023
25	BM	ChL-Ls	2.07	2.10	2.12	2.14	2.10	0.588	0.003
63	BM	EcR-G	4.16	4.11	4.19	4.16	4.05	0.584	0.016
26	BM	ChL-Sn	2.74	2.78	2.85	2.97	2.93	0.578	0.004
170	BM	PuR-Gn	9.96	9.91	10.09	10.20	9.98	0.577	0.027
49	CM	EcL-ChR	8.15	8.12	8.26	8.32	8.14	0.569	0.005
39	BM	CphL-Sto	0.93	0.90	0.91	0.91	0.80	0.569	0.016
18	BM	AlR-SbalR	0.99	0.91	0.89	0.89	0.88	0.569	0.036
37	BM	CphL-Ls	0.57	0.58	0.60	0.61	0.59	0.563	0.015
159	CM	PuL-ChR	7.50	7.48	7.61	7.73	7.56	0.561	0.010
101	BM	GoL-Ls	4.96	4.97	5.07	5.15	5.28	0.560	0.063
125	BM	IlR-Sn	5.08	5.04	5.12	5.05	4.94	0.556	0.006
206	CM	ZyR-GoL	11.72	11.63	11.86	11.83	11.83	0.550	0.055
129	CM	ImL-ChR	7.19	7.18	7.31	7.43	7.26	0.545	0.037
189	BM	SpnR-LnR	0.31	0.25	0.30	0.30	0.28	0.543	0.020
77	BM	EnL-Li	6.53	6.50	6.54	6.49	6.36	0.542	0.025
13	BM	AlR-ChR	2.58	2.59	2.66	2.81	2.73	0.538	0.021
163	BM	PuL-Prn	3.98	3.98	3.94	3.95	3.96	0.535	0.031
169	BM	PuR-G	3.02	3.00	3.07	3.07	3.00	0.532	0.020
81	BM	EnL-Tr	6.95	6.70	6.73	7.36	7.03	0.528	0.010
48	BM	EcL-ChL	5.90	5.86	6.02	6.05	5.99	0.527	0.029
105	BM	GoR-Gn	6.22	6.11	6.31	6.36	6.34	0.527	0.091
168	BM	PuR-ChR	5.86	5.84	5.98	6.04	5.95	0.525	0.041
173	BM	PuR-Sn	4.78	4.74	4.82	4.74	4.64	0.524	0.039
127	HM	Im-Im	4.40	4.33	4.42	4.49	4.33	0.522	0.039
62	BM	EcR-FtR	2.02	1.83	1.73	1.73	1.73	0.515	0.050
133	CM	ImL-IlR	5.40	5.33	5.43	5.49	5.32	0.514	0.023
123	BM	IlR-Ls	6.18	6.20	6.32	6.36	6.29	0.513	0.008
167	CM	PuR-ChL	7.47	7.46	7.62	7.68	7.52	0.512	0.029
88	BM	EnR-Ls	5.15	5.16	5.27	5.33	5.35	0.506	0.094
131	BM	ImL-Gn	9.82	9.79	9.95	10.07	9.88	0.503	0.057
1	HM	Al-Al	3.10	3.02	3.07	3.18	3.18	0.501	0.031
117	BM	IlL-Sn	5.04	5.03	5.05	5.04	5.02	0.498	0.022
139	CM	ImR-GoL	9.23	9.21	9.41	9.48	9.45	0.497	0.009
99	BM	GoL-G	8.71	8.72	8.91	8.95	8.92	0.497	0.020
93	BM	FtL-N	4.75	4.49	4.49	4.46	4.37	0.497	0.028
31	BM	ChR-Sn	2.82	2.81	2.91	3.03	2.88	0.495	0.019
145	BM	LnL-Prn	1.25	1.21	1.28	1.28	1.31	0.495	0.109
40	BM	CphR-ChR	1.71	1.70	1.71	1.74	1.61	0.493	0.019
45	BM	CphR-Sto	0.87	0.85	0.86	0.87	0.80	0.493	0.034
165	BM	PuL-Tr	7.05	6.77	6.82	7.53	7.20	0.492	0.012
197	BM	ZyL-G	6.29	6.26	6.45	6.52	6.44	0.49	0.083
7	BM	AlL-Prn	1.59	1.56	1.62	1.68	1.69	0.489	0.071
89	BM	EnR-Sn	3.87	3.82	3.87	3.81	3.79	0.485	0.017
207	BM	ZyR-GoR	4.78	4.69	4.65	4.52	4.49	0.485	0.031
4	BM	AlL-Gn	6.49	6.44	6.55	6.75	6.58	0.485	0.068
69	BM	EcR-Sto	6.84	6.82	6.95	6.92	6.82	0.485	0.098
162	BM	PuL-Ls	5.91	5.95	6.05	6.12	6.10	0.483	0.051
94	BM	FtL-Tr	6.33	6.36	6.49	7.25	6.87	0.482	0.054
104	BM	GoR-G	8.74	8.68	8.92	8.96	8.85	0.478	0.251
108	BM	GoR-Tr	13.20	13.01	13.21	13.57	13.29	0.478	0.251
142	VM	Li-Gn	2.87	2.86	2.99	3.17	3.14	0.477	0.167
147	BM	LnL-Sn	1.15	1.16	1.15	1.16	1.21	0.476	0.061
112	BM	IlL-Gn	10.10	10.06	10.22	10.34	10.14	0.475	0.010
61	BM	EcR-ChR	5.54	5.51	5.65	5.74	5.69	0.475	0.062
138	BM	ImR-Gn	9.83	9.79	9.97	10.07	9.86	0.475	0.063
141	BM	ImR-Sn	4.51	4.47	4.55	4.47	4.38	0.473	0.134
95	BM	FtR-N	4.77	4.52	4.56	4.50	4.42	0.473	0.165

to be continued

continuation

178	BM	SbalR-Ls	1.58	1.67	1.73	1.88	1.91	0.471	0.075
54	CM	EcL-IlR	7.04	6.94	7.07	7.06	6.88	0.471	0.090
8	BM	AlL-SbalL	0.96	0.87	0.88	0.91	0.86	0.469	0.133
3	CM	AlL-ChR	4.40	4.37	4.45	4.61	4.48	0.468	0.445
174	BM	PuR-Tr	6.98	6.78	6.83	7.28	7.06	0.467	0.104
72	BM	EnL-AlL	2.96	2.96	3.03	2.96	2.98	0.467	0.145
11	BM	AlL-Tr	9.87	9.62	9.73	10.25	9.95	0.466	0.147
65	BM	EcR-GoR	5.79	5.77	5.90	5.93	5.87	0.465	0.102
107	BM	GoR-Prn	5.76	5.65	5.92	5.98	5.88	0.464	0.095
161	BM	PuL-Gn	9.95	9.91	10.08	10.20	10.00	0.464	0.133
183	VM	Sn-Ls	1.36	1.42	1.48	1.61	1.63	0.464	0.655
126	BM	IlR-Tr	7.18	6.99	7.05	7.47	7.25	0.458	0.041
23	BM	ChL-Gn	4.30	4.31	4.32	4.37	4.25	0.458	0.076
198	BM	ZyL-Gn	10.18	10.17	10.15	10.15	10.12	0.455	0.097
28	BM	ChR-Gn	4.29	4.27	4.30	4.36	4.21	0.454	0.067
195	VM	Tr-Gn	16.01	15.77	15.97	16.55	16.12	0.453	0.701
10	BM	AlL-Sto	2.98	2.97	3.02	3.14	3.06	0.448	0.214
137	BM	ImR-G	2.58	2.56	2.63	2.63	2.57	0.448	0.570
102	BM	GoL-Prn	5.74	5.75	5.91	6.04	6.13	0.442	0.074
30	BM	ChR-Ls	2.14	2.14	2.16	2.20	2.05	0.441	**< 0.001***
209	BM	ZyR-Sn	6.46	6.33	6.46	6.31	6.18	0.439	0.126
154	VM	N-Gn	9.99	9.96	10.15	10.24	10.04	0.438	0.105
116	BM	IlL-N	3.22	3.18	3.22	3.27	3.18	0.438	0.805
175	BM	SbalL-Ls	1.59	1.68	1.73	1.84	1.91	0.436	0.208
184	VM	Sn-Prn	1.00	0.97	1.06	1.06	1.01	0.435	0.198
199	BM	ZyL-GoL	4.69	4.75	4.60	4.48	4.56	0.434	0.175
78	BM	EnL-Ls	5.13	5.18	5.27	5.34	5.38	0.432	0.083
82	BM	EnR-AlR	2.98	2.94	3.02	2.95	2.97	0.430	0.089
9	BM	AlL-Sn	1.65	1.64	1.63	1.69	1.72	0.430	0.346
191	BM	SpnR-Sn	1.01	1.02	1.04	1.05	1.05	0.428	0.140
24	BM	ChL-Li	2.24	2.26	2.23	2.21	2.11	0.425	0.110
53	BM	EcL-GoL	5.76	5.81	5.90	5.90	5.94	0.417	0.114
44	BM	CphR-Sn	1.31	1.35	1.44	1.55	1.55	0.416	0.162
41	BM	CphR-Gn	4.50	4.42	4.49	4.57	4.36	0.410	0.319
96	BM	FtR-Tr	6.38	6.40	6.54	6.85	6.63	0.410	0.334
103	BM	GoL-Tr	13.27	13.04	13.20	13.89	13.60	0.409	0.136
134	BM	ImL-Sn	4.48	4.47	4.49	4.46	4.45	0.408	0.103
29	BM	ChR-Li	2.24	2.26	2.23	2.21	2.11	0.406	0.233
91	BM	EnR-Tr	6.91	6.71	6.74	7.24	6.96	0.404	0.016
204	BM	ZyR-G	6.30	6.29	6.50	6.53	6.38	0.404	0.113
106	BM	GoR-Ls	5.01	4.89	5.09	5.11	5.09	0.402	0.518
42	BM	CphR-Li	1.68	1.61	1.56	1.47	1.31	0.400	0.082
57	BM	EcL-Sto	6.83	6.82	6.93	6.93	6.82	0.399	0.134
47	BM	EcL-AlL	3.87	3.86	3.92	3.81	3.77	0.398	0.517
43	BM	CphR-Ls	0.54	0.54	0.56	0.58	0.55	0.397	0.014
196	VM	Tr-Sn	10.36	10.13	10.20	10.64	10.38	0.396	0.218
38	BM	CphL-Sn	1.32	1.37	1.43	1.56	1.59	0.395	0.096
132	CM	ImL-GoR	9.23	9.13	9.37	9.46	9.35	0.395	0.097
151	VM	Ls-Gn	4.31	4.23	4.29	4.36	4.16	0.391	0.297
180	BM	SbalR-Sn	0.85	0.88	0.92	0.99	0.95	0.390	0.203
187	BM	SpnL-SbalL	0.57	0.55	0.63	0.65	0.56	0.386	0.186
85	BM	EnR-G	2.18	2.18	2.21	2.21	2.12	0.384	0.226
188	BM	SpnL-Sn	1.01	1.02	1.04	1.05	1.05	0.378	0.256
164	BM	PuL-Sn	4.74	4.73	4.75	4.73	4.72	0.372	0.085
50	BM	EcL-FtL	2.17	1.83	1.72	1.72	1.71	0.371	0.081
52	BM	EcL-Gn	10.16	10.11	10.28	10.36	10.18	0.367	0.210
148	BM	LnR-Prn	1.26	1.20	1.25	1.25	1.27	0.366	0.093
202	BM	ZyL-Sn	6.36	6.39	6.33	6.29	6.41	0.365	0.320
75	BM	EnL-G	2.18	2.16	2.20	2.21	2.11	0.364	0.345
155	VM	N-Prn	3.34	3.37	3.32	3.23	3.26	0.363	0.217
90	BM	EnR-Sto	5.67	5.66	5.76	5.80	5.75	0.361	0.308
150	BM	LnR-Sn	1.19	1.15	1.18	1.18	1.18	0.360	0.772
83	BM	EnR-ChR	5.54	5.51	5.65	5.74	5.69	0.359	0.790
5	BM	AlL-Ls	2.51	2.53	2.58	2.72	2.74	0.358	0.319
119	CM	IlR-FtL	7.87	7.68	7.75	7.72	7.56	0.357	0.207
64	BM	EcR-Gn	10.18	10.11	10.30	10.37	10.17	0.355	0.506

to be continued

concluded

12	CM	AlR-ChL	4.36	4.36	4.42	4.58	4.51	0.347	0.583
166	HM	Pu-Pu	5.40	5.33	5.42	5.49	5.33	0.347	0.718
92	HM	Ft-Ft	8.68	8.70	8.81	8.71	8.52	0.344	0.381
157	VM	N-Sto	6.23	6.26	6.37	6.38	6.29	0.343	0.350
130	BM	ImL-G	2.58	2.54	2.60	2.64	2.53	0.340	0.471
80	BM	EnL-Sto	5.67	5.68	5.77	5.82	5.76	0.339	0.496
140	CM	ImR-IlL	5.40	5.33	5.42	5.49	5.33	0.335	0.227
203	BM	ZyL-Tr	9.65	9.35	9.61	10.47	10.06	0.332	0.316
200	CM	ZyL-GoR	11.69	11.59	11.78	11.79	11.84	0.322	0.242
153	VM	Ls-Sto	0.56	0.53	0.52	0.50	0.43	0.315	0.763
60	CM	EcR-ChL	8.14	8.10	8.28	8.28	8.12	0.304	0.637
51	BM	EcL-G	4.13	4.05	4.14	4.14	3.99	0.303	0.414
210	BM	ZyR-Tr	9.48	9.41	9.64	9.99	9.71	0.286	0.572
27	BM	ChL-Tr	12.41	12.16	12.35	12.99	12.63	0.270	0.429
186	BM	SpnL-LnL	0.29	0.25	0.32	0.31	0.27	0.263	0.247
190	BM	SpnR-SbalR	0.56	0.59	0.62	0.65	0.58	0.263	0.247
135	CM	ImR-ChL	7.17	7.15	7.32	7.38	7.22	0.260	0.679
86	BM	EnR-Gn	9.37	9.30	9.48	9.60	9.44	0.257	0.497
67	BM	EcR-N	3.92	3.86	3.94	3.90	3.80	0.246	0.635
79	BM	EnL-Sn	3.84	3.84	3.85	3.81	3.84	0.231	0.534
14	BM	AlR-Gn	6.48	6.45	6.55	6.76	6.59	0.230	0.479
97	VM	G-Gn	10.93	10.89	11.11	11.20	10.97	0.225	0.662
111	CM	IlL-FtR	7.96	7.68	7.76	7.76	7.58	0.224	0.705
205	BM	ZyR-Gn	10.24	10.09	10.21	10.13	10.00	0.212	0.751
32	BM	ChR-Tr	12.40	12.20	12.38	12.88	12.56	0.210	0.869
172	BM	PuR-Prn	4.00	3.98	3.98	3.92	3.85	0.124	0.990
34	BM	CphL-ChL	1.61	1.63	1.64	1.65	1.61	0.119	0.936
58	BM	EcL-Tr	7.73	7.41	7.49	8.22	7.83	0.114	0.958
59	BM	EcR-AlR	3.89	3.86	3.96	3.81	3.73	0.100	0.997
66	CM	EcR-IlL	7.06	6.97	7.08	7.10	6.91	0.091	0.934
100	BM	GoL-Gn	6.23	6.19	6.32	6.44	6.45	0.076	0.999

Source: prepared by the author.
* Significant difference between age groups within male group.
[a] Identical averages.

3.9 Discriminating Potential

Compiled results of all analyzed groups, including LASSO selection, are displayed in Table 2.7. The first four columns represent LASSO selected measures according to each analyzed group and the corresponding scores were calculated by the sum of group indications (Sc) (shown in the fifth column). Measures selected at least once by LASSO, and already included according to prior established criteria for general frequency (CV) and reliability (Rc), are classified in final selection (FS) as having high discriminatory potential. Results of facial side differences are also displayed in the very last column.

From a total of 211 measures, 35 were selected according to established criteria (28 BM, 3 VM, 4HM). Best score measure is for *Spn-Spn,* demonstrating its high reliability and low frequency independently of the individual's sex and age. The measures scored in three categories are *AlR-ChR, ChR-Ls, EcR-AlR and En-En.* Those scored in two categories are *ChL-Ls, ChR-Li, CphR-ChR, EnL-Ls, EnR-G, GoL-*

Ls, Im-Im, Ls-Li and N-Sto, followed by the one-scored measures *AlL-ChL, AlL-Prn, AlL-Sn, AlR-Prn, Cph-Cph, CphL-Li, CphR-Li, EcL-GoL, EnL-AlL, EnR-AlR, EnR-Sn, GoL-Prn, GoR-Ls, GoR-Prn, IlL-GoL, IlL-N, IlR-N, N-Prn, PuR-G, PuR-Prn and PuR-Sn.*

In FPA analysis, considering both facial sides separately is essential to better understand the morphometry of the face, especially when assessing angles and other facial geometries. However, for a more general and concise application without considering facial sides, BMs showing no significant difference between facial sides (*AlL-Prn*, *AlR-Prn*, *EnL-AlL*, *EnR-AlR*, *GoL-Prn* and *GoR-Prn)*, statistically equal measures (*AlL-Sn* and *ChR-Li*) and measures that do present facial side differences but where both were classified for final selection (*AlL-ChL*, *AlR-ChR*, *CphL-Li*, *CphR-Li*, *IlL-N* and *IlR-N*) were grouped to better assist future studies. In this sense, a list of 16 facial measures may be a better choice, namely: *Al-Ch, Al-Prn*, *Al-Sn*, *Ch-Li*, *Ch-Ls*, *Cph-Cph*, *Cph-Li*, *En-Al*, *En-En*, *Go-Prn*, *Il-N*, *Im-Im*, *Ls-Li*, *N-Prn*, *N-Sto*, and *Spn-*Spn (9 BM, 4 HM, and 3 VM) (Appendix B).

This final list aims to include only measures in which both sides are included in the final selection, regardless of their score. In this regard, *EcL-GoL, EnR-G, EnR-Sn, CphR-ChR, GoR-Ls, IlL-GoL*, *PuR-G, PuR-Prn*, *PuR-Sn*, *EnL-Ls*, *GoL-Ls* and *EcR-AlR* measures were excluded from this list and two measures were combined without having the same score, that is *Al-Ch* and *Ch-Ls*. Distribution results of those 16 measures is graphically presented in ranges of 0.10 to better assist further studies and evidence evaluation of facial metric traits (APPENDIX C).

Table 2.7 - Summary of discriminative potential analysis. The columns A, S, M and F represent LASSO regression indications of low frequency by groups of *age*, *sex*, *male* and *female* respectively. Measure score (Sc) displays the sum of LASSO indications and, together with frequency analysis (CV) and reliability classification (Rc) (the three middle columns), represent the three established criteria for final selection (FS) by means of discrimating potential. Side difference results (S≠) are summarized in the very last column

T	Measures	A	S	M	F	Sc	CV	Rc	FS	S≠	T	Measures	A	S	M	F	Sc	CV	Rc	FS	S≠
HM	Al-Al						*	*		–	BM	GoR-Prn		*			*	*	*	*	
BM	AlL-ChL			*		*	*	*	*	*	BM	GoR-Tr		*	*		**	*			
CM	AlL-ChR	*	*		*	***		*		*	VM	G-Sn						*	*		–
BM	AlL-Gn	*				*	*				HM	Il-Il							*		–
BM	AlL-Ls			*		*	*			*	CM	IlL-FtR		*			*	*			*
BM	AlL-N						*	*			BM	IlL-Gn							*		
BM	AlL-Prn				*	*	*	*	*		BM	IlL-GoL		*			*	*	*	*	
BM	AlL-SbalL			*	*	**	*				BM	IlL-ImL							*		
BM	AlL-Sn			*		*	*	*	*	=	BM	IlL-Ls	*	*			**		*		
BM	AlL-Sto			*		*	*				BM	IlL-N		*			*	*	*	*	*
BM	AlL-Tr		*			*	*				BM	IlL-Sn							*		
CM	AlR-ChL		*			*		*		*	BM	IlL-Tr						*			

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continuation

BM	AlR-ChR	*	*		*	***	*	*	*****	*	CM	IlR-FtL	*	*			**					*
BM	AlR-Gn						*				BM	IlR-Gn										
BM	AlR-Ls	*	*			**	*			*	BM	IlR-GoR		*			*	*				
BM	AlR-N						*	*			BM	IlR-ImR							*			
BM	AlR-Prn		*			*	*	*	*****		BM	IlR-Ls							*			
BM	AlR-SbalR				*	*	*				BM	IlR-N		*			*	*	*	*****	*	
BM	AlR-Sn						*	*		=	BM	IlR-Sn	*				*		*			
BM	AlR-Sto						*	*			BM	IlR-Tr						*				
BM	AlR-Tr						*				HM	Im-Im	*	*			**	*	*	*****	–	
HM	Ch-Ch	*	*	*	*	****	*			–	BM	ImL-ChL	*	*			**		*		*	
BM	ChL-Gn		*			*	*			*	CM	ImL-ChR							*		*	
BM	ChL-Li						*	*		=	BM	ImL-G	*				*		*		*	
BM	ChL-Ls		*		*	**	*	*	*****	*	BM	ImL-Gn							*			
BM	ChL-Sn	*	*		*	***	*			*	CM	ImL-GoR		*			*					
BM	ChL-Tr	*	*			**	*			*	CM	ImL-IlR		*			*		*			
BM	ChR-Gn	*	*		*	***	*			*	BM	ImL-Sn						*	*			
BM	ChR-Li	*	*			**	*	*	*****	=	CM	ImR-ChL	*	*			**		*		*	
BM	ChR-Ls	*	*		*	***	*	*	*****	*	BM	ImR-ChR		*			*		*		*	
BM	ChR-Sn				*	*	*			*	BM	ImR-G						*	*		*	
BM	ChR-Tr		*			*	*				BM	ImR-Gn										
HM	Cph-Cph		*			*	*	*	*****	–	CM	ImR-GoL			*		*		*			
BM	CphL-ChL	*		*		**	*			*	CM	ImR-IlL							*			
BM	CphL-Gn		*			*	*			*	BM	ImR-Sn						*	*			
BM	CphL-Li				*	*	*	*	*****	*	VM	Li-Gn		*			*	*			–	
BM	CphL-Ls			*		*	*			*	VM	Li-Sto		*	*	*	***	*			–	
BM	CphL-Sn	*	*	*		***	*				HM	Ln-Ln		*			*	*			–	
BM	CphL-Sto				*	*	*			*	BM	LnL-Prn	*	*		*	***	*			*	
BM	CphR-ChR	*	*			**	*	*	*****	*	BM	LnL-SbalL		*			*	*				
BM	CphR-Gn	*	*			**	*			*	BM	LnL-Sn	*			*	**	*				
BM	CphR-Li		*			*	*	*	*****	*	BM	LnR-Prn		*	*	*	***	*			*	
BM	CphR-Ls	*	*		*	***	*				BM	LnR-SbalR	*	*	*	*	****	*				
BM	CphR-Sn						*	*		*	BM	LnR-Sn			*		*	*				
BM	CphR-Sto						*				VM	Ls-Gn						*			–	
HM	Ec-Ec	*		*		**				–	VM	Ls-Li	*	*			**	*	*	*****	–	
BM	EcL-AlL						*	*			VM	Ls-Sto		*			*	*			–	
BM	EcL-ChL	*	*			**		*		*	VM	N-Gn		*			*	*			–	
CM	EcL-ChR	*	*			**					VM	N-Prn			*		*	*	*	*****	–	
BM	EcL-FtL		*	*	*	***	*				VM	N-Sn						*	*		–	
BM	EcL-G	*	*			**				*	VM	N-Sto	*	*			**	*	*	*****	–	
BM	EcL-Gn	*	*			**					BM	PuL-ChL	*	*			**		*		*	
BM	EcL-GoL		*			*	*	*	*****		CM	PuL-ChR							*		*	
CM	EcL-IlR	*	*			**		*		*	BM	PuL-G				*	*		*		*	
BM	EcL-N		*		*	**	*			*	BM	PuL-Gn	*	*			**		*			
BM	EcL-Sn		*			*		*			BM	PuL-Ls		*			*		*			
BM	EcL-Sto										BM	PuL-Prn						*	*			
BM	EcL-Tr						*				BM	PuL-Sn						*	*			
BM	EcR-AlR	*	*		*	***	*	*	*****		BM	PuL-Tr						*				
CM	EcR-ChL	*	*			**		*			HM	Pu-Pu	*				*		*		–	
BM	EcR-ChR	*	*		*	***		*		*	CM	PuR-ChL		*			*		*		*	
BM	EcR-FtR	*	*			**	*				BM	PuR-ChR							*		*	
BM	EcR-G		*			*				*	BM	PuR-G	*				*	*	*	*****	*	
BM	EcR-Gn	*	*			**					BM	PuR-Gn		*			*					
BM	EcR-GoR	*	*			**	*				BM	PuR-Ls		*			*		*			
CM	EcR-IlL	*	*			**				*	BM	PuR-Prn	*				*	*	*	*****		
BM	EcR-N		*			*	*			*	BM	PuR-Sn	*				*		*	*****		
BM	EcR-Sn		*			*		*			BM	PuR-Tr						*				
BM	EcR-Sto							*			BM	SbalL-Ls		*	*	*	***	*				
BM	EcR-Tr						*				BM	SbalL-Prn		*			*	*			*	
HM	En-En	*	*		*	***	*	*	*****	–	BM	SbalL-Sn						*				
BM	EnL-AlL		*			*	*	*	*****		BM	SbalR-Ls			*	*	**	*				
BM	EnL-ChL	*	*			**		*		*	BM	SbalR-Prn	*				*	*			*	
BM	EnL-EcL	*		*	*	***				*	BM	SbalR-Sn						*				
BM	EnL-G		*		*	**		*		*	HM	Sbal-Sbal	*	*	*		***	*			–	
BM	EnL-Gn										VM	Sn-Gn						*			–	
BM	EnL-Li							*			VM	Sn-Ls						*			–	
BM	EnL-Ls	*	*			**	*	*	*****		VM	Sn-Prn		*		*	**	*			–	
BM	EnL-Sn						*	*			VM	Sn-Sto						*	*		–	
BM	EnL-Sto		*			*		*			BM	SpnL-LnL	*	*		*	***	*				
BM	EnL-Tr						*				BM	SpnL-SbalL				*	*	*				
BM	EnR-AlR		*			*	*	*	*****		BM	SpnL-Sn	*	*		*	***	*			=	
BM	EnR-ChR		*		*	**		*		*	BM	SpnR-LnR						*				
BM	EnR-EcR	*	*	*	*	****				*	BM	SpnR-SbalR	*		*		**	*				
BM	EnR-G			*	*	**	*	*	*****	*	BM	SpnR-Sn				*	*	*			=	
BM	EnR-Gn										HM	Spn-Spn	*	*	*	*	****	*	*	*****	–	
BM	EnR-Li		*			*		*			VM	Sto-Gn	*				*	*			–	
BM	EnR-Ls						*				VM	Tr-G						*			–	

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concluded

BM	EnR-Sn	*				*		*	*	VM	Tr-Gn			*			*	*	–
BM	EnR-Sto							*		VM	Tr-Sn							*	–
BM	EnR-Tr				*		*			BM	ZyL-G			*			*		
HM	Ft-Ft	*	*	*		***			–	BM	ZyL-Gn	*	*				**		
BM	FtL-N						*		*	BM	ZyL-GoL				*	*	**	*	
BM	FtL-Tr				*		*			CM	ZyL-GoR	*	*				**		*
BM	FtR-N		*				*		*	BM	ZyL-Prn			*			*	*	
BM	FtR-Tr						*			BM	ZyL-Sn			*		*	**	*	
VM	G-Gn		*			*			–	BM	ZyL-Tr					*	*	*	
HM	Go-Go	*		*	*	***	*		–	BM	ZyR-G	*	*				**	*	
BM	GoL-G	*				*		*		BM	ZyR-Gn	*				*	**		
BM	GoL-Gn						*			CM	ZyR-GoL								*
BM	GoL-Ls		*		*	**	*	*	*	BM	ZyR-GoR	*	*			*	***	*	
BM	GoL-Prn			*		*	*	*	*	BM	ZyR-Prn			*			*	*	
BM	GoL-Tr		*			*	*			BM	ZyR-Sn			*		*	**	*	
BM	GoR-G							*		BM	ZyR-Tr			*			*	*	
BM	GoR-Gn	*	*			**	*			HM	Zy-Zy	*			*		**		–
BM	GoR-Ls			*		*	*	*	*										

Source: prepared by the author.
*****A: LASSO indication for age group; S: LASSO indication for sex group; M: LASSO indication for male group: F: LASSO indication for female group; Sc: score; f: frequency results; Rc: reliability results; FS: final selection; S≠: side difference; =: identical averages for both sides; -: not classified (VM and HM); R: right side; L: left side.

4 Discussion

Studies of the frequencies and distributions of facial feature measures within a specific population are essential for calculation of inclusion/exclusion probabilities, in order to add weight to the strength of match decisions in FFI cases (1, 5). In forensic science, this lack of documented distributions of population-specific facial features, together with evaluative protocols, prevents application of the most logical framework (the likelihood ratio (LR)) for inferring the identity of a source (4, 5). This logical approach to evidence evaluation consists of assigning weight to two mutually exclusive hypotheses: the prosecution hypothesis (Hp) that the compared faces/traces/marks have the same source (inclusion probability); and the defense hypothesis (Hd) that the compared faces/traces/marks have alternative sources (exclusion probability) (28, 29). In order to calculate the likelihood of the evidence in the second hypothesis, the examiner must consider how probable it would be to observe the same facial pattern if images were acquired from different persons (29). In such cases, between-source variability (BSV) studies, for example those, such as this one, that assess the rarity and frequency of facial features in specific populations, are of utmost importance in order to correctly evaluate LRs (29).

At present, the lack of such quantitative facial data means that FFI conclusions are based solely on examiners' experience and empirically reported as verbal expressions, based on a sliding scale of degree of support: *very strong*, *strong*, *moderate*, *limited or no support* (29, 30). Since many intrinsic and extrinsic factors

(e.g., facial pose, lighting, camera angle, facial expression) can influence the variability of linear measurements on 2D-images, further studies of their intraindividual variability, are necessary for LR calculation and, hence, numerical expression of the probative strength of conclusions. Independently of the approach used by examiners to report their conclusions, the balance of probabilities of whether or not sets of facial features share the same source is better performed when grounded by frequency studies (29). The rarer a certain feature is within a population, the greater is its capacity for individualization and the more significant is the match between compared 2D-images when this certain feature is present in both (1, 2).

Along with providing FPA frequency data for different age and sex groups, the present study also provides a list of potentially discriminatory FPA measures. In an attempt to uncover the most relevant measures for distinguishing adult individuals, regardless of sex and age, this work was conducted in a way that allowed exclusion of measures displaying the greatest consistencies among groups (i.e., high frequencies) and variabilities inconsistent with interindividual variation. Considering that many factors can influence the variability of FPA measures, and that a single examiner analyzed each sample, reliability classification considered only measures in which sample dispersion differed from the interexaminer group by less than or equal to 30%. Higher differences were considered more consistent with methodological error than interindividual variation. All the influencing factors may introduce different sources of variation in frequency analyses, even when images are acquired under very controlled situations. Non-interest sources of variation may disguise truthful human variation, especially when groups with different characteristics are linked together, as in general frequency analysis (CV). Since all age and sex groups were considered as a larger group, greater errors are expected and a larger threshold was considered, in order to not exclude potentially discriminatory measures. Age groups characterized by inconsistency and major facial changes, i.e. children and sub-adults, were not included in this research in order to remove sources of variation more consistent with the growth process than interindividual variation.

All linear measures were converted into iris ratios to minimize the influence of imaging acquisition factors and to make measures more similar for comparison purposes. It is well-known that using proportionality indices (PIs), percentages, ratios, and indices, rather than absolute measures, prior to imaging analysis reduces quantitative differences in images acquired under adverse conditions (6, 7, 17). The

high frequency, reproducibility and reliability of HVID were confirmed in this study,thus confirming its relevance in FPA analysis (12, 14, 18, 19). As expected, iris diameter of both sides (*IlL-ImL* and *IlR-ImR*) were classified as being not statistically different within all analyzed groups. This means that, independently of the age and sex of the individual, this measure is consistently equal. These results provide further consolidation that iris diameter is a valuable measure for understanding human physical variation, as well as for abovementioned applications. Additional assessments comparing the performances of different approaches may confirm its relevance for human individualization purposes.

A specific methodology for frontal-view facial image analysis was used in order to minimize systematic errors introduced by landmark positioning. This methodology showed greater robustness and reproducibility for almost all 16 landmarks analyzed (error rate ≤ 1 mm/4.35 px). The exceptions were *Zy* and *Lm,* which showed undesirable variability results (error rate > 1 mm) when applied to placement of vertical measures, particularly when performed by people without knowledge in anatomy and/or physical anthropology (18). The high variability and unreliability of *Zy* measures were also confirmed in the present study, together with a better performance when applied for horizontal measures (18). Indeed, the horizontal *Zy* measure (i.e., *Zy-Zy*) performed considerably better than other BMs or CMs that included this landmark. Considering measure types, it was also observed that VMs showed greater differences between groups than HMs, supporting the fact that closer HM values are more likely to be found within populations. On the contrary, HM showed better results for discriminating between male and female groups.

As suggested by other studies, transient measures and those that lack stability with time were excluded, since they may not be appropriate for a forensic investigation (5). Although also considered inappropriate, a landmark from hairline (i.e., *Tr*) was included because is practically the only vertical reference from the frontal region. Nonetheless, results confirmed its unreliability in the same way as for *Ln, Sbal, and Zy* landmark-related measures. The measures that were found to be the most reproducible and consistent confirmed previous studies that indicate landmarks from the eye and mouth regions are more reliable (i.e., *Al, Cph, Il, Im, Pu*) (24-26). One unexpected result was the classification of *Spn-Spn* (HM) as a potential measure reference for human discrimination. This result has not been reported previously and

shows that the distance between both upper landmarks of the nostrils is different and reliable enough to possibly evolve imaging analysis.

As linear measures are obtained by joining two reference landmarks, it would have been possible to generate 506 linear distances in this study (23 x 22), by using the 23 photo-anthropometric landmarks (7). However, of all these measures, a subset of 211 was selected after consideration of related publications and the feasibility to obtain important indices and facial angles from the measures. In total, 35 measures passed all the selection criteria and eventually, to reduce the list of measures to a useful minimum, only 16 were selected as having greatest discriminatory potential overall: *Al-Ch, Al-Prn*, *Al-Sn*, *Ch-Li*, *Ch-Ls*, *Cph-Cph*, *Cph-Li*, *En-Al*, *En-En*, *Go-Prn*, *Il-N*, *Im-Im*, *Ls-Li*, *N-Prn*, *N-Sto*, and *Spn*-Spn.

In view of no previous studies having considered iris ratios for frequency evaluation, some outcomes can not be properly compared. In general, studies have suggested that the most relevant measures in image comparisons for FFI purposes are *En-En* (intercanthal), *Pu-Pu* (interpupillary), *Ch-Ch* (lip width), *Al-Al* (nasal width), *Zy-Zy* (horizontal facial width), *Ec-N*, *Ec-Sto*, *N-G*, and *Go-Go* (base of the chin) (7, 17, 31). According to these works, the applicability of these measures is justified by their low variation over time and consistency even after weight gain/loss and with different facial expressions. The frequency of these measures within relevant populations was not, however, considered (7, 31). This research showed that all of those measures undergo considerable changes over time, especially *Ch-Ch* and *Al-Al* and none of them were classified in the group of the 16 measures with the greatest discriminating potentials. Nonetheless, some measures involving landmarks proposed as useful by previously conducted studies, such as *Al, Ch*, *Go, N, Prn*, *Pu* and *Sto,* were within the measures classified for final selection, showing that these landmarks may provide discriminatory potential if combined differently. Results of *Prn* do corroborate previous study results, which suggested this landmark as an important reference in this respect (7). Measures composed of *Ec*, *En* and *Pu* landmarks are commonly used as references (i.e., *Ec-Ec*, *En-En*, and *Pu-Pu*) for image normalization, due to their high stability through time and with facial expressions, hence inconsistency with great discriminating potential (7, 17). Indeed, only *En-En* measures showed discriminatory potential in the present study.

It was observed that measure errors were considerably greater than in other studies, including the reference methodology (18). This can be explained by the fact

that the reference sample was composed of just one age group (i.e., 40-years-old), as well as that variability was assessed as a function of landmarks and not facial measures. Since linear measures are obtained by the union of two landmarks, as mentioned previously, adding both landmarks in the same measure may increase general variability. Further studies assessing the discriminatory performance of indices, angles and other facial relations are of extreme relevance for a more robust evaluation.

LASSO logistic regression was used to confirm the least frequent measures between groups. This machine-learning-based tool is a powerful feature selection technique that is very useful to solve regression problems, especially by reducing the influence of less important variables (32). This analysis is presented as a particular section due to the large number of initial variables. Considering that mild thresholds were established for other selections, it was possible to provide a more consistent, robust and reliable list for further studies. Nevertheless, in view of the present study aimed at determining measures with greatest discriminatory potential, it is important that, in future works, their potential is tested with larger facial databases and between different age and sex groups for more reliable conclusions.

5 Conclusion

In this work, a set of 16 facial photo-anthropometric measures are indicated as having great potential for distinguishing between faces of adult individuals in bidimentional images, independently of sex and age. These Euclidean distances divided by the iris diameter (iris ratios) were shown to be reliable and variable enough to differentiate individuals. Future works in this field should, however, test the performances of these measures with larger facial databases, in order to reach more confident conclusions.

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Appendix A –

Difference (≠) between facial side (R-right and L-left) for BM (bilateral measure) and CM (cross-side measure)

Type	Measure	L	R	≠	p-value	Type	Measure	L	R	≠	p-value
BM	Al-Ch	2.77	2.81	0.04	**< 0.001***	BM	Go-G	9.07	9.08	0.01	0.833
CM	Al-Ch	4.63	4.62	0.01	0.025	BM	Go-Gn	6.58	6.55	0.03	0.015
BM	Al-Gn	6.89	6.89	0.00	0.009	BM	Go-Ls	5.26	5.23	0.03	0.235
BM	Al-Ls	2.77	2.79	0.02	**< 0.001***	BM	Go-Prn	6.11	6.06	0.05	0.043
BM	Al-N	4.15	4.15	0.00	0.372	BM	Go-Tr	13.79	13.61	0.18	0.244
BM	Al-Prn	1.70	1.68	0.02	0.045	CM	Il-Ft	7.85	7.83	0.02	**< 0.001***
BM	AL-Sbal	0.94	0.95	0.01	0.026	BM	Il-Gn	10.51	10.50	0.01	0.847
BM	Al-Sn	1.74	1.76	0.02	**0.001***	BM	Il-Go	6.37	6.36	0.01	0.787
BM	Al-Sto	3.17	3.17	0.00	0.066	BM	Il-Im	1.00	1.00	0.00	0.005
BM	Al-Tr	10.12	10.05	0.07	0.012	BM	Il-Ls	6.42	6.43	0.01	0.306
BM	Ch-Gn	4.49	4.45	0.04	**< 0.001***	BM	Il-N	3.35	3.36	0.01	**< 0.001***
BM	Ch-Li	2.22	2.22	0.00	**0.001***	BM	Il-Sn	5.10	5.11	0.01	0.143
BM	Ch-Ls	2.14	2.17	0.03	**< 0.001***	BM	Il-Tr	7.51	7.37	0.14	0.567
BM	Ch-Sn	2.96	3.00	0.04	**< 0.001***	BM	Im-Ch	6.04	6.07	0.03	**< 0.001***
BM	Ch-Tr	12.87	12.83	0.04	**< 0.001***	CM	Im-Ch	7.45	7.42	0.03	**< 0.001***
BM	Cph-Ch	1.64	1.70	0.06	**< 0.001***	BM	Im-G	2.62	2.66	0.04	**< 0.001***
BM	Cph-Gn	4.68	4.67	0.01	**< 0.001***	BM	Im-Gn	10.25	10.24	0.01	0.865
BM	Cph-Li	1.53	1.51	0.02	**< 0.001***	CM	Im-Go	9.57	9.59	0.02	0.020
BM	Cph-Ls	0.62	0.59	0.03	**< 0.001***	CM	Im-Il	5.48	5.48	0.00	0.005
BM	Cph-Sn	1.55	1.55	0.00	0.118	BM	Im-Sn	4.53	4.54	0.01	0.181
BM	Cph-Sto	0.90	0.87	0.03	**< 0.001***	BM	Ln-Prn	1.32	1.30	0.02	**< 0.001***
BM	Ec-Al	3.83	3.83	0.00	0.966	BM	Ln-Sbal	0.51	0.52	0.01	0.579
BM	Ec-Ch	6.10	5.81	0.29	**< 0.001***	BM	Ln-Sn	1.22	1.23	0.01	0.276
CM	Ec-Ch	8.35	8.33	0.02	0.119	BM	Pu-Ch	6.07	6.10	0.03	**< 0.001***
BM	Ec-Ft	1.85	1.84	0.01	0.805	CM	Pu-Ch	7.75	7.73	0.02	**< 0.001***
BM	Ec-G	4.14	4.20	0.06	**< 0.001***	BM	Pu-G	3.06	3.09	0.03	**< 0.001***
BM	Ec-Gn	10.53	10.53	0.00	0.424	BM	Pu-Gn	10.37	10.36	0.01	0.834
BM	Ec-Go	6.02	6.01	0.01	0.449	BM	Pu-Ls	6.19	6.19	0.00	0.382
CM	Ec-Il	7.08	7.11	0.03	**< 0.001***	BM	Pu-Prn	4.01	4.00	0.01	0.302
BM	Ec-N	3.97	4.00	0.03	**< 0.001***	BM	Pu-Sn	4.80	4.80	0.00	0.161
BM	Ec-Sn	5.36	5.39	0.03	0.005	BM	Pu-Tr	7.29	7.18	0.11	0.580
BM	Ec-Sto	6.98	6.99	0.01	0.280	BM	Sbal-Ls	1.87	1.88	0.01	0.071
BM	Ec-Tr	7.98	7.83	0.15	0.020	BM	Sbal-Prn	1.45	1.43	0.02	**< 0.001***
BM	En-Al	3.03	3.02	0.01	0.006	BM	Sbal-Sn	0.97	0.98	0.01	0.450
BM	En-Ch	5.78	5.81	0.03	**< 0.001***	BM	Spn-Ln	0.31	0.30	0.01	0.570
BM	En-Ec	2.45	2.49	0.04	**< 0.001***	BM	Spn-Sbal	0.63	0.63	0.00	0.405
BM	En-G	2.18	2.20	0.02	**< 0.001***	BM	Spn-Sn	1.08	1.08	0.00	**0.001***
BM	En-Gn	9.80	9.79	0.01	0.021	BM	Zy-G	6.52	6.56	0.04	0.020
BM	En-Li	6.61	6.61	0.00	0.010	BM	Zy-Gn	10.41	10.41	0.00	0.786
BM	En-Ls	5.43	5.43	0.00	0.274	CM	Zy-Go	12.00	12.04	0.02	**< 0.001***
BM	En-Sn	3.90	3.89	0.01	0.509	BM	Zy-Go	4.68	4.66	0.04	0.390
BM	En-Sto	5.89	5.88	0.01	0.014	BM	Zy-Prn	6.12	6.10	0.02	0.621
BM	En-Tr	7.14	7.08	0.06	0.901	BM	Zy-Sn	6.42	6.44	0.02	0.320
BM	Ft-N	4.67	4.69	0.02	**< 0.001***	BM	Zy-Tr	10.15	9.92	0.23	0.597
BM	Ft-Tr	6.93	6.76	0.17	0.011						

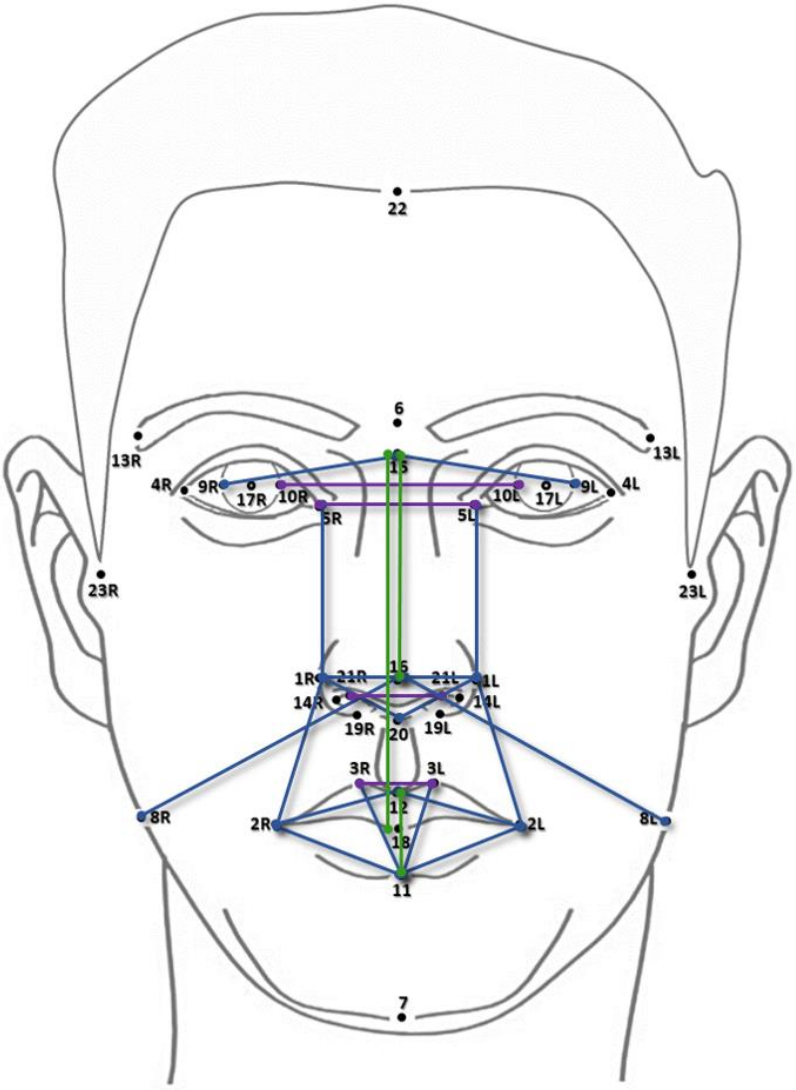
Source: prepared by the author.

*Significant difference between facial sides.

Appendix B –

FPA measures classified as potentially discriminating

Classified measures	
Type	**Measure**
BM	Al-Ch
BM	Al-Prn
BM	Al-Sn
BM	Ch-Li
BM	Ch-Ls
HM	Cph-Cph
BM	Cph-Li
BM	En-Al
HM	En-En
BM	Go-Prn
BM	Il-N
HM	Im-Im
VM	Ls-Li
VM	N-Prn
VM	N-Sto
HM	Spn-Spn



Source: prepared by the author.

3 CHAPTER II – Discriminatory power of photo-anthropometric facial measures between unrelated individuals

Abstract

Distinguishing individuals by their facial appearance is a challenging task in forensic science, especially in Forensic Facial Identification (FFI) examinations. Although its metric approach (i.e., facial photo-anthropometry – FPA) is underestimated and discouraged by current general guidelines for human individualization purposes, studies have shown it to be a valuable tool for the prediction of sex, age and ancestry, indicating that it may have some potential in discriminating individuals. Previous work (Chapter I) suggested 16 FPA measures potentially capable of discriminating unrelated Brazilian individuals. Nonetheless, these measures have not yet been tested. The work presented herein therefore aims to verify the distinguishing potential of these FPA measures (Euclidean distances), as well as 21 angles and 20 indices obtained from them, and determine how many would be necessary to distinguish one individual from all others. Standardized frontal view facial images of 920 individuals, of both sexes and from eight age groups (5, 15, 20, 30, 40, 50, 60, over 70 years old ± one year), were analyzed. The analysis is based on finding duplicate values considering ranges of three sources of variability: interindividual (ER), intraindividual intraexaminer (RAA) and intraindividual interexaminer (RAE). It was concluded that a combination of 15 Euclidean distances or 20 indices was sufficient to achieve a probability of finding less than one individual in a population of one million (10^6) with the same values. The same probability was achieved using 18 angles in age groups of 15 and 70 year olds, whereas in age groups of 5, 50 and 60 year olds, 17 angles were required. These results strongly support the hypothesis that FPA measures, especially Euclidean distances, can be used for discriminating Brazilian human faces depicted on frontal view standardized images.

1 Introduction

There is a growing demand among law enforcement agencies worldwide for facial individualization through comparison of bidimensional (2D) images. This procedure assumes that human faces are unique, even though this cannot be demonstrated empirically (1, 2). The theory of facial uniqueness assumes that, present on each individual, there is at least one specific facial characteristic that considerably

increases the probability of that face being distinct within a specific population, even in the case of identical twins (monozygotic, MZT) (2, 3). Indeed, studies have shown that this theoretically identical group (same genetic code – DNA) have facial differences that can be used to differ one from the other (3, 4). When considering the metric approach towards facial individualization (i.e., photo-anthropometry – FPA), only few studies to date have proposed assessing how effectively this inherently objective method of facial imaging analysis is able to distinguish between human faces.

One particular study in facial anthropometry concluded that human face “singularity” can be achieved using a combination of a minimum of eight measures (1). Measures were, however, taken directly from individuals and only absolute sizes were considered, instead of a range for finding duplicate values within a database, making this evaluation not suitable for FPA analysis. Considering singular quantitative values without including a variability range in facial imaging analysis is senseless, in view of the large number of intrinsic and extrinsic factors that influence the variability of the measures (e.g., variations in camera angle, lenses, resolution, lighting and facial pose/expression). In fact, managing FPA variability is the most arduous and challenging task for those who deal with this type of examination. Studies have argued that the variability of facial measures of the same individual can be as great as their variability between different individuals (5-8). Moreover, high correlation found between measures gives rise to practical limitations in face discrimination, even with high-quality frontal view standardized images (5-7).

Finding measures that are capable of distinguishing unrelated individuals could uncover new understanding of human face variation and support practical FFI examinations in real cases, particularly in the detection of fraudulent identity documents. In these cases, where facial images are acquired under sufficiently standardized conditions, the specific facial structures required for measurement are in better condition for analysis, with facial proportions, including the iris diameter, more amenable to comparison. Recent studies appointed horizontal visible iris diameter (HVID) as a sensitive tool for detecting facial growth and estimating the age of children and sub-adults, by using this facial reference as a common denominator in the determination of proportions and ratios (9-11). One study indicated 16 FPA Euclidean distances (i.e., iris ratios) as potential measures for discriminating unrelated Brazilian individuals. Nonetheless, their applicability for facial discrimination has not yet been assessed.

With this in mind, the aim of this study was to verify the discriminatory potential of these FPA measures by investigating whether or not two or more faces of unrelated Brazilian individuals have the same combination of Euclidean distances (ED), indices (IN) and angles (AN), by considering individuals of both sex and from different age groups (5, 15, 20, 30, 40, 50, 60, over 70 years old ± one year). This analysis was conducted by finding duplicate values considering ranges of three sources of variability: interindividual, intraindividual when analyzed by the same examiner (intraexaminer), and intraindividual when analyzed by different examiners (interexaminer) in order to calculate the percentage of statistically different measures. The second objective was to verify the number of measures that are sufficient to discriminate an individual, by finding duplicate values within the sample.

2 Material and methods

2.1 Reference facial images

Two groups of images were analyzed. The first group, named control group (CG), was composed of 60 frontal view facial images from 10 individuals taken twice on the same day (9 am and 5 pm) and then on four separate days within a week interval. All images were obtained under very controlled conditions, in order to reduce the influence of image acquisition factors as much as possible. Images were captured using the same light source and a DSLR camera, with no interchangeable lenses, positioned at 1.2 m from the individual's face and at a resolution of 560 x 720 pixels. Subjects were asked to adopt a neutral facial expression and their faces were aligned with the Frankfurt plane.

The sample group (SG) consisted of standardized frontal view facial images from 920 individuals of both sexes and from eight age groups (5, 15, 20, 30, 40, 50, 60, and over 70 years old ± one year), randomly selected from a Brazilian civilian database. Each age group consisted of 120 images of equal proportions of both sex, except for the 5-years age group that was composed of 80 images. All images underwent a pre-selection process following the inclusion criteria: all facial landmarks visible, faces aligned with the Frankfurt plane, neutral facial expression, absence of beard and/or mustache and absence of excessive make-up. Sample images were acquired at resolutions of 480 x 640 pixels.

2.2 Metric analysis

A manual approach to FPA landmark-positioning proposed by Flores et al. (12) was used for metric assessment. The following 14 landmarks were considered: Alare (*Al*); Chelion (*Ch*); Crista Philtre (*Cph*); Gnathion (*Gn*); Gonion (*Go*); Iridion Laterale (*Il*); Labiale Inferius (*Li)*; Labiale Superius (*Ls*); Nasion (*N*); Superius Nostril (*Spn*); Pronasale (*Prn*); Pupil (*Pu*); Subnasale (*Sn*); and, Stomion (*Sto*) (APPENDIX B). These landmarks were chosen based on the indication, from a previous study (Chapter I), of having the greatest discriminatory potential measures. From these 16 Euclidean distances (ED), 20 indices (IN) and 21 angles (AN) were also established. The inclusion of *Im-Im* measure was only possible for IN and ED analysis, due to the absence of other required measures containing the *Im* landmark for creating angles.

The FPA analysis of the SG was carried out by a single examiner and, for CG, three examiners performed the analysis in duplicate with a week interval between analyses. For mapping, a non-commercial software package for two-dimensional facial analysis (SAFF-2D®, Forensic Facial Analysis System, Department of Federal Police, Brazil) was used. The software allows examiners to locate the facial landmarks on images and automatically register them through Cartesian coordinates (X, Y).

2.3 Data treatment

Initially, 16 ED were calculated from the Cartesian coordinates (X, Y) by applying the Pythagorean Theorem. Of all measures, 4 were horizontal (HM), 3 vertical (VM) and 9 bilateral (BM). As a reference study, EDs were calculated by applying iris diameter (Euclidean distance mean between *Iridion Laterale* and *Iridion Mediale* landmarks from both sides of the face) as a common denominator (iris ratio). BMs were determined by calculating the mean of both sides (R – right and L – Left).

Indices were calculated by dividing the smaller measure by the larger measure then multiplying by 100, in order to generate a list of best-ranked measures according to reference study (13-15). For angle calculation, each proportioned measure was first converted into an actual physical scale (i.e., from px to mm), by dividing by a scaling factor of 2 px mm^{-1}, which made them suitable for angle calculation using the cosine rule. Considering that the horizontal visible iris diameter (HVID) is described to be around 11.5 mm (16-18), and that the average of this measure on images was 23

pixels, a ratio of 2 px mm^{-1} (23/11.5) was determined. From these numerical results obtained after application of the scaling factor, the arccosine was determined using the ACOS function in Microsoft® Office Excel. Since the returned angles were given in radians, they were converted into degrees using the DEGREES function of the same program.

2.4 Results assessment

First, CG was used to assess sources of variability for each measure (ED, AN, and IN). This analysis investigated three sources of variability: interindividual (ER), intraindividual (RA) when analyzed by the same examiner (intraexaminer – RAA), and intraindividual when analyzed by different examiners (interexaminer - RAE). The latter two evaluate the agreement of examiners' interpretations as a result of the method, indicating their consistency. ER is the source of variability that represents differences between individuals. Standard deviation (SD) of each measure was calculated to describe data error, and, from the variance (Var.) calculation, variability percentages (VSP) were obtained by mixed effects models, in order to better estimate and distinguish the contribution of each source on total variability (ER, RAA, and RAE). In this sense, VSP values from all sources sum to a total of 100%. This logistic regression model is indicated to capture the heterogeneity between and within samples and was applied using the *lmer* function in the *lme4* package for R.

The SG was used to assess the discriminatory power (DP) of the measures by searching for duplicate analyses. After estimating different variation sources, confidence intervals (CI) were calculated by the square root of RAA and RAE variances, in order to determine combined standard deviations (Appendix A). They were used to calculate the percentage of statistically different measures when considering a single variable and multiple variables together. In the first one, just one variable per group of measures (ED, AN, IN) was analyzed whereas for the latter, more than one was used for the analysis and the averages of the results are presented. Measures, angles and indices with fewer duplicates have the greatest capacity to discriminate one sample from the other.

3 Results

Results were organized into three sections. Analysis of measure variability sources (section 3.1) followed by discriminatory power of a single variable (section 3.2) and, finally, discrimination power of multiple variables (section 3.3). The analysis of variability source was split according to the evaluated measure: ED (section 3.1.1), IN (section 3.1.2), and AN (section 3.1.3).

3.1 Variability source analysis

Through this analysis it was possible to verify the variable component (ER, RAA, and RAE) that contributes the most to the variation seen for a measure. As expected, variability values of RAA were substantially smaller than those for RAE for all analyzed measures, showing that measurements performed by the same examiner are more reproducible than those carried out by different examiners. Indeed, VSPs for RAA were very small, not contributing less than 0.7% of total variability (VSP ≤ 0.675%; SD ≤ 1.003). RAE variability results (SD) ranged from 0.061 (ED *Il-N*) to 11.473 (AN *AlR-Prn-AlL*).

As also expected, greater interindividual (ER) than intraindividual (RA) variability was observed for almost all measures analyzed, except for *Al-Sn/Go-Prn*, *Al-Sn/Il-N*, *En-En/En-Al*, and *Ls-Li-ChR*, which revealed only slight differences between both variation sources. Comparison of measure type revealed EDs showed the least variation (SD < 0.500) for all three sources evaluated. Variabilities lower than 13.000 (SD) were seen for all IN and AN measures, except for IN *Cph-Cph/Cph-Li* (SD = 19.450).

Since ED measures had already been initially selected according to reliability and error criteria, this work will not discuss methodological errors or examiner “accuracy”. Variability source analysis was primarily calculated to create CI for finding duplicate analysis.

3.1.1 Euclidean Distance (ED)

Table 3.1 displays the variability source analysis results for all 16 Euclidean distances. The highest RAA variability percentages were observed for *Al-Ch* (0.675%),

N-Sto (0.565%) and *Al-Sn* (0.430%). These results indicate that, even for the same individual analyzed by the same examiner, with just a few hours/days between replicate analyses, major differences can be seen between measures involving landmarks in the mouth and nasal region, particularly the *Al* landmark.

Measures *Cph-Cph*, *Cph-Li*, *En-Al*, *En-En*, *Ls-Li*, *N-Prn* and *Spn-Spn* displayed no intraindividual variability when analyzed by the same examiner (SD = 0.000; VSP = 0.000%). As a result, greater ER than RA values were observed for these measures, indicating that interindividual differences are the primary source of their variability. This result corroborates previous studies (Chapter I) that classified these measures as some of the least frequent EDs and hence highlighted them as potentially discriminating.

For RAE, measures that presented the highest VSPs were *N-Prn* (40.068%), *Ch-Li* (35.261%), and *Ch-Ls* (32.941%), whereas lower VSPs were obtained for *Ls-Li* (7.954%), *Cph-Li* (8.106%) and *Im-Im* (8.931%). This highlights a high degree of consistency between examiners, confirming previous studies that state the mouth region measures are the most reproducible/reliable ones (19-21).

From ER analysis, the lowest variability percentages, and thus the least potential to discriminate individuals, were seen for *N-Prn* (59.932%), *Ch-Li* (64.631%) and *Ch-Ls* (67.008%) measures. On the contrary, the best ED measures according to discriminating potential were revealed to be *Ls-Li* (92.046%), *Cph-Li* (91.894%), *Im-Im* (90.796%), and *Il-N* (89.763%).

Table 3.1 - Variability source analysis for Euclidean distances (ED). Variance (Var.) and standard deviation (SD) values by the analyzed groups: interindividual (ER); intraindividual (RA) intraexaminer (RAA); and MR interexaminer (RAE). Variability source percentual (VSP - %) values by group analyzed

Euclidean distance	Var.			SD			VSP (%)		
	ER	RA		ER	RA		ER	RA	
		RAA	RAE		RAA	RAE		RAA	RAE
Al-Ch	0.074	0.001	0.015	0.271	0.024	0.121	82.751	0.675	16.575
Al-Prn	0.029	0.000	0.005	0.170	0.006	0.070	85.497	0.119	14.384
Al-Sn	0.021	0.000	0.010	0.147	0.012	0.101	67.536	0.430	32.034
Ch-Li	0.013	0.000	0.007	0.116	0.005	0.085	64.631	0.108	35.261
Ch-Ls	0.015	0.000	0.008	0.124	0.003	0.087	67.008	0.051	32.941
Cph-Cph	0.033	0.000	0.008	0.182	0.000	0.091	79.924	0.000	20.076
Cph-Li	0.093	0.000	0.008	0.305	0.000	0.091	91.894	0.000	8.106

to be continued

concluded

En-Al	0.071	0.000	0.013	0.267	0.000	0.115	84.464	0.000	15.536
En-En	0.076	0.000	0.010	0.275	0.000	0.098	88.822	0.000	11.178
Go-Prn	0.184	0.001	0.034	0.429	0.025	0.184	84.217	0.283	15.500
Il-N	0.034	0.000	0.004	0.184	0.011	0.061	89.763	0.322	9.915
Im-Im	0.148	0.000	0.015	0.385	0.021	0.121	90.796	0.273	8.931
Ls-Li	0.099	0.000	0.009	0.315	0.000	0.093	92.046	0.000	7.954
N-Prn	0.110	0.000	0.073	0.331	0.000	0.271	59.932	0.000	40.068
N-Sto	0.230	0.001	0.031	0.480	0.039	0.175	87.790	0.565	11.645
Spn-Spn	0.023	0.000	0.005	0.152	0.000	0.071	82.138	0.000	17.862

Source: prepared by the author.

3.1.2 Indices (IN)

Table 3.2 shows the variability source analysis results for all 20 indices. The highest VSPs in RAA were observed for *Al-Ch/En-En* (0.648%)*, Spn-Spn/Al-Ch* (0.253%), *Cph-Cph/Im-Im* (0.163%) and *Cph-Cph/Im-Im* (0.096%). On the contrary, all other measures presented VSPs and RAA variabilities (SD) of zero. As a result, great RAE values were also observed for these measures, especially *En-En/En-Al* (80.358%)*, Al-Sn/Go-Prn* (53.961%)*, Al-Sn/Il-N* (50.459%) *and Al-Prn/N-Prn* (44.960%). These results revealed that interexaminer variability has a substantially greater contribution, and therefore ER a substantially smaller one, to the total variability. Greatest interexaminer (ER) variability percentages were observed for *Im-Im/N-Sto* (96.540%), *Ls-Li/Ch-Li* (90.824%), *Ls-Li/N-Sto* (89.359%), *Cph-Cph/Cph-Li* (89.340%), and *Cph-Li/Al-Ch* (89.113%), revealing greater differences between human faces for these measures.

Table 3.2 - Variability source analysis for indices (IN). Variance (Var) and standard deviation (SD) values by the analyzed groups: interindividual (ER); intraindividual (RA) intraexaminer (RAA); and RA interexaminer (RAE). Variability source percentual (VSP - %) values by group analyzed

Indice	Var.			SD			VSP (%)		
	ER	RA		ER	RA		ER	RA	
		RAA	RAE		RAA	RAE		RAA	RAE
Al-Ch/En-En	134.049	1.006	20.244	11.578	1.003	4.499	86.317	0.648	13.035
Al-Prn/Il-N	23.227	0.000	4.704	4.819	0.000	2.169	83.160	0.000	16.840
Al-Prn/N-Prn	47.888	0.000	39.118	6.920	0.000	6.254	55.040	0.000	44.960
Al-Sn/Go-Prn	3.268	0.000	3.830	1.808	0.000	1.957	46.039	0.000	53.961
Al-Sn/Il-N	8.366	0.000	8.521	2.892	0.000	2.919	49.541	0.000	50.459
Ch-Li/Go-Prn	7.933	0.000	2.290	2.817	0.000	1.513	77.598	0.000	22.402
Ch-Li/Im-Im	13.488	0.000	2.420	3.673	0.000	1.556	84.790	0.000	15.210

to be continued

concluded

Ch-Ls/Ch-Li	10.795	0.000	5.076	3.286	0.000	2.253	68.017	0.000	31.983
Ch-Ls/En-Al	24.768	0.000	12.898	4.977	0.000	3.591	65.757	0.000	34.243
Cph-Cph/Cph-Li	378.305	0.407	44.732	19.450	0.638	6.688	89.340	0.096	10.564
Cph-Cph/Im-Im	14.581	0.032	4.757	3.819	0.177	2.181	75.278	0.163	24.559
Cph-Li/Al-Ch	111.125	0.000	13.576	10.542	0.000	3.685	89.113	0.000	10.887
En-En/En-Al	26.710	0.000	109.273	5.168	0.000	10.453	19.642	0.000	80.358
Im-Im/N-Sto	33.240	0.000	1.191	5.765	0.000	1.091	96.540	0.000	3.460
Ls-Li/Ch-Li	144.514	0.000	14.600	12.021	0.000	3.821	90.824	0.000	9.176
Ls-Li/N-Prn	65.902	0.000	26.201	8.118	0.000	5.119	71.552	0.000	28.448
Ls-Li/N-Sto	19.970	0.000	2.378	4.469	0.000	1.542	89.359	0.000	10.641
Spn-Spn/Al-Ch	69.004	0.215	15.789	8.307	0.464	3.974	81.173	0.253	18.573
Spn-Spn/Ch-Ls	55.980	0.000	18.501	7.482	0.000	4.301	75.160	0.000	24.840
Spn-Spn/En-En	30.008	0.000	9.605	5.478	0.000	3.099	75.754	0.000	24.246

Source: prepared by the author.

3.1.2 Angles (AN)

Table 3.3 shows the variability source analysis results for all 21 angles. The highest RAA percentage variabilities were observed for *Ls-Li-ChR* (0.711%), *CphL-CphR-Li* (0.524%) and *Li-Ls-ChL* (0.468%), respectively. *AlR-ChR-Ls, AlR-ChR-Li, ChR-Ls-ChL, Sto-N-IlL, Sto-N-IlR, AlL-ChL-Ls, Prn-AlL-Sn, CphR-CphL-Li, IlR-N-IlL, GoL-Prn-N, GoR-Prn-N, AlR-Prn-AlL* and *Sn-AlL-ChL* presented RAA percentages of zero, revealing practically no differences between faces analyzed by the same examiner. When comparing with abovementioned groups (ED and IN), lowest RAA differences were observed for IN, in which 80% measures presented zero differences, against 43.75% for the ED and 61.90% for the AN groups.

For RAE, angles with highest VSPs were *Ls-Li-ChR* (52.681%), *AlR-ChR-Ls* (47.136%) and *AlR-Prn-AlL* (45.929%), whereas *CphL-Li-CphR* (10.709%), *Sto-N-IlL* (12.854%) and *EnR-EnL-AlL* (12.869%) gave the lowest variability percentages and thus greatest consistency between examiners was seen for these angles.

ER analysis showed lowest percentages of variability among individuals for *Prn-AlL-Sn* (21.384%), *Ls-Li-ChR* (46.608%) and *AlR-ChR-Ls* (52.864%) angles. On the contrary, the highest VSPs were observed for *CphL-Li-CphR* (89.190), *Sto-N-IlL* (87.146), *EnR-EnL-AlL* (86.966), *CphL-CphR-Li* (86.493) and *IlR-N-IlL* (86.121), thus revealing greater differences between human faces for the latter measures. Bilateral angles, such as *EnR-EnL-AlL* and *CphL-CphR-Li,* performed differently, confirming the existence of facial side differences.

Table 3.3 - Variability source analysis for angles (AN). Variance (Var) and standard deviation (SD) values by the analyzed groups: interindividual (ER); intraindividual (RA) intraexaminer (RAA); and RA interexaminer (RAE). Variability source percentual (VSP - %) values by group analyzed

Angle	Var.			SD			VSP (%)		
	ER	RA		ER	RA		ER	RA	
		RAA	RAE		RAA	RAE		RAA	RAE
AlL-ChL-Ls	25.434	0.000	8.357	5.043	0.000	2.891	75.269	0.000	24.731
AlR-ChR-Li	23.318	0.000	17.878	4.829	0.000	4.228	56.603	0.000	43.397
AlR-ChR-Ls	14.635	0.000	13.049	3.826	0.000	3.612	52.864	0.000	47.136
AlR-Prn-AlL	154.960	0.000	131.627	12.448	0.000	11.473	54.071	0.000	45.929
ChR-Ls-ChL	113.647	0.000	27.916	10.661	0.000	5.284	80.280	0.000	19.720
CphL-CphR-Li	65.211	0.395	9.789	8.075	0.628	3.129	86.493	0.524	12.983
CphL-Li-CphR	152.057	0.173	18.257	12.331	0.416	4.273	89.190	0.102	10.709
CphR-CphL-Li	32.374	0.000	10.403	5.690	0.000	3.225	75.680	0.000	24.320
EnL-EnR-AlR	15.620	0.032	10.545	3.952	0.180	3.247	59.623	0.124	40.253
EnR-EnL-AlL	11.999	0.023	1.776	3.464	0.151	1.332	86.966	0.166	12.869
GoL-Prn-N	13.435	0.000	8.111	3.665	0.000	2.848	62.355	0.000	37.645
GoR-Prn-GoL	11.081	0.022	3.483	3.329	0.148	1.866	75.969	0.149	23.882
GoR-Prn-N	33.795	0.000	5.449	5.813	0.000	2.334	86.115	0.000	13.885
IlR-N-IlL	19.042	0.000	3.069	4.364	0.000	1.752	86.121	0.000	13.879
Li-Ls-ChL	44.053	0.291	17.837	6.637	0.539	4.223	70.846	0.468	28.686
Li-Ls-ChR	29.553	0.152	10.492	5.436	0.390	3.239	73.520	0.379	26.101
Ls-Li-ChR	12.732	0.194	14.391	3.568	0.441	3.794	46.608	0.711	52.681
Prn-AlL-Sn	15.066	0.000	55.390	7.442	0.000	3.882	78.616	0.000	21.384
Sn-AlL-ChL	28.307	0.000	12.990	5.320	0.000	3.604	68.544	0.000	31.456
Sto-N-IlL	7.147	0.000	1.054	2.673	0.000	1.027	87.146	0.000	12.854
Sto-N-IlR	3.730	0.000	0.913	1.931	0.000	0.956	80.330	0.000	19.670

Source: prepared by the author.

3.2 Discriminatory power analysis – One variable

In this analysis, the percentage of statistically different measurements is determined for each individual measure, taking into account the CIs calculated in above section.

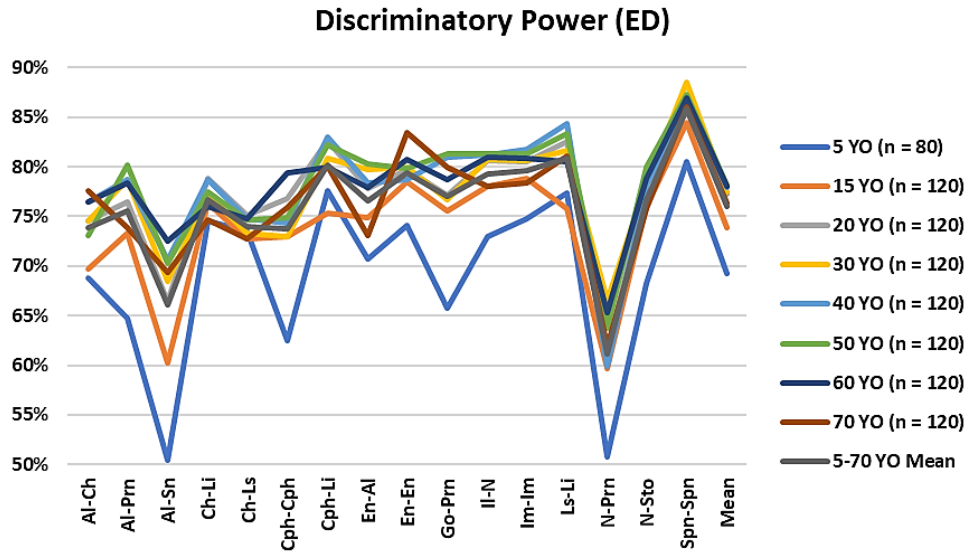
3.2.1 Euclidean Distance (ED)

In general, the most discriminating ED measures were found to be *Spn-Spn*, *Ls-Li, Cph-Li* and *Im-Im* (Figure 3.1 and Table 3.4). The first one confirmed its potential for discriminating faces within all age groups analyzed. This measure was followed by

Cph-Li (5 YO), *Im-Im* (15 YO), *Cph-Li* (20 YO), *Ls-Li* (30, 40, and 50 YO), *Il-N* (60 YO) and *En-En* (70 YO) (Table 3.4).

Considering all ED measures analyzed, the greatest percentages, and hence greatest potentials for distinguishing human faces, were observed in age groups of 40 and 60 year olds. Percentages were all above 50%, showing that most ED measures were different. As expected, the greatest differences were observed in young groups of age, that is 5 YO and 15 YO groups.

Figure 3.1 – Graphical representation of DP analysis of one variable for Euclidean distances (ED) by age group



Source: prepared by the author.

Table 3.4 - Discriminatory power analysis of one variable for Euclidean distances (ED) and by age group (5, 15, 20, 30, 40, 50, 60 and 70 years old – YO). Mean percentage results for all age groups are displayed in the last column and mean percentage results by age group are displayed in the last row

ED	5 YO	15 YO	20 YO	30 YO	40 YO	50 YO	60 YO	70 YO	5-70 YO
	(n = 80)	(n = 120)	(n = 120)	(n = 120)	(n = 120)	(n = 120)	(n = 120)	(n = 120)	Mean
Al-Ch	68.80%	69.71%	74.51%	74.48%	76.40%	73.12%	76.48%	77.58%	73.89%
Al-Prn	64.72%	73.32%	76.47%	78.71%	78.67%	80.15%	78.39%	73.82%	75.53%
Al-Sn	50.41%	60.21%	66.41%	68.47%	70.64%	70.22%	72.52%	69.38%	66.03%
Ch-Li	74.49%	76.29%	78.87%	77.25%	78.75%	77.49%	76.02%	74.62%	76.72%
Ch-Ls	73.51%	72.68%	75.14%	73.32%	74.71%	74.64%	74.71%	72.68%	73.92%
Cph-Cph	62.47%	72.91%	76.79%	73.01%	74.31%	74.87%	79.41%	75.85%	73.70%
Cph-Li	77.56%	75.31%	82.70%	80.88%	82.97%	82.14%	79.99%	80.07%	80.20%
En-Al	70.66%	74.87%	77.80%	79.71%	78.36%	80.28%	77.89%	73.10%	76.58%

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concluded

En-En	74.05%	78.47%	79.73%	79.99%	78.70%	79.85%	80.70%	83.47%	79.37%
Go-Prn	65.73%	75.56%	77.16%	76.72%	80.92%	81.34%	78.68%	79.96%	77.01%
Il-N	72.97%	77.98%	80.66%	80.74%	81.20%	81.26%	80.97%	78.07%	79.23%
Im-Im	74.78%	78.87%	80.55%	80.62%	81.79%	81.32%	80.85%	78.35%	79.64%
Ls-Li	77.31%	75.78%	82.48%	81.60%	84.36%	83.31%	80.55%	81.05%	80.81%
N-Prn	50.73%	59.71%	61.01%	66.51%	59.90%	63.67%	65.29%	61.89%	61.09%
N-Sto	68.26%	75.95%	78.19%	78.35%	78.18%	79.99%	78.84%	75.83%	76.70%
Spn-Spn	80.51%	84.50%	86.55%	88.49%	86.33%	87.24%	86.96%	86.02%	85.83%
Mean	69.19%	73.88%	77.19%	77.43%	77.89%	78.18%	78.02%	76.36%	76.02%

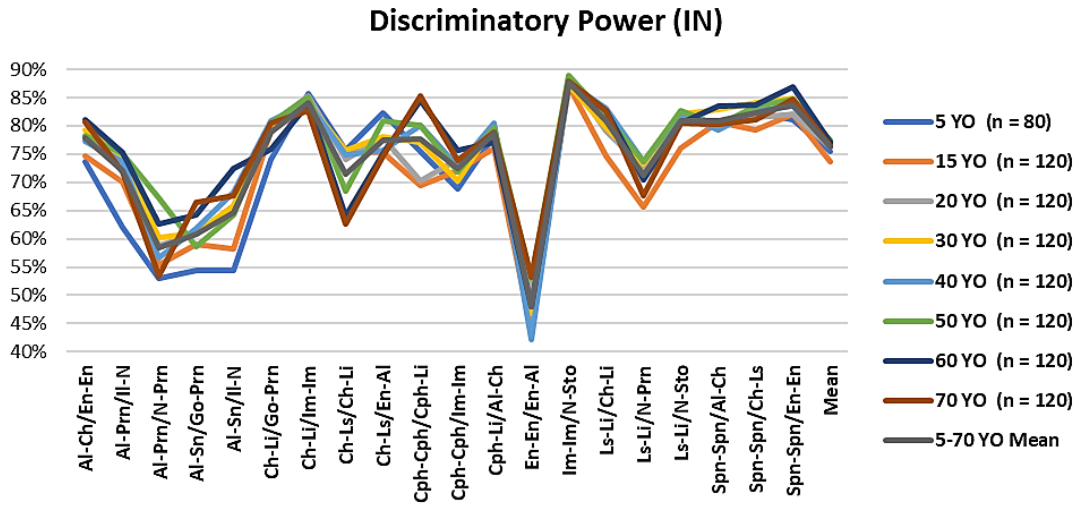
Source: prepared by the author.

3.2.2 Indices (IN)

Considering all age groups, the most discriminating IN measures were *Im-Im/N-Sto, Ch-Li/Im-Im, Spn-Spn/En-En* and *Spn-Spn/Ch-Ls* (Figure 3.2 and Table 3.5). The first one was found to be the most discriminating measure for all age groups, consistently revealing significant differences with the other INs. This measure was followed by *Ch-Li/Im-Im* in the 5, 15, 20, 40, and 50 YO groups, by *Spn-Spn/En-En* in groups of 30 and 60 YOs and by *Cph-Cph/Cph-Li* in the 70 YO group (Table 3.5).

Considering all analyzed IN measures, the greatest percentages, and hence greatest potentials for distinguishing human faces, were observed in age groups of 50 and 60 year olds. En-En/En-Al was the only measure to present percentages lower than 50%, revealing to be the least discriminating IN, especially in age groups of 5, 15, 30, 40 and 60 YO.

Figure 3.2 – Graphical representation of DP analysis of one variable for indices (IN) by age group



Source: prepared by the author.

Table 3.5 - Discriminatory power analysis of one variable for indices (IN) and by age group (5, 15, 20, 30, 40, 50, 60 and 70 years old – YO). Mean percentage results for all age groups are displayed in the last column and mean percentage results by each age group are displayed in the last row. Values lower than 50% are shaded with light gray

Indice	5 YO	15 YO	20 YO	30 YO	40 YO	50 YO	60 YO	70 YO	5-70 YO
	(n = 80)	(n = 120)	(n = 120)	(n = 120)	(n = 120)	(n = 120)	(n = 120)	(n = 120)	Mean
Al-Ch/En-En	73.70%	74.65%	77.70%	79.37%	77.24%	78.36%	80.99%	80.76%	77.85%
Al-Prn/Il-N	62.09%	70.00%	73.66%	74.57%	73.74%	75.04%	75.22%	71.83%	72.02%
Al-Prn/N-Prn	53.10%	55.32%	58.73%	60.13%	56.54%	67.20%	62.56%	53.40%	58.37%
Al-Sn/Go-Prn	54.46%	59.03%	60.88%	60.98%	61.93%	58.68%	64.26%	66.40%	60.83%
Al-Sn/Il-N	54.40%	58.29%	65.76%	65.91%	68.33%	64.22%	72.55%	67.66%	64.64%
Ch-Li/Go-Prn	74.08%	79.23%	80.24%	79.87%	80.90%	80.52%	75.90%	80.52%	78.91%
Ch-Li/Im-Im	85.60%	83.15%	85.21%	83.92%	84.02%	85.04%	83.82%	82.65%	84.18%
Ch-Ls/Ch-Li	75.63%	75.63%	74.15%	75.59%	74.89%	68.47%	64.13%	62.58%	71.38%
Ch-Ls/En-Al	82.34%	75.34%	77.97%	78.11%	75.69%	80.95%	75.15%	74.64%	77.52%
Cph-Cph/Cph-Li	75.44%	69.45%	70.21%	77.03%	80.01%	80.00%	84.50%	85.25%	77.74%
Cph-Cph/Im-Im	68.83%	72.00%	74.01%	70.20%	72.94%	71.89%	75.59%	73.81%	72.41%
Cph-Li/Al-Ch	78.20%	76.15%	78.50%	79.99%	80.39%	79.72%	77.17%	78.89%	78.63%
En-En/En-Al	46.65%	43.73%	50.07%	46.76%	42.21%	53.04%	47.94%	53.17%	47.95%
Im-Im/N-Sto	86.87%	87.09%	88.67%	87.34%	87.75%	88.95%	87.54%	87.91%	87.77%
Ls-Li/Ch-Li	82.82%	74.59%	79.03%	79.62%	83.17%	81.74%	82.69%	82.72%	80.80%
Ls-Li/N-Prn	72.34%	65.64%	72.68%	73.25%	73.63%	73.73%	70.53%	67.70%	71.19%
Ls-Li/N-Sto	81.84%	76.12%	80.90%	82.11%	82.00%	82.77%	80.46%	80.52%	80.84%
Spn-Spn/Al-Ch	80.25%	80.74%	80.32%	82.86%	79.29%	80.01%	83.47%	80.38%	80.92%
Spn-Spn/Ch-Ls	82.56%	79.19%	81.40%	84.13%	82.61%	83.49%	83.63%	81.11%	82.27%
Spn-Spn/En-En	81.04%	82.03%	82.18%	84.92%	83.56%	84.68%	86.81%	84.71%	83.74%
Mean	75.56%	73.65%	76.33%	76.98%	76.96%	77.45%	76.99%	76.51%	76.30%

Source: prepared by the author.

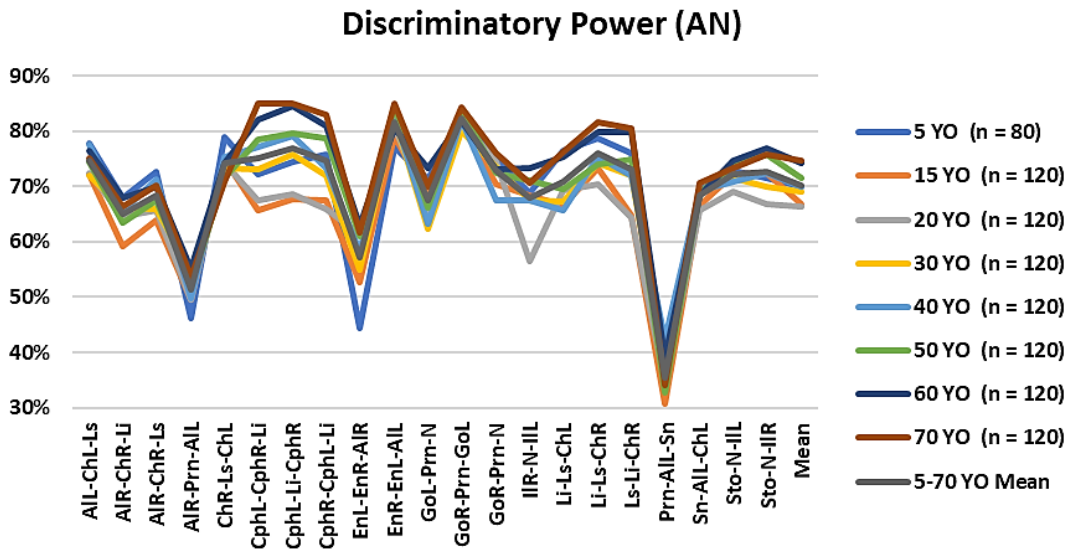
3.2.2 Angles (AN)

In general, the most discriminating AN measures across all age groups are *GoR-Prn-GoL*, *EnR-EnL-AlL, CphL-Li-CphR* and *Li-Ls-ChR* (Figure 3.3 and Table 3.6). The first one was shown to be the most discriminating measure for the groups of 5, 15, 20, and 30 year olds, followed by *ChR-Ls-ChL* (5 YO) and *EnR-EnL-AlL* (15, 20 and 30 YO). The order of ANs *GoR-Prn-GoL* and *EnR-EnL-AlL* is inverted for the 40 and 50 YO groups. For the 60 YO group, the most discriminating measure was *CphL-Li-CphR* followed by *CphL-CphR-Li* and, for the 70 YO group, *CphL-CphR-Li* and *EnR-EnL-AlL* were observed to be the most discriminant ANs.

Taking all analyzed AN measures into consideration, the greatest percentages, and hence greatest potentials for distinguishing human faces, were observed in the

age groups of 60 and 70 year olds. Percentages lower than 50% were only observed for angles *AlR-Prn-AlL* (5YO, 15 YO, 20YO, and 40YO), *EnL-EnR-AlR* (5YO) and *Prn-AlL-Sn* in all age groups analyzed, revealing to be the least discriminating AN.

Figure 3.3 – Graphical representation of DP analysis of one variable for angles (AN) by age groups.



Source: prepared by the author.

Table 3.6 - Discriminatory power analysis of one variable for angles (AN) and by age group (5, 15, 20, 30, 40, 50, 60 and 70 years old – YO). Mean percentage results for all age groups are displayed in the last column and mean percentage results by each age group are displayed in the last row. Values lower than 50% are shaded with light gray

Angle	5 YO (n = 80)	15 YO (n = 120)	20 YO (n = 120)	30 YO (n = 120)	40 YO (n = 120)	50 YO (n = 120)	60 YO (n = 120)	70 YO (n = 120)	5-70 YO Mean
AlL-ChL-Ls	77.70%	72.13%	72.44%	72.04%	77.63%	74.44%	76.49%	75.04%	74.74%
AlR-ChR-Li	67.96%	59.20%	64.52%	66.04%	65.48%	63.43%	67.88%	66.37%	65.11%
AlR-ChR-Ls	72.54%	63.92%	65.60%	65.86%	71.30%	67.45%	70.01%	70.08%	68.35%
AlR-Prn-AlL	46.09%	49.57%	49.52%	54.81%	49.75%	52.51%	55.05%	53.46%	51.35%
ChR-Ls-ChL	78.97%	74.82%	74.26%	73.28%	75.38%	71.58%	74.13%	70.95%	74.17%
CphL-CphR-Li	72.12%	65.63%	67.50%	73.08%	77.20%	78.38%	82.11%	85.10%	75.14%
CphL-Li-CphR	74.39%	67.75%	68.67%	75.79%	79.16%	79.59%	84.53%	84.99%	76.86%
CphR-CphL-Li	75.69%	67.51%	65.89%	71.98%	73.26%	78.71%	80.89%	82.96%	74.61%
EnL-EnR-AlR	44.34%	52.72%	61.52%	54.85%	58.18%	61.04%	62.99%	61.67%	57.16%
EnR-EnL-AlL	77.12%	79.12%	80.87%	82.48%	82.79%	84.47%	80.41%	85.10%	81.55%
GoL-Prn-N	71.34%	68.14%	65.53%	62.41%	63.31%	66.16%	73.29%	69.96%	67.52%
GoR-Prn-GoL	82.77%	81.50%	81.84%	80.10%	82.10%	83.82%	81.92%	84.36%	82.30%
GoR-Prn-N	74.81%	70.48%	74.35%	73.45%	67.52%	72.37%	73.17%	76.09%	72.78%
IlR-N-IlL	68.78%	68.39%	56.40%	67.40%	67.45%	70.98%	73.34%	70.53%	67.91%

to be continued

concluded

Li-Ls-ChL	76.37%	66.53%	69.22%	67.27%	65.67%	69.48%	75.34%	76.32%	70.78%
Li-Ls-ChR	78.68%	73.32%	70.50%	74.28%	75.42%	74.02%	79.86%	81.67%	75.97%
Ls-Li-ChR	76.01%	64.73%	64.24%	71.90%	71.89%	75.00%	79.89%	80.57%	73.03%
Prn-AlL-Sn	32.42%	30.67%	34.43%	38.20%	42.25%	32.65%	39.08%	34.06%	35.47%
Sn-AlL-ChL	69.39%	66.50%	65.80%	68.78%	69.38%	68.84%	68.39%	70.57%	68.46%
Sto-N-IlL	72.90%	72.16%	69.04%	71.57%	70.80%	73.82%	74.62%	73.35%	72.28%
Sto-N-IlR	71.54%	72.38%	66.79%	70.06%	72.42%	75.71%	76.81%	75.87%	72.70%
Mean	69.92%	66.72%	66.41%	68.98%	69.93%	71.57%	74.17%	74.57%	70.28%

Source: prepared by the author.

3.3 Discriminatory power analysis – Multiple variables

By this analysis it was possible to evaluate the number of measures necessary for discrimination of one individual from another in the sample, according to measures analyzed and age group. Contrary to discriminatory power analysis of one variable, measures are presented as the probability of finding any two (or more) measures within each particular age group, without specifying which measures.

3.3.1 Euclidean Distance (ED)

It was observed that 15 ED measures were necessary in order to obtain a probability of finding less than one duplicate in a population of 10^6 (1,000,000 individuals) (Table 3.7). The same probability was observed even using less measures in age groups of 15 (14 ED), 20 (14 ED), 40 (13 ED), 50 (14 ED), 60 (14 ED) and 70 YO (13 ED). The probability of finding the same two EDs within a particular age group started from a percentage of less than 9.3% (5 YO).

Table 3.7 – Match probability for Euclidean distances (ED) and by age group (5, 15, 20, 30, 40, 50, 60 and 70 years old – YO)

ED	5 YO	15 YO	20 YO	30 YO	40 YO	50 YO	60 YO	70 YO
2	9.294304%	6.890523%	5.276377%	5.163982%	4.954599%	4.843021%	4.798203%	5.524276%
3	3.215077%	2.122049%	1.443652%	1.396133%	1.304472%	1.279812%	1.220538%	1.496324%
4	1.186309%	0.703720%	0.430495%	0.413496%	0.373865%	0.373557%	0.337604%	0.433181%
5	0.465388%	0.248260%	0.137917%	0.133675%	0.115017%	0.119692%	0.102047%	0.132123%
6	0.194699%	0.092303%	0.046968%	0.047629%	0.037281%	0.042160%	0.034286%	0.041996%
7	0.087191%	0.035762%	0.016851%	0.019064%	0.012355%	0.016381%	0.013007%	0.013737%
8	0.041683%	0.014218%	0.006303%	0.008684%	0.004012%	0.006976%	0.005527%	0.004530%
9	0.020965%	0.005682%	0.002425%	0.004443%	0.001211%	0.003161%	0.002532%	0.001453%

to be continued

concluded

10	0.010796%	0.002214%	0.000941%	0.002447%	0.000317%	0.001439%	0.001182%	0.000427%
11	0.005470%	0.000802%	0.000353%	0.001372%	0.000064%	0.000609%	0.000526%	0.000103%
12	0.002573%	0.000246%	0.000115%	0.000739%	0.000008%	0.000215%	0.000200%	0.000015%
13	0.001017%	0.000050%	0.000025%	0.000350%	**0.000000%**	0.000050%	0.000050%	0.000000%
14	0.000264%	**0.000000%**	**0.000000%**	0.000117%	**0.000000%**	**0.000000%**	**0.000000%**	**0.000000%**
15	**0.000000%**	**0.000000%**	**0.000000%**	**0.000000%**	**0.000000%**	**0.000000%**	**0.000000%**	**0.000000%**

Source: prepared by the author.

3.3.2 Indices (IN)

For IN, it was seen that 20 INs were necessary to achieve a probability of finding less than one duplicate in a population of 10^6 (1,000,000 individuals) (Table 3.8). The same probability was observed even using less measures in age groups of 5 (15 IN), 20 (16 IN), 30 (16 IN), 40 (16 IN), 60 (16 IN) and 70 YO (19 IN). The probability of finding the same two INs was highest for 15 year olds at a percentage of 7.3%.

Table 3.8 – Match probability for indices (IN) and by age group (5, 15, 20, 30, 40, 50, 60 and 70 years old – YO)

IN	5 YO	15 YO	20 YO	30 YO	40 YO	50 YO	60 YO	70 YO
2	6.971352%	7.326109%	6.006929%	5.667920%	5.784756%	5.539363%	5.452676%	5.833481%
3	2.054797%	2.211091%	1.655487%	1.520013%	1.550936%	1.503821%	1.437233%	1.587203%
4	0.657738%	0.722042%	0.491456%	0.441100%	0.450451%	0.444011%	0.415601%	0.464937%
5	0.228736%	0.255882%	0.156521%	0.137667%	0.141799%	0.140941%	0.131997%	0.144913%
6	0.085566%	0.098062%	0.053049%	0.045653%	0.048203%	0.047574%	0.045663%	0.047760%
7	0.033669%	0.040180%	0.018848%	0.015796%	0.017536%	0.016953%	0.016887%	0.016732%
8	0.013494%	0.017312%	0.006866%	0.005583%	0.006726%	0.006375%	0.006503%	0.006316%
9	0.005309%	0.007699%	0.002500%	0.001977%	0.002663%	0.002545%	0.002533%	0.002595%
10	0.001971%	0.003469%	0.000888%	0.000690%	0.001060%	0.001086%	0.000969%	0.001151%
11	0.000660%	0.001553%	0.000300%	0.000235%	0.000410%	0.000493%	0.000352%	0.000536%
12	0.000187%	0.000676%	0.000094%	0.000077%	0.000149%	0.000231%	0.000117%	0.000251%
13	0.000040%	0.000277%	0.000027%	0.000023%	0.000047%	0.000106%	0.000033%	0.000112%
14	0.000005%	0.000102%	0.000006%	0.000006%	0.000012%	0.000044%	0.000007%	0.000045%
15	**0.000000%**	0.000031%	0.000001%	0.000001%	0.000002%	0.000014%	0.000001%	0.000014%
16	**0.000000%**	0.000006%	**0.000000%**	**0.000000%**	**0.000000%**	0.000003%	**0.000000%**	0.000003%
17	**0.000000%**	0.000002%	**0.000000%**	**0.000000%**	**0.000000%**	0.000002%	**0.000000%**	0.000001%
18	**0.000000%**	0.000001%	**0.000000%**	**0.000000%**	**0.000000%**	0.000001%	**0.000000%**	0.000001%
19	**0.000000%**	0.000001%	**0.000000%**	**0.000000%**	**0.000000%**	0.000001%	**0.000000%**	**0.000000%**
20	**0.000000%**	**0.000000%**	**0.000000%**	**0.000000%**	**0.000000%**	**0.000000%**	**0.000000%**	**0.000000%**

Source: prepared by the author.

3.2.1 Angles (AN)

For AN, it was shown that 21 measures were not sufficient to achieve a probability of finding less than one duplicate in a population of 10^6 (1,000,000 individuals) in all age groups (Table 3.9). This probability was achieved in age groups of 5, 15, 50, 60 and 70 YO using 17, 18, 17, 17 and 18 ANs, respectively. Considering age groups of 20, 30 and 40 YO, 21 ANs were necessary to observe a probability of finding less than one duplicate in a population of 10^5 (100,000). The probability of finding the same two ANs was again highest for 15 year olds at 10.9%.

Table 3.9 – Match probability for angles (AN) and by age group (5, 15, 20, 30, 40, 50, 60 and 70 years old – YO)

AN	5 YO	15 YO	20 YO	30 YO	40 YO	50 YO	60 YO	70 YO
2	8.667254%	10.862750%	10.808730%	9.361168%	8.782513%	8.286114%	6.846368%	6.815726%
3	2.700495%	3.827973%	3.800360%	3.064095%	2.807923%	2.554074%	1.896375%	1.880858%
4	0.887033%	1.407487%	1.403590%	1.049931%	0.948574%	0.828184%	0.551671%	0.544482%
5	0.311945%	0.537359%	0.544793%	0.375905%	0.339307%	0.283053%	0.170210%	0.166225%
6	0.119358%	0.211569%	0.221642%	0.140319%	0.128798%	0.101964%	0.056169%	0.053611%
7	0.050262%	0.085089%	0.093971%	0.054574%	0.052115%	0.038611%	0.019936%	0.018230%
8	0.023291%	0.034511%	0.041171%	0.022154%	0.022649%	0.015277%	0.007615%	0.006504%
9	0.011694%	0.013885%	0.018446%	0.009415%	0.010648%	0.006250%	0.003104%	0.002419%
10	0.006190%	0.005431%	0.008349%	0.004191%	0.005408%	0.002602%	0.001323%	0.000929%
11	0.003344%	0.002014%	0.003764%	0.001941%	0.002923%	0.001078%	0.000572%	0.000363%
12	0.001785%	0.000686%	0.001663%	0.000919%	0.001637%	0.000432%	0.000241%	0.000140%
13	0.000910%	0.000205%	0.000705%	0.000432%	0.000921%	0.000161%	0.000095%	0.000052%
14	0.000427%	0.000050%	0.000278%	0.000193%	0.000505%	0.000052%	0.000033%	0.000017%
15	0.000174%	0.000009%	0.000097%	0.000077%	0.000259%	0.000013%	0.000009%	0.000004%
16	0.000056%	0.000001%	0.000027%	0.000024%	0.000119%	0.000002%	0.000001%	0.000001%
17	**0.000000%**	0.000001%	0.000023%	0.000014%	0.000040%	**0.000000%**	**0.000000%**	0.000001%
18	**0.000000%**	**0.000000%**	0.000007%	0.000005%	0.000031%	**0.000000%**	**0.000000%**	**0.000000%**
19	**0.000000%**	**0.000000%**	0.000006%	0.000003%	0.000014%	**0.000000%**	**0.000000%**	**0.000000%**
20	**0.000000%**	**0.000000%**	0.000002%	0.000002%	0.000012%	**0.000000%**	**0.000000%**	**0.000000%**
21	**0.000000%**	**0.000000%**	0.000002%	0.000001%	0.000006%	**0.000000%**	**0.000000%**	**0.000000%**

Source: prepared by the author.

4 Discussion

As a branch of the longest-used scientific tool for understanding human physical variation (i.e., anthropometry), FPA analysis has great potential for the metric assessment of facial differences. The variability between individuals makes it possible for one person to be distinguished from another. Nonetheless, this interindividual variability is just one component of all sources of deviation influencing the reliable and of-interest measurements on 2D-images (e.g., methodological, biological and those related to time or the imaging acquisition process itself). As a consequence, even measures taken from the same individual will rarely be the same (5, 22). In this sense, the main challenge in FPA studies, as well as in their application in FFI casework, is to understand the extent to which each factor influences FPA measurements, and hence the variability range in which the same individual can still be considered as being himself. This is vital information to support evidence evaluation in FFI cases.

This large number of influencing factors (e.g., variations in camera angle, lenses and image resolution) means facial measurements are a non-fixed feature and explains why variability ranges must be considered instead of absolute values in FPA analysis. Specifying ranges of possible values not only decreases false rejection probabilities, but also increases the probability to falsely including unlikely persons within the same category, making the accurate distinction of individuals even more critical. Indeed, some studies suggest that FPA measures are not sufficiently discriminant to positively individualize an individual (5, 6, 8). Nonetheless, most of these studies failed to address preliminary and necessary steps in FPA analysis, such as the application of methodologies suitable for indirect 2D-image analysis (i.e., photo-anthropometry) (5, 6, 8), use of a variability range instead of absolute values for “match” decisions (1, 5), estimation of methodological errors, including examiner “accuracy” (5, 6), assessment of large number of measures (6, 8), use of stable measures as references to calculate facial proportions (8) and evaluation of large samples (5, 6, 8). As a result, authors claim that the variability of measures taken from the same individual can be as great as measures from different individuals.

Each of these imperative procedures was observed by the present study and, as a result, FPA measures were found to be distinct enough to distinguish individuals depicted on standardized frontal view facial images. One step of utmost importance in

FPA analysis is to firstly convert linear measures into Proportionality Indices (PIs), percentages, ratios, indices or angles in order to nullify the effect of different acquisition conditions of compared images (5, 8, 23). Non-linear measures are indicated to express the shape instead of the size (i.e., facial morphometry) and to reveal on facial dimension as a percentage of another (24). Linear measures can be expressed as ratios by dividing them by any other measure (5, 23). Recent studies referred to the iris diameter as a valuable reference in imaging analysis, due to its low variability and long-term stability, along with the fact that it is the most isometric distance of the human face (9-11, 14). This provides a common denominator for measures taken under different situations, making them adequate for comparison. Therefore, measures from both image groups were calculated in relation to this facial reference (i.e., iris ratios).

Potentially valuable measures for facial discrimination were assessed as well as morphometric facial relations obtained from them, such as indices and angles, in order to verify those that have the greatest potential for human differentiation. Contrary to previous studies that claim reduced chance of error when applying indices and angles rather than linear measures (5, 23), present study results revealed that Euclidean distances actually perform better in terms of reliability, examiner consistency and discriminatory power. Indeed, fewer ED measures were required to discriminate individuals. This result corroborates a previous study in which linear measurements showed better results over angular ones when assessed for age estimation purposes (25).

In general, DP results indicate that *Spn-Spn* (ED), *Ls-Li* (ED)*, Cph-Li* (ED), *Im-Im/N-Sto* (IN)*, Ch-Li/Im-Im* (IN)*, Spn-Spn/En-En* (IN)*, GoR-Prn-GoL* (AN) and *EnR-EnL-AlL* (AN) have great capacity to differentiate unrelated individuals. The first abovementioned ED and IN, along with both ANs, demonstrate the greatest DP, independently of age group. Least discriminant measures were *Prn-AlL-Sn* (AN), *En-En/En-Al* (IN) and *AlR-Prn-AlL* (AN). The first two showed less than 50% of statistically different measurements in most age groups. The latter presented equal numbers of age groups with less and more than 50% of statistically different measures. All other measures revealed more than half the measures were statistically different within each age group, revealing more dissimilarities than similarities between facial measures and thus confirming FPA discriminatory power. DP results also revealed a high correlation of measures with age, especially angles. The *Spn-Spn* measure, as both ED and IN, was confirmed to be a valuable tool for distinguishing individuals. One particular point

to highlight is that these findings were achieved within a population of high miscegenation (Brazilian) and inherently large variability. Assessing populations of different ethnicities is essential to provide global information about metric facial patterns.

In order to minimize the most commonly encountered methodological errors in landmark positioning, the same adapted methodology for indirect facial analysis as that applied in the reference study was used. This approach demonstrated greater robustness and reproducibility over other methods when positioning almost all analyzed facial landmarks, thus enabling more reliable measures to be established. Indeed, intraexaminer variability was very low (SD < 1.003 or 0.50 mm, in actual physical scale), showing that FPA measurements can be highly reproducible and reliable when taken by the same examiner, on images acquired under controlled situations and when applying an approach suitable for 2D-image analysis. Surprisingly, interexaminer results were still found to be undesirable for some measures, such as *AlR-Prn-AlL* and *En-En/Al-Al*, reaching variabilities of almost 6 mm in actual physical scale. Apart from these two measures, ER variabilities were all within a range of 3.35 mm (SD ≤ 6.688, *Cph-Cph/Cph-Li*).

Considering the conditions in which intraexaminer analysis was conducted, it is likely that the obtained results arose from the expected FPA variability of the same individual (26). It is important, however, to highlight that this information, as it is represented, does not express the within source variability (WSV) applied in statistical inferences of the identity of a source in forensic science (26). Frequency WSV data are needed to assign the first hypothesis (Hp) of the most logical framework for evidence evaluation, i.e., the likelihood ratio (LR), and probably represents one of the most challenging tasks for the application of statistical models in FFI cases (27). In order to provide quantitative information about the distribution of FPA measures when considering different images of the same person, studies assessing their variability in diverse imaging acquisition conditions are crucial to generate WSV data. Despite the expected variability range seen in standardized frontal view images of the same person being investigated as part of this study, evaluating their frequencies under non-controlled environments is a necessary step towards opening new possibilities, in terms of numerically expressing the probative strength of conclusions in FFI cases.

In the forensic context, the probability of discrimination (DP) is complementary to the probability of match (PM) and is described by the following formula: DP = 1 –

PM (28). PM represents the probability of matching two individuals at random within some population. Whilst low DP implies that a chance match between faces of two different individuals is likely, high DP values, on the other hand, imply that a random match is unlikely, which could be particularly significant for exclusion purposes (28, 29). It is important to highlight that, in the present study, the probability of a match described by multiple variables analysis does not represent the complementary probability of DP, since it is determined as the probability of finding any two (or more) equal measures within a population.

DP multiple variable analysis revealed that a combination of 15 Euclidean distances and 20 indices was sufficient to achieve a probability of finding less than one individual in a population of a million (10^6) with the same facial measures. The same probability was achieved using 18 angles in age groups of 15 and 70 years old, whereas in age groups of 5, 50 and 60 years old, 17 angles were required. For other age groups, 21 angles were necessary to a probability of finding less than one duplicate in a population of 10^5 (100,000). Independently of their type, the probability of finding the same two measures was low to start with (i.e., a maximum of 10.9%) and decreased as more measures were included. Previous studies concluded that human face singularity can be achieved with a combination of a minimum of eight measures (1). Nonetheless, in this work, measurements were taken directly from individuals and sources of variability commonly resulting from the imaging acquisition process were not considered. Moreover, absolute measures were used for finding duplicate/target values. This procedure, *per se,* decreases the number of measures required to find duplicates.

The number of available measures (16 ED, 20 IN, and 21 AN) determined how the probabilities of finding duplicates would be reported on Tables 3.7, 3.8 and 3.9, that is to the order of 10^{-6} (0,000001). Analyzing duplicates to an order greater than 10^{-6} would require the inclusion of more measures that had been classified as potentially discriminant. Since probabilities cannot be reported as “none” or “zero”, present findings are reported as “less than one individual” in the analyzed population (1,000,000). Meaning that, no duplicates were found within this population but that they could be present if results were relevant to a population of 10^7 (10,000,000). The present findings are extremely promising and show that FPA measures are unique enough to support discrimination of two faces, even when sources of variability are considered. The probability of observing these specific measures was found to be very

low and surely the probability would be lower still if a second person sharing the same uncommon measure were to be considered (30).

Another particular point to stress is that DP with multiple variable analysis considered the average of measures that presented duplicate values by each age group, without considering measures separately or even discriminatory potential scores (Chapter I). These procedures might decrease the number of measures required for human discrimination, since DP of more measures would be considered in the relevant formula. A more general analysis was conducted for the purpose of simplifying the results. However, further future studies considering measure scores will be of substantial relevance to support present results.

Recent studies argue that narrowing possible sources of a forensic trace/mark to a single object/person is unscientific, irrelevant and even unhelpful for common source attributions in individualization testimonies (30, 31). This belief stems from the fact that linking sources is often based on the assumption that every individual is unique, even though uniqueness is an unproven/unprovable concept (30, 31). For a feature to be considered unique, the probability of finding duplicates within the entire population of the Earth should be technically zero (30, 32). As explained above, this is mathematically impossible. There will always be a probability, no matter how small, of finding duplicates of considered features, especially FPA measures, either alone or in combination with others (26, 30). Moreover, not finding a duplicate within a specific population does not mean that no duplicates exist at all (30). Some authors (30, 32) argue that even when the inverse of the likelihood of duplication exceeds the approximate population of the Earth, that is around 7.7 billion, it is not possible to conclude a human feature is unique without assessing them all (32).

Although some authors suggest general thresholds for inclusion criteria, e.g., reporting acceptable error values of 0.5% or ± 2 SD (6, 33), the present study showed that measures must be considered individually as a result of the distinct behavior of each measure for each age group analyzed. Since FPA analysis involves consideration of numerous sources of variability, taking them all into account could, in fact, reveal measures to be non-discriminant. Despite present results confirming the discriminatory power of FPA measures, this approach is not yet recommended for determination of a match in FFI cases. It is mandatory that measures, and the numbers of them, suggested as discriminatory in this work are tested also in uncontrolled situations, under non-standardized conditions and in more practical forensic casework.

This information is essential to ascertain acceptable values of error in real casework, in order to support an individualization, an exclusion or even to designate a conclusion as inconclusive.

5 Conclusion

In this work, a combination of 15 Euclidean distances or 20 indices was required to achieve a probability of finding less than one individual with duplicate measures in a population of one million. The same probability was achieved using 18 angles in age groups of 15 and 70 year olds, whereas in age groups of 5, 50 and 60 year olds, 17 angles were required. For other age groups, 21 angles were necessary to a probability of finding less than one duplicate in a population of 10^5 (100,000). These results strongly support the hypothesis that FPA measures, and especially Euclidean distances divided by the iris diameter (i.e. iris ratio) can be used for discriminating human faces depicted on frontal view standardized images.

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Appendix A –

Considered confidence intervals (CI) for Euclidean distances (ED), indices (IN), and angles (AN).

ED	CI	IN	CI	AN	CI
Al-Ch	0.126	Al-Ch/En-En	4.609	AlL-ChL-Ls	2.890
Al-Prn	0.071	Al-Prn/Il-N	2.168	AlR-ChR-Li	4.228
Al-Sn	0.100	Al-Prn/N-Prn	6.254	AlR-ChR-Ls	3.612
Ch-Li	0.084	Al-Sn/Go-Prn	1.957	AlR-Prn-AlL	11.472
Ch-Ls	0.089	Al-Sn/Il-N	2.919	ChR-Ls-ChL	5.283
Cph-Cph	0.089	Ch-Li/Go-Prn	1.513	CphL-CphR-Li	3.191
Cph-Li	0.089	Ch-Li/Im-Im	1.555	CphL-Li-CphR	4.293
En-Al	0.114	Ch-Ls/Ch-Li	2.252	CphR-CphL-Li	3.225
En-En	0.100	Ch-Ls/En-Al	3.591	EnL-EnR-AlR	3.252
Go-Prn	0.187	Cph-Cph/Cph-Li	6.718	EnR-EnL-AlL	1.341
Il-N	0.063	Cph-Cph/Im-Im	2.188	GoL-Prn-N	2.847
Im-Im	0.122	Cph-Li/Al-Ch	3.684	GoR-Prn-GoL	1.872
Ls-Li	0.095	En-En/En-Al	10.453	GoR-Prn-N	2.334
N-Prn	0.270	Im-Im/N-Sto	1.091	IlR-N-IlL	1.751
N-Sto	0.179	Ls-Li/Ch-Li	3.820	Li-Ls-ChL	4.257
Spn-Spn	0.071	Ls-Li/N-Prn	5.118	Li-Ls-ChR	3.262
–	–	Ls-Li/N-Sto	1.542	Ls-Li-ChR	3.819
–	–	Spn-Spn/Al-Ch	4.000	Prn-AlL-Sn	7.442
–	–	Spn-Spn/Ch-Ls	4.301	Sn-AlL-ChL	3.604
–	–	Spn-Spn/En-En	3.099	Sto-N-IlL	1.026
–	–	–	–	Sto-N-IlR	0.955
Mean	**0.115**		**3.642**		**3.572**

Source: prepared by the author.

4 CHAPTER III – Distinguishing power of photo-anthropometric facial measures between identical twins

Abstract

Distinguishing identical twins (monozygotic, univiteline or MZT) by their facial appearances represents a challenging task in forensic science, especially in Forensic Facial Identification (FFI) procedures that aim to individualise humans based on comparison of bidimensional (2D) facial images. The metric approach for facial imaging analysis (i.e., facial photo-anthropometry – FPA) commonly involves measuring distances and proportions between reference points on the face (namely, landmarks). This approach has never been applied to assess facial differences between MZT. Understanding the extent to which different facial features contribute to the variability seen in this specific group, and hence also potential usefulness of these measures for differentiating MZT, can progress how facial evidence is evaluated as well as broadening the knowledge about how different the faces are of identical twins. To this end, the present work aims to verify how distinct a set of FPA measures (Euclidean distances, indices and angles) are between MZT and determine their discriminatory powers (DPs). Standardized frontal view facial images of 882 pairs of MZT of both sexes and from nine age groups (5, 10, 15, 20, 30, 40, 50, 60 and over 70 years old ± one year) were analyzed. For both age group and sex, the discriminatory power of FPA measures was assessed using confidence intervals of FPA variability and by verifying whether compared measures for the twin-pairs fell within this interval. These results showed that FPA measures (Euclidean distances, indices and angles) of MZT are distinct enough to potentially differentiate one from another. The most discriminating features between MZT are different from those found as most discriminating for unrelated individuals, revealing distinct facial differences.

1 Introduction

Human individualization through the analysis and comparison of facial structures depicted on 2D-images is a constant and challenging task among law enforcement agencies worldwide. This process is even more arduous when distinguishing individuals whose facial characteristics are theoretically identical, as in the case of monozygotic twins (identical, univiteline or MZT) (1, 2). The equivalence of

their genetic code (DNA) results in huge similarity between their anatomical structures, hindering not only the automated process of facial recognition, but also the examiner-dependent identification one (FFI) (2, 3).

Although the development of verification systems (i.e., one-to-many, facial recognition - FR) is of great importance for monitoring and surveillance security issues, what is seen in everyday forensic casework is a large increase in the number of requests for manual examinations, both computer-assisted or not, on 2D-images (i.e. facial mapping or one-to-one comparisons (FFI)) (4, 5). This, is achieved using examiner-dependent methodologies for the comparison of facial structures. Despite its relevance, only few scientific works aim to further improve these analyses and even fewer studies have focused on MZT, which is an increasing number population with a current prevalence of 0.3 to 0.4% (3, 6).

This investigation into the facial features that have the most influence in the variability and differentiation between MZT is of extreme relevance to forensic science (2, 7). Most of the dissimilarities that are seen in MZT are a result of environmental, behavioral or epigenetic factors and become more evident over time (2, 8). Confirming these differences reinforces the conception of human face distinctiveness, since even individuals with the same genetic code possess distinguishable facial characteristics (8). Indeed, studies have shown that even MZT have facial singularities that can be verified and used to differentiate one from another (8-11). Nonetheless, FPA differences between MZT have to date not been assessed.

This work therefore aims to verify how distinct a set of FPA measures are (Euclidean distances, indices and angles) between monozygotic twins, using measures previously selected as the most discriminating between unrelated persons and considering FPA methodological variability ranges. To my knowledge, this is the first time a metric FPA approach has been applied to the assessment of such a large sample and covering also different sex and age groups. Iris diameter measure was used for image normalization by creating ratios from original measures, in view of its promising results in detecting facial growth (12-14).

2 Material and methods

2.1 Reference facial images

Standardized frontal view facial images of 882 MZT pairs (1764 images in total) of both sexes and from nine age groups (5, 10, 15, 20, 30, 40, 50, 60 and over 70 years old ± one year) were selected from a Brazilian civilian database. On account of being a convenient sample, each age group differs in the number of analyzed images, as follows: 5-years-old (n=84), 10-years-old (n=99), 15-years-old (n=123), 20-years-old (n=117), 30-years-old (n=106), 40-years-old (n=118), 50-years-old (n=107), 60-years-old (n=97) and over 70-years-old (n=31).

A database search was carried out in a way to assure that only images with the same maternal affiliation, location and date of birth would be included. All images underwent a pre-selection process using these inclusion criteria: similar facial patterns (MZT sample verification), all facial landmarks visible, faces aligned with the Frankfurt plane, neutral facial expression, absence of beard, mustache and makeup. Images were acquired at resolutions of 640 x 480 pixels.

2.2 Metrical analysis

A manual FPA landmark-positioning approach proposed by Flores et al. (15) was used for metric assessment. The following 14 landmarks were considered: Alare (*Al*); Chelion (*Ch*); Crista Philtre (*Cph*); Gnathion (*Gn*); Gonion (*Go*); Iridion Laterale (*Il*); Labiale Inferius (*Li)*; Labiale Superius (*Ls*); Nasion (*N*); Superius Nostril (*Spn*); Pronasale (*Prn*); Pupil (*Pu*); Subnasale (*Sn*); and Stomion (*Sto*) (APPENDIX B). These landmarks were necessary to generate the measures determined in the previous study as having the greatest discriminatory potentials (Chapter I). From these 16 Euclidean distances (ED), 20 indices (IN) and 21 angles (AN) were also established. Since angles are established by combining two measures with the same landmark, and no additional measures composed of the *Im* landmark were classified as potentially discriminating, the *Im-Im* measure was only assessed with regards to IN and ED.

The FPA analysis was carried out by one examiner. Inter- and intraexaminer variabilities established in a previous study (Chapter II) were used as confidence intervals (CI), in order to assess how distinct the measures are between MZT. For

mapping, a non-commercial software package for two-dimensional facial analysis (SAFF-2D®, Forensic Facial Analysis System, Department of Federal Police, Brazil) was used. The software allows examiners to locate facial landmarks on images and to automatically register them through Cartesian coordinates (X, Y).

2.3 Data treatment

All measures were calculated in the same way as in the reference study (Chapter II). A total of 16 Euclidean distances (ED), 20 indices (IN) and 20 angles (AN) were obtained. Prior to generating indices and angles, all EDs were firstly divided by the iris diameter (Euclidean distance mean between *Iridion Laterale* and *Iridion Mediale* landmarks from both sides of the face) to create iris ratios. The same scaling factor of 2 px mm^{-1} was applied, based on the fact that the horizontal visible iris diameter (HVID) average from the sample was also 23 pixels.

2.4 Results assessment

First, intra-twin pair (intra-MZT) and inter-twin pair (inter-MZT) variabilities were assessed using descriptive analyses (standard deviation). Confidence intervals (CI) established in a previous study (Chapter II) were used for discriminatory power (DP) analysis and represented the expected FPA variability resulted from interexaminer and intraindividual variations.

Discriminatory power was assessed by checking whether the measures for each twin within a pair were found within this range (finding duplicate analyses) (16). CI were used to calculate the percentage of statistically different measures, when considering both a single variable and also multiple variables together. In single variable analysis, just one variable per group of measures (ED, AN, IN) was analyzed, whereas for the latter, multiple variables were used and the results are presented as their averages. Measures, angles and indices with fewer duplicates have the greatest capacity to discriminate one twin from another. Since all measures demonstrate negligible differences between males and females, discriminatory results are presented as a supporting material (Appendix A). Results of all statistical analyses were assessed against a statistical significance level of 5% ($\alpha = 0.05$).

3 Results

Results are organized into three sections. In the first section, intra- and inter-MZT variability was investigated. Discriminatory power analyses results, for one and multiple variables, are reported in sections 3.2.1 and 3.2.2, respectively. All sections were divided according to evaluated measure (i.e. ED, IN and AN).

3.1 Variability analysis

Variability results for intra- and inter-MZT groups, together with considered confidence intervals (CI) for ED, IN, and AN, are displayed in Figures 4.1, 4.2 and 4.3, respectively.

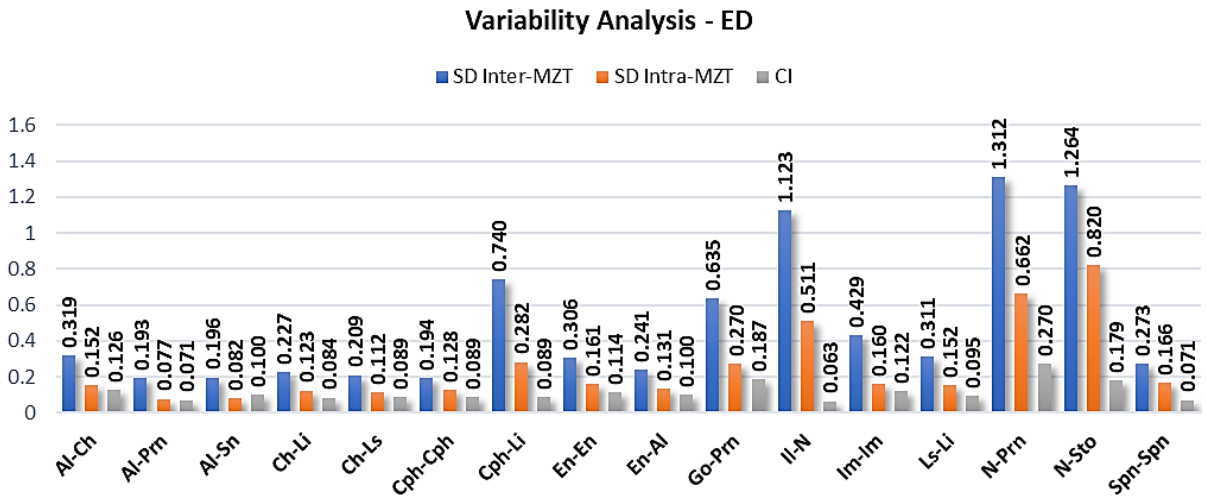
3.1.1 Euclidean Distance (ED)

The most variable EDs between MZTs (intra-MZT) were *N-Sto* (SD=0.820), *N-Prn* (SD=0.662), *Il-N* (SD=0.511) and *Cph-Li* (SD=0.282) (Figure 4.1). The same measures were also the most variable between pairs of twins (inter-MZT), with variabilities (SD) of 1.264, 1.312, 1.123 and 0.740, respectively. Least variable measures between MZTs were found to be *Al-Prn* (SD=0.077), *Al-Sn* (SD=0.082), *Ch-Ls* (SD=0.112) and *Ch-Li* (SD=0.123), whereas *Al-Prn* (SD=0.193), *Cph-Cph* (SD=0.194), *Al-Sn* (SD=0.196) and *Ch-Ls* (SD=0.209) were among the least variable between pairs.

As expected, for all analyzed EDs, greater variability was seen in the inter- than the intra-MZT group, which in turn showed greater variability than the CI group, except for *Al-SN* where the CI variability value was slightly greater than that of the intra-MZT group (0.100 vs 0.082, respectively). Indeed, measure variabilities between MZTs of the same pair were closer to the methodological variabilities than the inter-MZT variabilities were, confirming that differences seen between twins of the same pair are more likely due to same person variation (CI). The greatest differences in variability between MZT groups were observed for *N-Prn*, *Il-N*, *Cph-Li and N-Sto*, indicating particular variability patterns between the groups. Despite *N-Sto* and *N-Prn* demonstrating relatively high FPA variabilities (CI), the variability differences of these

measures between MZT-groups was found to be much higher than that the maximum observed for ED, that is CI = 0.27.

Figure 4.1 - Variability analysis and FPA variability (CI) for Euclidean distances (ED). Standard deviation (SD) values by inter-MZT and intra-MZT groups



Source: prepared by the author.

3.1.2 Indices (IN)

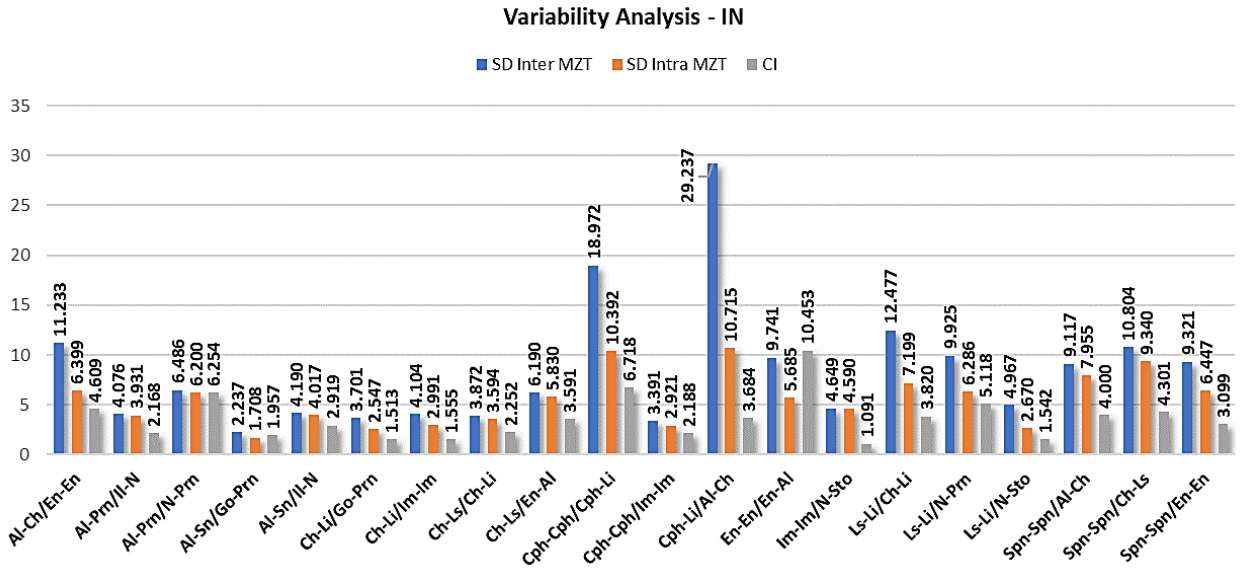
The most variable IN measures between MZTs (intra-MZT) were *Cph-Li/Al-Ch* (SD=10.715), *Cph-Cph/Cph-Li* (SD=10.392), *Spn-Spn/Ch-Ls* (SD=9.340) and *Spn-Spn/Al-Ch* (SD=7.955) (Figure 4.2). On the other hand, the most variable IN measures between MZT pairs (inter-MZT) were *Cph-Li/Al-Ch* (SD=29.237), *Cph-Cph/Cph-Li* (SD=18.972), *Ls-Li/Ch-Li* (SD=12.477) and *Al-Ch/En-En* (SD=11.233). The least variable measures between MZTs were *Al-Sn/Go-Prn* (SD=1.708), *Ch-Li/Go-Prn* (SD=2.547), *Ls-Li/N-Sto* (SD=2.670) and *Cph-Cph/Im-Im* (SD=2.921), whereas *Al-Sn/Go-Prn* (SD=2.237), *Cph-Cph/Im-Im* (SD=3.391), *Ch-Li/Go-Prn* (SD=3.701) and *Ch-Ls/Ch-Li* (SD=3.872) were among the least variable of the between-pair measures. In general, all INs demonstrate greater variability compared to ED measures.

Again, and as expected, all analyzed INs showed greater inter- than intra-MZT variability. For the majority of INs, greater variabilities were also observed in the intra-MZT group than the CI group, confirming that the variability in IN measures of the same individual is lower than that between MZTs and pairs of twins. This assertion was not valid for *Al-Prn/N-Prn*, *Al-Sn/Go-Prn* and *En-En/En-Al*. The first two revealed very

close variabilities and therefore do not significantly affect this conclusion. On the contrary, *En-En/En-Al* was particularly variable even for measures taken of the same person. Indeed, *En-En/En-Al* revealed the highest methodological error (CI=10.453).

Comparing both MZT groups, the greatest variability differences were observed for *Cph-Li/Al-Ch*, *Cph-Cph/Cph-Li*, *Ls-Li/Ch-Li* and *Al-Ch/En-En,* whereas the most similar values were observed for *Im-Im/N-Sto*, *Al-Prn/Il-N*, *Al-Sn/Il-N* and *Ch-Ls/Ch-Li*.

Figure 4.2 - Variability analysis and FPA variability (CI) for indices (IN). Standard deviation (SD) values by inter-MZT and intra-MZT groups



Source: prepared by the author.

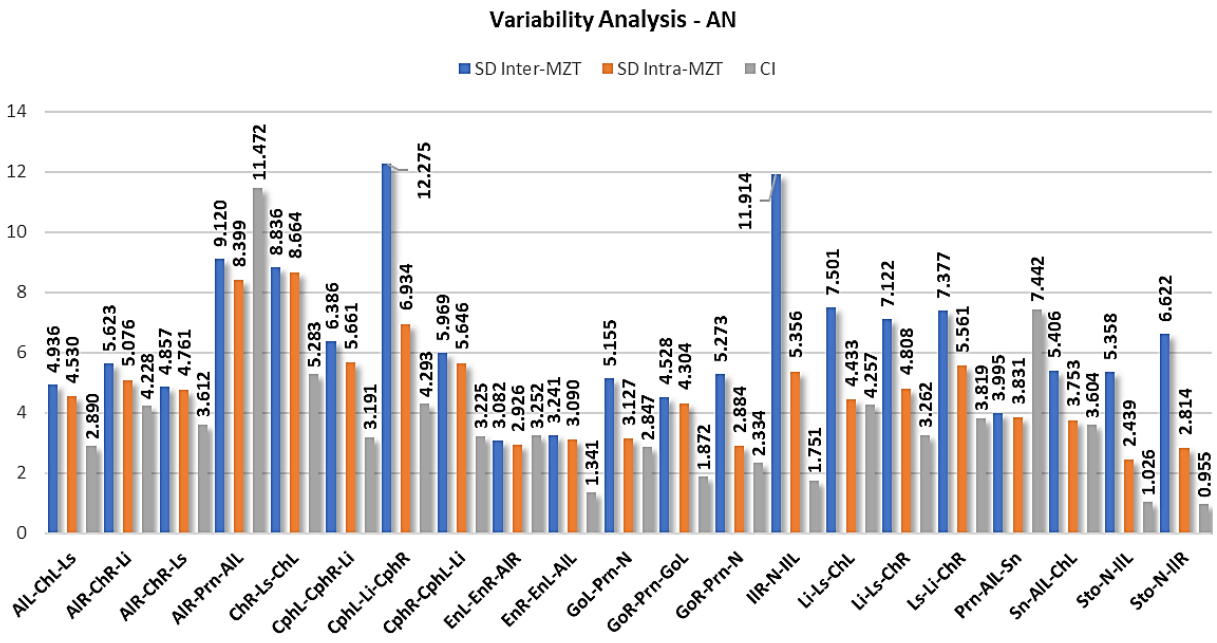
3.1.3 Angles (AN)

The most variable AN measures between MZTs (intra-MZT) were *ChR-Ls-ChL* (SD=8.664), *AlR-Prn-AlL* (SD=8.399), *CphL-Li-CphR* (SD=6.934) and *CphL-CphR-Li* (SD=5.661) (Figure 4.3). Regarding the inter-MZT group, the most variable AN measures were *CphL-Li-CphR* (SD=12.275), *IlR-N-IlL* (SD=11.914), *AlR-Prn-AlL* (SD=9.120) and *ChR-Ls-ChL* (SD=8.836). The least variable measures between MZTs were *Sto-N-IlL* (SD=2.439), *Sto-N-IlR* (SD=2.814), *GoR-Prn-N* (SD=2.884) and *EnL-EnR-AlR* (SD=2.926), whereas *EnL-EnR-AlR* (SD=3.082), *EnR-EnL-AlL* (SD=3.241), *Prn-AlL-Sn* (SD=3.995) and *GoR-Prn-GoL* (SD=4.528) were the least variable measures between twin pairs.

As expected, greater inter-MZT than intra-MZT variability was seen for all analyzed ANs. For almost all ANs, greater variability values were observed for the intra-MZT group than the CI group, except for *EnL-EnR-AlR*, *Prn-AlL-Sn* and *AlR-Prn-AlL*. The intra- and inter-MZT variabilities for *EnL-EnR-AlR* were very close and did not significantly influence present findings. *AlR-Prn-AIL* displayed the highest methodological error (CI=11.472), despite presenting relatively similar values between the MZT groups analyzed. On the contrary, *Prn-AlL-Sn* was shown to be particularly variable even when considering measures taken from the same person (CI=7.442, against SD of 3.995 and 3.831 for inter and intra-MZT, respectively).

Comparing both MZT groups, the greatest variability differences were observed for *IlR-N-IlL*, *CphL-Li-CphR*, *Sto-N-IlR* and *Sto-N-IlL,* whereas the most similar values were observed for *AlR-ChR-Ls*, *EnR-EnL-AlL*, *EnL-EnR-AlR* and *Prn-AlL-Sn*.

Figure 4.3 - Variability analysis and FPA variability (CI) for angles (AN). Standard deviation (SD) values by inter-MZT and intra-MZT groups



Source: prepared by the author.

3.2 Discriminatory power analysis

Discriminatory power was divided into two sections: the first considering just one variable and the second multiple variables. All measures demonstrated similar results between sex group. Indeed, mean differences between the two groups were 3.91 ± 0.03 (ED), 2.63 ± 0.02 (IN) and 4.74 ± 0.04 (AN) (Appendix A). The greatest differences were seen for ED *N-Prn* (12.80%), IN *Al-Prn/N-Prn* (10.28%) and AN *GoL-Prn-N* (14.19%).

Regarding FPA variability, the highest confidence intervals (CI) were observed for *N-Prn* (0.270), *En-En/En-Al* (10.453) and *AlR-Prn-AlL* (11.472) (Figures 4.1, 4.2, and 4.3, respectively). Except for the latter two measures, methodological variabilities were all below 7.442 (*Prn-AlL-Sn*). Of the three measures investigated, the smallest variabilities were observed for Euclidean distances, confirming the results from previous studies (Chapters I and II).

3.2.1 Discriminatory power analysis – One variable

In this analysis, the percentages of statistically different measurements for single measures were evaluated , taking into account CIs calculated in previous study (Chapter II).

3.2.1.1 Euclidean distances (ED)

Considering EDs, the most discriminating measure between MZTs was found to be *Spn-Spn* (Table 4.1). Indeed, higher percentages of statistically different twins were seen in age groups of 5-years-old (YO) (83.33%), 15-YO (70.73%), 30-YO (75.47%), 40-YO (77.12%), 50-YO (79.25%), 60-YO (81.44%) and 70-YO (83.87%). This result corroborates previous studies (Chapters I and II) that indicated the *Spn-Spn* measure as having one of the greatest discriminatory potentials between unrelated individuals. Indeed, this measure, together with *Ls-Li*, *Cph-Li* and *Im-Im*, were the most discriminatory in all age groups of unrelated individuals (5, 15, 20, 30, 40, 50, 60 and over 70 years old). For 10-YO and 20-YO groups, better discriminatory results were presented by the *N-Sto* (75.76%) and *Ls-Li* (63.38%) measures, respectively.

Considering all age groups together, EDs with the greatest discriminatory powers were *Spn-Spn* (75.07%), *N-Sto* (65.63%), *Ls-Li* (65.15%) and *Cph-Li* (62.36%). Except for *N-Sto,* which was especially discriminant between MZTs, the other three measures also demonstrated good performances in discriminating unrelated individuals. Measures with lower percentages of statistically different twins, and thus also lower discriminatory powers, were *Al-Sn* (30.49%), *Al-Prn* (41.40%), *N-Prn* (45.86%) and *Il-N* (49.96%), compared to *N-Prn* (61.09%), *Al-Sn* (66.03%), *Cph-Cph* (73.70%) *and Al-Ch* (73.89%) from the reference study. Regarding the ED measure, groups of 40-YO, 60-YO and 70-YO presented the highest mean percentages of discriminating power between MZTs (56.25%, 62.90%, and 60.37%, respectively). This result confirms that MZT differences increase over time.

In some cases, low discriminatory powers were observed for the measures that displayed the greatest variabilities, such as *Il-N* and *N-Prn*, indicating that the variabilities seen here are not consistent with human variation.

Table 4.1 - Discriminatory power analysis for Euclidean distances (ED) by age group. Mean percentages for all age groups are displayed in the last column (5-70 YO) and mean percentages by each age group are displayed in the last row (Mean). Values lower than 50% are shaded light gray

ED	5 YO	10 YO	15 YO	20 YO	30 YO	40 YO	50 YO	60 YO	70 YO	5-70 YO
	(n = 84)	(n = 99)	(n = 123)	(n = 117)	(n = 106)	(n = 118)	(n = 107)	(n = 97)	(n = 31)	Mean
Al-Ch	54.76%	35.35%	44.72%	38.46%	50.94%	58.47%	53.27%	56.70%	74.19%	51.87%
Al-Prn	36.90%	42.42%	23.58%	41.88%	41.51%	40.68%	45.79%	54.64%	45.16%	41.40%
Al-Sn	28.57%	19.19%	17.07%	37.61%	28.30%	29.66%	38.32%	40.21%	35.48%	30.49%
Ch-Li	59.52%	49.49%	61.79%	63.25%	55.66%	55.93%	65.42%	63.92%	77.42%	61.38%
Ch-Ls	50.00%	36.36%	43.90%	52.14%	48.11%	53.39%	58.88%	59.79%	64.52%	51.90%
Cph-Cph	45.24%	60.61%	51.22%	61.21%	53.77%	57.63%	58.49%	61.86%	80.65%	58.96%
Cph-Li	61.90%	67.68%	56.10%	61.54%	55.66%	62.71%	58.88%	69.07%	67.74%	62.36%
En-Al	57.14%	69.70%	61.79%	60.68%	50.94%	60.17%	59.81%	59.79%	61.29%	60.15%
En-En	51.19%	60.61%	47.97%	41.03%	50.94%	46.61%	44.86%	63.92%	64.52%	52.41%
Go-Prn	54.76%	71.72%	54.47%	63.25%	54.72%	60.17%	65.42%	62.89%	51.61%	59.89%
Il-N	44.05%	73.74%	47.15%	44.44%	41.51%	56.78%	42.06%	51.55%	48.39%	49.96%
Im-Im	54.76%	71.72%	52.03%	47.86%	47.17%	61.02%	45.79%	51.55%	67.74%	55.52%
Ls-Li	61.90%	59.60%	65.85%	68.38%	63.21%	66.10%	64.49%	69.07%	67.74%	65.15%
N-Prn	48.81%	24.24%	52.85%	45.30%	40.57%	53.39%	47.66%	51.55%	48.39%	45.86%
N-Sto	66.67%	75.76%	61.79%	67.52%	56.60%	60.17%	66.36%	68.04%	67.74%	65.63%
Spn-Spn	83.33%	58.59%	70.73%	65.81%	75.47%	77.12%	79.25%	81.44%	83.87%	75.07%
Mean	53.72%	54.80%	50.81%	53.77%	50.94%	56.25%	55.92%	60.37%	62.90%	55.50%

Source: prepared by the author.

3.2.1.2 Indices (IN)

Considering INs, the most similar and greatest discriminatory powers between twins were observed for *Im-Im/N-Sto and Ch-Li/Im-Im*. The first measure was able to distinguish more twins of 15-YO (83.74%), 40-YO (87.29%), 50-YO (85.05%), 60-YO (87.63%) and 70-YO (90.32%) (Table 4.2). For the 5-YO group, better discriminatory results were seen for *Spn-Spn/Al-Ch* (84.52%), whereas *Ch-Li/Im-Im* (94.95%) performed better amongst 10-YOs. Equal discriminatory powers were presented by *Im-Im/N-Sto* and *Ch-Li/Im-Im* in the groups of 30 and 20-YOs (84.62% and 76.42%, respectively). The first also revealed one of the greatest discriminatory powers between unrelated individuals of all age groups (Chapter II), followed by *Ch-Li/Im-Im* (5, 15, 20, 40 and 50 YO), *Spn-Spn/En-En* (30 and 60 YO) and *Cph-Cph/Cph-Li* (70).

Considering all age groups together, the greatest discriminatory powers were observed for *Ch-Li/Im-Im* (82.11%), *Im-Im/N-Sto* (82.05%), *Spn-Spn/Ch-Ls* (74.47%) and *Ls-Li/Ch-Li* (73.29%). The first three were also the most discriminating between unrelated individuals, together with *Spn-Spn/En-En*. Measures with the least percentages of statistically different twins, thus revealing lower discriminatory powers, were *En-En/En-Al* (17.26%), *Al-Sn/Il-N* (33.74%), *Al-Sn/Go-Prn* (44.10%) and *Al-Prn/N-Prn* (40.46%). This same pattern was observed in the reference study. Groups of 5-, 60- and 70-YOs presented the highest mean percentages of discriminating power between MZTs (64.52%, 64.64% and 68.06%, respectively), indicating greater facial differences between MZTs in those age groups. Unexpectedly, greater differences were also observed in the 5-YO group. This could be attributed to the difficulty in establishing standardized imaging protocols for young children.

In some cases, low discriminatory powers were observed amongst the measures displaying the greatest variability results, such as the *Cph-Li/Al-Ch, Cph-Cph/Cph-Li* and *Spn-Spn/Ch-Ls* indices, indicating that the variabilities seen here are not a result of human variation.

Table 4.2 - Discriminatory power analysis for indices (IN) by age group. Mean percentages for all age groups are displayed in the last column (5-70 YO) and mean percentages by each age group are displayed in the last row (Mean). Values lower than 50% are shaded light gray

IN	5 YO	10 YO	15 YO	20 YO	30 YO	40 YO	50 YO	60 YO	70 YO	5-70 YO
	(n = 84)	(n = 99)	(n = 123)	(n = 117)	(n = 106)	(n = 118)	(n = 107)	(n = 97)	(n = 31)	Mean
Al-Ch/En-En	66.67%	46.46%	56.10%	48.72%	48.11%	66.10%	57.01%	64.95%	83.87%	59.78%
Al-Prn/Il-N	50.00%	30.30%	34.15%	42.74%	44.34%	39.83%	47.66%	59.79%	48.39%	44.13%
Al-Prn/N-Prn	54.76%	18.18%	37.40%	33.33%	33.02%	47.46%	41.12%	50.52%	48.39%	40.46%
Al-Sn/Go-Prn	47.62%	27.27%	42.28%	41.88%	33.96%	46.61%	55.14%	50.52%	51.61%	44.10%
Al-Sn/Il-N	35.71%	13.13%	23.58%	32.48%	32.08%	32.20%	44.86%	41.24%	48.39%	33.74%
Ch-Li/Go-Prn	77.38%	75.76%	65.85%	68.38%	71.70%	60.17%	68.22%	71.13%	74.19%	70.31%
Ch-Li/Im-Im	80.95%	94.95%	77.24%	84.62%	76.42%	76.27%	82.24%	82.47%	83.87%	82.11%
Ch-Ls/Ch-Li	78.57%	46.46%	65.85%	64.10%	73.58%	71.19%	67.29%	64.95%	61.29%	65.92%
Ch-Ls/En-Al	72.62%	78.79%	73.17%	64.96%	62.26%	75.42%	69.16%	68.04%	77.42%	71.32%
Cph-Cph/Cph-Li	60.71%	43.43%	50.41%	60.34%	57.55%	56.78%	60.38%	68.04%	64.52%	58.02%
Cph-Cph/Im-Im	51.19%	50.51%	52.85%	56.03%	54.72%	54.24%	58.49%	58.76%	70.97%	56.42%
Cph-Li/Al-Ch	67.86%	57.58%	44.72%	58.97%	56.60%	56.78%	51.40%	60.82%	61.29%	57.34%
En-En/En-Al	25.00%	11.11%	20.33%	13.68%	6.60%	19.49%	15.89%	20.62%	22.58%	17.26%
Im-Im/N-Sto	79.76%	63.64%	83.74%	84.62%	76.42%	87.29%	85.05%	87.63%	90.32%	82.05%
Ls-Li/Ch-Li	79.76%	74.75%	74.80%	70.09%	70.75%	74.58%	66.36%	71.13%	77.42%	73.29%
Ls-Li/N-Prn	64.29%	37.37%	52.03%	51.28%	49.06%	53.39%	58.88%	57.73%	70.97%	55.00%
Ls-Li/N-Sto	70.24%	47.47%	66.67%	62.39%	63.21%	66.95%	60.75%	72.16%	77.42%	65.25%
Spn-Spn/Al-Ch	84.52%	51.52%	70.73%	69.23%	70.75%	69.49%	72.64%	80.41%	83.87%	72.57%
Spn-Spn/Ch-Ls	76.19%	62.63%	67.48%	77.78%	70.75%	81.36%	70.75%	79.38%	83.87%	74.47%
Spn-Spn/En-En	66.67%	46.46%	59.35%	64.10%	66.04%	72.03%	66.98%	82.47%	80.65%	67.19%
Mean	64.52%	48.89%	55.93%	57.49%	55.90%	60.38%	60.01%	64.64%	68.06%	59.54%

Source: prepared by the author.

3.2.1.3 Angles (AN)

A greater correlation with age was seen in discriminatory powers of AN measures. The best distinguishing performances in 40-YO (80.53%), 50-YO (82.08%) and 60-YO (79.57%) groups were observed for *GoR-Prn-GoL* (Table 4.3). In the 5-YO group, the best discriminatory results were observed for *ChR-Ls-ChL* (83.33%). A particularly discriminant measure, *Sto-N-IIR* (72.73%), was revealed in the 10-YO group. For 15-YOs, both *Li-Ls-ChR* and *ChR-Ls-ChL* (75.61%) presented the highest discriminatory results. The most discriminant angle within the 20-YO and 30-YO groups was *EnR-EnL-AlL* (73.50% and 76.42%, respectively). For the 70-YO group,the most discriminant angle was *Li-Ls-ChL* (93.55%). Except for *GoR-Prn-GoL* and *EnR-EnL-AlL,* which showed great discriminatory powers also between unrelated

individuals, other angles showed a peculiar behavior for MZTs, especially *Sto-N-IlR* and *Li-Ls-ChL*.

Considering all age groups together, ANs with the greatest discriminatory powers were *Li-Ls-ChR* (73.57%), *GoR-Prn-GoL* (72.72%), *Li-Ls-ChL* (71.62%) and *EnR-EnL-AlL* (71.18%) compared to *GoR-Prn-GoL* (82.30%), *EnR-EnL-AlL* (81.55%), *CphL-Li-CphR* (76.86%) *and Li-Ls-ChR* (75.97%) in the reference study. Angles with the least percentages of statistically different twins, and thus also the lowest discriminatory powers, were *Prn-AlL-Sn* (13.20%), *AlR-Prn-AlL (21.57%)*, *EnL-EnR-AlR* (43.40%) and *IlR-N-IlL* (51.59%). The same pattern was observed amongst unrelated individuals, except for the latter, which was replaced by the *AlR-ChR-Li* in the reference study. With regards to analyzed angles, groups of 5-, 60-, and 70-YOs gave the highest mean percentages of discriminating power between MZTs (64.47%, 64.42%, 66.97%, respectively), indicating greater facial differences between MZTs in those age groups. Unexpectedly again, large differences were observed in the 5-YO group.

Despite observing high variability for the *AlR-Prn-AlL* measure, it showed the lowest discriminatory power among analyzed ANs, indicating that the variability seen here is not consistent with human variation. Low values in terms of variability and discriminatory power were found for EnL-EnR-AlR.

Table 4.3 - Discriminatory power analysis for angles (AN) by age group. Mean percentages for all age groups are displayed in the last column (5-70 YO) and mean percentages by each age group are displayed in the last row (Mean). Values lower than 50% are shaded light gray

AN	5 YO	10 YO	15 YO	20 YO	30 YO	40 YO	50 YO	60 YO	70 YO	5-70 YO
	(n = 84)	(n = 99)	(n = 123)	(n = 117)	(n = 106)	(n = 118)	(n = 107)	(n = 97)	(n = 31)	Mean
AlR-ChR-Ls	69.05%	39.39%	54.47%	47.01%	45.28%	61.02%	56.07%	59.79%	64.52%	55.18%
AlL-ChL-Ls	79.76%	55.56%	69.92%	67.52%	62.26%	70.34%	71.03%	74.23%	74.19%	69.42%
AlR-ChR-Li	67.86%	39.39%	52.03%	48.72%	52.83%	53.39%	59.81%	54.64%	45.16%	52.65%
AlR-Prn-AlL	26.51%	16.16%	15.45%	17.09%	16.04%	19.49%	31.78%	25.77%	25.81%	21.57%
ChR-Ls-ChL	83.33%	58.59%	75.61%	68.38%	63.21%	70.94%	69.16%	74.23%	64.52%	69.77%
CphL-CphR-Li	78.57%	52.53%	54.47%	68.97%	61.32%	65.25%	67.92%	71.13%	70.97%	65.68%
CphL-Li-CphR	60.71%	38.38%	47.97%	57.76%	56.60%	55.08%	61.32%	67.01%	70.97%	57.31%
CphR-CphL-Li	73.81%	58.59%	59.35%	54.31%	63.21%	66.10%	73.58%	74.23%	93.55%	68.53%
EnL-EnR-AlR	41.67%	28.28%	39.84%	43.59%	50.94%	42.37%	38.32%	44.33%	61.29%	43.40%
EnR-EnL-AlL	67.86%	53.54%	70.73%	73.50%	76.42%	77.12%	77.57%	79.38%	64.52%	71.18%
GoL-Prn-N	65.48%	35.35%	58.54%	64.10%	65.09%	61.86%	67.29%	71.13%	58.06%	60.77%
GoR-Prn-GoL	78.57%	42.42%	70.73%	64.66%	75.24%	80.53%	82.08%	79.57%	80.65%	72.72%

to be continued

concluded

GoR-Prn-N	69.05%	44.44%	68.29%	70.09%	65.09%	70.34%	76.64%	75.26%	87.10%	69.59%
IIR-N-IIL	48.81%	65.66%	50.41%	41.03%	43.40%	49.15%	46.73%	54.64%	64.52%	51.59%
Li-Ls-ChL	82.14%	51.52%	65.04%	58.97%	73.58%	70.34%	70.09%	79.38%	93.55%	71.62%
Li-Ls-ChR	79.76%	59.60%	75.61%	65.81%	67.92%	70.34%	78.50%	74.23%	90.32%	73.57%
Ls-Li-ChR	69.05%	46.46%	60.16%	52.14%	60.38%	61.86%	73.83%	78.35%	74.19%	64.05%
Prn-AlL-Sn	11.90%	17.17%	8.13%	15.38%	11.32%	13.56%	13.08%	18.56%	9.68%	13.20%
Sn-AlL-ChL	67.86%	62.63%	53.66%	68.38%	58.49%	63.56%	55.14%	60.82%	74.19%	62.75%
Sto-N-IIL	66.67%	66.67%	64.23%	56.41%	58.49%	61.02%	64.49%	68.04%	61.29%	63.03%
Sto-N-IIR	65.48%	72.73%	63.41%	69.23%	56.60%	73.73%	76.64%	68.04%	77.42%	69.25%
Mean	64.47%	47.86%	56.10%	55.86%	56.37%	59.88%	62.43%	64.42%	66.97%	59.37%

Source: prepared by the author.

3.2.2 Discriminatory power analysis – Multiple variables

From this analysis, it was possible to observe the number of measures that are necessary to discriminate one twin from another in the different age groups. Contrary to discriminatory power analysis of one variable, measures are presented here as the probability of finding the same two (or more) measures between MZTs, without specifying which measures.

3.2.2.1 Euclidean Distance (ED)

It was observed that 16 ED measures were not sufficient to achieve a probability of finding less than one duplicate twin in a population of 10^6 (1,000,000 MZTs) in ages groups of 10, 50 and 60 year olds (Table 4.4). In age groups of 20 and 70 YOs, 16 EDs were sufficient to achieve a probability of less than one duplicate twin in a population of a million. This same probability was obtained even using fewer measures (i.e., 15 ED) in age groups of 5, 15, 30 and 40 year olds. The probability of finding the same two EDs started at a percentage of less than 41.02% (70 YOs). Comparing to unrelated individuals, as expected, worse discriminatory power results were observed between MZTs, especially for age groups of 10, 50 and 60 year olds. Indeed, all measures assessed were not able to reach such a probability in all age groups analyzed.

Table 4.4 – Match probability within MZT pairs for Euclidean distances (ED) by age group (5, 15, 20, 30, 40, 50, 60 and 70 years old – YO)

ED	5 YO (%)	10 YO (%)	15 YO (%)	20 YO (%)	30 YO (%)	40 YO (%)	50 YO (%)	60 YO (%)	70 YO (%)
2	31.260000	32.416000	27.581000	30.532000	27.343000	32.323000	32.738000	37.689000	41.022000
3	19.056000	20.186000	15.624000	18.036000	15.308000	18.839000	20.374000	24.254000	27.840000
4	11.915000	13.101000	9.099000	11.072000	8.823000	11.087000	13.319000	16.031000	19.642000
5	7.549000	8.825000	5.386000	7.041000	5.162000	6.574000	9.115000	10.849000	14.344000
6	4.805000	6.154000	3.208000	4.616000	3.029000	3.923000	6.513000	7.505000	10.782000
7	3.048000	4.434000	1.904000	3.097000	1.767000	2.354000	4.841000	5.310000	8.297000
8	1.909000	3.298000	1.114000	2.108000	1.016000	1.415000	3.727000	3.853000	6.499000
9	1.165000	2.535000	0.634000	1.442000	0.570000	0.847000	2.954000	2.881000	5.151000
10	0.681000	2.017000	0.345000	0.980000	0.308000	0.499000	2.396000	2.232000	4.097000
11	0.373000	1.665000	0.175000	0.655000	0.157000	0.284000	1.980000	1.798000	3.235000
12	0.183000	1.426000	0.079000	0.423000	0.073000	0.150000	1.662000	1.510000	2.496000
13	0.074000	1.264000	0.029000	0.256000	0.029000	0.068000	1.415000	1.316000	1.832000
14	0.020000	1.153000	0.007000	0.136000	0.008000	0.021000	1.222000	1.186000	1.210000
15	**0.000000**	1.073000	**0.000000**	0.054000	**0.000000**	**0.000000**	1.071000	1.095000	0.605000
16	**0.000000**	1.010000	**0.000000**	**0.000000**	**0.000000**	**0.000000**	0.952000	1.031000	**0.000000**

Source: prepared by the author.

3.2.2.2 Indices (IN)

For IN, it was seen that 20 INs were necessary to achieve a probability of finding less than one duplicate twin in a population of 10^6 (1,000,000 MZTs) (Table 4.5). This same probability was obtained even using fewer measures (i.e., 19 IN) in age groups of 5, 20, 30, 40, 50 and 70 years old. The probability of finding the same two INs started at a percentage of less than 47.09% (70 YO). In general, MZTs needed more measures than unrelated individuals to reach “zero” probabilities at the order of 10^{-6} (0.000001), except for age groups of 15 and 70 YOs, which revealed the same probability.

Table 4.5 – Match probability within MZT pairs for indices (IN) by age group (5, 15, 20, 30, 40, 50, 60 and 70 years old – YO)

IN	5 YO (%)	10 YO (%)	15 YO (%)	20 YO (%)	30 YO (%)	40 YO (%)	50 YO (%)	60 YO (%)	70 YO (%)
2	42.487000	26.906000	33.201000	34.229000	32.105000	37.467000	37.799000	42.664000	47.097000
3	28.413000	16.220000	20.719000	20.861000	18.977000	23.760000	24.607000	28.674000	33.005000
4	19.224000	10.444000	13.527000	12.953000	11.558000	15.333000	16.432000	19.587000	23.337000
5	13.118000	7.056000	9.183000	8.154000	7.255000	10.040000	11.196000	13.574000	16.590000
6	9.001000	4.943000	6.436000	5.183000	4.686000	6.661000	7.746000	9.525000	11.820000
7	6.192000	3.563000	4.626000	3.316000	3.103000	4.473000	5.415000	6.750000	8.412000
8	4.258000	2.628000	3.390000	2.127000	2.096000	3.035000	3.807000	4.817000	5.962000
9	2.917000	1.972000	2.522000	1.363000	1.434000	2.077000	2.677000	3.453000	4.191000

to be continued

concluded

10	1.982000	1.499000	1.898000	0.868000	0.988000	1.428000	1.872000	2.478000	2.910000
11	1.330000	1.148000	1.441000	0.548000	0.679000	0.981000	1.294000	1.777000	1.985000
12	0.874000	0.882000	1.102000	0.340000	0.462000	0.668000	0.877000	1.270000	1.320000
13	0.559000	0.676000	0.846000	0.206000	0.308000	0.446000	0.578000	0.902000	0.847000
14	0.342000	0.513000	0.648000	0.121000	0.199000	0.287000	0.365000	0.635000	0.518000
15	0.196000	0.381000	0.493000	0.067000	0.121000	0.174000	0.215000	0.441000	0.294000
16	0.102000	0.274000	0.367000	0.035000	0.067000	0.096000	0.115000	0.299000	0.149000
17	0.044000	0.185000	0.260000	0.015000	0.031000	0.044000	0.051000	0.194000	0.062000
18	0.013000	0.112000	0.167000	0.005000	0.010000	0.013000	0.015000	0.114000	0.017000
19	**0.000000**	0.051000	0.081000	**0.000000**	**0.000000**	**0.000000**	**0.000000**	0.052000	**0.000000**
20	**0.000000**	**0.000000**	**0.000000**	**0.000000**	**0.000000**	**0.000000**	**0.000000**	**0.000000**	**0.000000**

Source: prepared by the author.

3.2.2.3 Angles (AN)

For AN, it was shown that 20 ANs were necessary to achieve a probability of finding less than one duplicate twin in a population of 10^6 (1,000,000 MZTs) (Table 4.6). This same probability was obtained even using fewer measures (i.e., 19 AN) in age groups of 20, 30, 50, 60 and 70 year olds. The probability of finding the same two ANs started at a percentage of less than 41.48% (70 YOs). Although MZT needed more measures than unrelated individuals to reach “zero” probabilities at the order of 10^{-6} in age groups of 5, 50, 60 and 70 YO, better discriminatory results were presented for MZT in age groups of 20, 30 and 40 YO. In these age groups, 21 ANs were required to achieve a probability of finding less than one duplicate in a population of 10^5 (100,000) unrelated individuals.

Table 4.6 – Match probability within MZT pairs for angles (AN) by age group (5, 15, 20, 30, 40, 50, 60 and 70 years old – YO)

AN	5 YO (%)	10 YO (%)	15 YO (%)	20 YO (%)	30 YO (%)	40 YO (%)	50 YO (%)	60 YO (%)	70 YO (%)
2	41.411000	26.869000	32.257000	31.760000	32.785000	36.190000	39.048000	41.162000	44.485000
3	26.770000	16.595000	18.960000	18.495000	19.378000	22.576000	24.536000	26.984000	29.314000
4	17.308000	10.825000	11.358000	10.954000	11.587000	14.416000	15.455000	17.900000	19.168000
5	11.176000	7.292000	6.914000	6.569000	6.970000	9.405000	9.746000	11.999000	12.441000
6	7.202000	5.011000	4.265000	3.971000	4.197000	6.255000	6.142000	8.113000	8.014000
7	4.630000	3.486000	2.658000	2.409000	2.519000	4.227000	3.860000	5.519000	5.121000
8	2.970000	2.438000	1.670000	1.460000	1.500000	2.892000	2.413000	3.762000	3.243000
9	1.902000	1.704000	1.056000	0.879000	0.881000	1.995000	1.495000	2.558000	2.032000
10	1.217000	1.184000	0.671000	0.523000	0.507000	1.382000	0.914000	1.723000	1.255000
11	0.778000	0.812000	0.428000	0.306000	0.284000	0.955000	0.547000	1.142000	0.761000
12	0.497000	0.547000	0.274000	0.174000	0.154000	0.655000	0.319000	0.737000	0.449000

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concluded

13	0.199000	0.358000	0.175000	0.095000	0.080000	0.443000	0.178000	0.458000	0.256000
14	0.199000	0.227000	0.111000	0.049000	0.040000	0.292000	0.094000	0.269000	0.138000
15	0.122000	0.137000	0.070000	0.023000	0.018000	0.185000	0.046000	0.146000	0.069000
16	0.072000	0.077000	0.042000	0.010000	0.008000	0.111000	0.020000	0.070000	0.030000
17	0.039000	0.039000	0.024000	0.003000	0.003000	0.060000	0.007000	0.027000	0.011000
18	0.018000	0.017000	0.012000	0.001000	0.001000	0.028000	0.001000	0.006000	0.002000
19	0.006000	0.005000	0.004000	**0.000000**	**0.000000**	0.009000	**0.000000**	**0.000000**	**0.000000**
20	**0.000000**	**0.000000**	**0.000000**	**0.000000**	**0.000000**	**0.000000**	**0.000000**	**0.000000**	**0.000000**

Source: prepared by the author.

4 Discussion

The discriminatory powers of FPA measures between MZTs is crucial missing information amongst the scientific community. Studies that have evaluated MZT facial differences mainly applied biometric systems to evaluate morphological features, such as moles, freckles and scars (2, 7, 9). Regarding differentiating MZT faces, studies indicate that human examiners outperform automated recognition systems, especially on images acquired under non-controlled situations (3, 8, 9). In such cases, influencing factors (e.g., lighting, camera angle, spatial image resolution and facial pose) prevent proper perception of facial structures. Depending on image acquisition conditions, small facial differences could go unnoticed and distinguishing theoretically identical faces may seem near impossible (10). Nonetheless, anthropometric information from more standardized images can provide valuable answers about an individual's biological profile (17-19), as well as frequencies and probabilities of human features, which are essential in order to support facial comparison evidence in everyday forensic casework (12, 18).

Studies of identical twins are particularly important to investigate human physical variation and rarity of features. The more differences that are found between MZT faces, the greater is the belief that human faces are unique. Although MZTs share the same DNA structure, epigenetic mechanisms can alter the way genes are expressed, leading to different phenotypes that can be verified and used for human individualization purposes (8). The main problem of assessing these differences by FPA analysis is to properly isolate desirable variability (i.e., human variability) from all other sources of variation that can result from analyzing a bidimensional representation of a tridimensional structure. Indeed, some studies claim that the variability of the same

individual can be even greater than all sources of FPA variability, making the discriminating process near to impossible (20-22).

To overcome such problems, several procedures were carried out to increase the reliability of the results of this work. Firstly, a reliable and adapted anthropometric-based approach for indirect 2D-image analysis was applied for quantitative assessment of facial structures (i.e., photo-anthropometry) (23). Secondly, measures were converted into ratios in order to nullify the effect of angular and rectilinear distortions of compared images (22). Thirdly, the horizontal visible iris diameter (HVID) was used as a fixed reference for the creation of those ratios (i.e., iris ratio). Recent studies designated this measure as the most sensitive tool for detecting facial growth and estimating the age of children and sub-adults (12, 24, 25). Such a designation is justified by HVIDs low variability and long-term stability, as well as the fact that it is the most isometric measure of the human face (12, 13, 23). Finally, an error range, instead of absolute values, was used to find duplicate measures.

As a result, metric differences were able to be verified and FPA analysis revealed potentially discriminating measures even between MZTs. Indeed, the use of the HVID reference for the creation of measures seemed to increase the sensitivity of the FPA method towards detecting facial differences. Although the percentages of statistically different measures between MZTs were, in general, lower than those found for unrelated individuals, almost 74% of groups analyzed presented differences above 50% (against 96.5% from unrelated individuals). This result means that measures were able to differentiate one twin from another in more than half of the twin-pairs analyzed. This is an excellent result, especially considering the application of error ranges that, despite being essential, can hinder the discriminating process by increasing the probability of finding duplicate values. Age groups in which the lowest percentages were most often found were 20 YO (ED) and 10 YO (IN and AN), indicating that MZTs within these age groups present more similarities than those in the others.

Measures with the greatest discriminatory powers between MZTs were *Spn-Spn* (ED)*, N-Sto* (ED)*, Ls-Li* (ED)*, Cph-Li* (ED)*, Ch-Li/Im-Im* (IN)*, Im-Im/N-Sto* (IN)*, Spn-Spn/Ch-Ls* (IN)*, Ls-Li/Ch-Li* (IN)*, Li-Ls-ChR* (AN)*, GoR-Prn-GoL* (AN)*, Li-Ls-ChL* (AN) *and EnR-EnL-AlL* (AN). On the contrary, *Al-Sn* (ED)*, Al-Prn* (ED)*, N-Prn* (ED)*, Il-N* (ED)*, En-En/En-Al* (IN)*, Al-Sn/Il-N* (IN)*, Al-Sn/Go-Prn* (IN)*, Al-Prn/N-Prn* (IN)*, Prn-AlL-Sn* (AN)*, AlR-Prn-AlL* (AN)*, EnL-EnR-AlR* (AN) *and IlR-N-IlL* (AN) were shown to be non-discriminatory measures. Compared to unrelated individuals, measures with

particular dissimilarities between MZTs were *N-Sto* (ED), *Ls-Li/Ch-Li* (IN) and *Li-Ls-ChL* (AN), highlighting that measures related to the thickness of the mouth (*Ls-L*i) and lower lip (*Ch-Li*), and to the distance between the nasal bridge and the midpoint of *rima oris* (i.e., the encounter of upper and lower lips) (*N-Sto*), are the most discriminatory for identical twins. One particular measure demonstrated great discriminatory power for both groups analyzed (unrelated persons and MZTs), that is *Spn-Spn* (distance between upper landmarks of both sides of the nostrils).

A strong correlation with age was also observed, especially in the case of angles. Contrary to results for unrelated individuals, *Al-Sn* (ED) showed a very low discriminatory power between MZTs in age groups of 10 and 20 year olds, demonstrating large similarities between measures defined as the distance between *the most lateral landmark of the nose wing* (p. 35) and *the lowermost landmark of the nose* (p. 33) (23). Concerning indices, *Ch-Li/Im-Im* and *Im-Im/N-Sto* were found to be extremely beneficial for differentiating MZTs of 10 and 70 years old, respectively. These measures also showed great DPs between unrelated individuals. The greatest distinguishing performances were observed for *Spn-Spn*, *CphR-CphL-Li* and *Li-Ls-ChL* among 70 year-old MZTs, meaning that angles composed of measures from the most lateral point of the mouth to its upper and lower extremes, or from this latter point to the uppermost landmark of the cupid's bow, were able to distinguish more MZTs than any other angles. The best discriminatory performances between unrelated individuals were observed for *Spn-Spn* (30 YO), *Im-Im/N-Sto* (50 YO) and, equally, *CphL-CphR-Li* and *EnR-EnL-AlL* (70 YO) in third place. The measures with the greatest similarities between MZTs across all age groups were *En-En/En-Al* (IN), *Prn-AlL-Sn* (AN) and *AlR-Prn-AlL* (AN). These measures are basically generated using landmarks of the nasal base (*Al*, *Prn*, *Sn*) and bridge areas (*En*). Indeed, indices composed of the intercanthal distance (*En-En*), and the distance between inner eye contour and the ipsilateral landmark of the nasal wing (*En-Al*), showed remarkable similarities between them.

Unexpectedly, differences observed between MZTs did not follow a perfect pattern with aging. In general, larger percentages of statistically different twins were found in the older age groups compared to the younger ones, corroborating the assertion that the accumulation of different life experiences and exposure to different factors determine dissimilarities in facial appearance that intensify with time (8). Indeed, the age group of 70 YOs showed the most differences between MZTs.

Nonetheless, large differences were also observed between MZTs of 5 years old, especially when indices and angles were used for facial assessment. This pattern was not observed in unrelated persons, revealing, as also observed in older groups, substantial MZT differences within this age. Even considering that images were taken cautiously and in a more controlled situation, this result could be attributed to the difficulty in establishing standardized imaging protocols for young children. Slight facial movements could have increased facial differences within this specific age group. Assuming that metric differences are indeed greater in this age group, present findings would strengthen even more the confidence in FPA methods as a more sensitive approach to detect human physical variation, especially for this age group. Morphological analysis has shown to be problematic in very young individuals, mainly due to the absence of facial features, which tend to gradually appear with age (2, 9). Further studies, however, comparing both approaches would be of the utmost benefit in order to reach more confident conclusions.

Comparing measure types, the variability in Euclidian distances was much lower than that in the other groups, corroborating the results of previous studies (Chapters I and II). Indices were best able to distinguish male from female MZTs, followed by Euclidean distances and angles. Measures yielding the highest differences between males and females were mostly related to the nasal region. This result is also in agreement with a previous study (Chapter I) that showed greater distinguishing potential between sexes for measures taken from both the mouth and nasal regions.

DPs of multiple variable analysis revealed that a combination of 20 indices or 20 angles was sufficient to achieve a probability of finding less than one twin-pair with the same measures in a population of one million MZT (10^6). Contrary to the results for unrelated individuals, good performances of Euclidean distances was not observed for all age groups of MZTs. In fact, 16 EDs were sufficient to achieve a probability of finding less than one duplicate twin in a population of 10^6 only for 5, 15, 20, 30, 40 and 70 YOs. Age groups of 10, 50 and 60 year olds still demonstrate 1% probability of finding duplicate measures between MZTs using 16 EDs. Multiple variable analysis in unrelated individuals revealed the opposite results in terms of measure performance. EDs performed better than other measure types between unrelated individuals. Indeed, a probability of finding less than one duplicate in a population of 10^6 (one million) was reached using only 15 EDs. The same probability was achieved using 16 INs in age groups of 5, 20, 30, 40 and 60 YOs and 18 ANs in age groups of 5, 15, 50,

60 and 70 YOs. For other age groups, 21 ANs were necessary to achieve probabilities of finding less than one duplicate in a population of 10^5 (100,000 individuals). Although multiple variable analysis on twins was performed comparing one twin with another, compared to one individual with the rest of the sample in unrelated individuals analysis, present findings further strengthen the usefulness of FPA methodology as a tool for facial discrimination.

The principle of finding duplicates was applied in order to calculate the probability of discrimination (DP). In forensic contexts, it is commonly used in situations where distribution probabilities are not available and represents the complementary probability to the probability of match (PM), represented by DP = 1 – PM (26, 27). The latter represents the probability of matching two individuals at random within some population. It is important to point out that the “probability of match” described in multiple variable analysis does not express the complementary probability of DP. The present analysis was calculated as the probability of finding any two (or more) equal measures between MTZs (26). Nonetheless, PM of each measure can be calculated from the given DP data (one variable analysis) and then combined DP can be determined. For example, considering the first three ANs of the 5 YO group *(AlR-ChR-Ls, AlL-ChL-Ls, AlR-ChR-Li)*, PM can be calculated by subtracting the converted decimal number of each DP by “1”, as follows:

$DP_1 = 1 - PM \Rightarrow 0.690 = 1 - PM \Rightarrow PM = 0.310$

$DP_2 = 1 - PM \Rightarrow 0.797 = 1 - PM \Rightarrow PM = 0.203$

$DP_3 = 1 - PM \Rightarrow 0.678 = 1 - PM \Rightarrow PM = 0.322$

$\therefore DP = 1 - (0.310^2 + 0.203^2 + 0.322^2) = 1 - 0.241 = 0.759$

This means that these combined metric facial features have a discriminatory power of 0.759. A low DP value implies that a match by chance between two different sources is likely, whereas a high DP implies that a match is unlikely and could be significant in forensic casework (26). It is important to highlight that, although DP is valuable for providing an evidential-type value, these values do not reveal the weight of the evidence in a particular case, in the same way as, for example, the likelihood ratio (LR) (26, 27). With regards to this logical framework for evidence evaluation (LR), studies on MZTs have the ability to provide useful information for the computation of between-source variability (BSV), which is a necessary step for calculation of the likelihood of evidence when compared faces/traces/marks are assumed to have

alternative sources (defense hypotheses) (28-30). In such cases, the examiner must consider the probability of observing the same facial pattern if images were acquired from different persons (29). In this sense, studies that assess the rarity and frequency of facial features in specific populations, such as MZTs, are of utmost importance to correctly evaluate LRs (29). For this purpose, distribution data for the MZT population are displayed in APPENDIX D.

Currently, the lack of quantitative data for the evaluation of facial evidence means FFI conclusions are primarily based on examiners' experience (28, 29). Generally, facial examinations are performed through visual comparisons and classification of facial features, according to their "similarities", as *similar in details*, *similar*, *no observation*, *different* or *different in details (27)*. Then, similarities and discrepancies are evaluated and classified, according to their DP, as *weakly discriminating*, *moderately discriminating* or *strongly discriminating* (27). Finally, conclusions are empirically reported as verbal expressions, usually based on a sliding scale of degree of support: *very strong*, *strong*, *moderate*, *limited* or *no support*. The most challenging part of categorical classifications is determining boundaries that can clearly distinguish one category from another. Converting qualitative characteristics into quantitative values decreases the subjectivity of the method and increases the capacity for data automation. One of the benefits of providing quantitative DP information is to bring more concrete definitions for examiner evaluation. Measures with DPs higher than 70% could be classified as *strongly discriminating,* for example. Whereas ranges of 40-70% and less than 40%, could be classified as *moderately discriminating* and *weakly discriminating,* respectively, bringing more objectivity to verbally expressed categories.

Regarding the calculation of LRs in FFI examinations, some other important considerations must be taken into account. This so-called 'one-to-one' comparison approach mostly involves the comparison of two sources of image, one from the suspect (S) and the other from the perpetrator (P). In such cases, the evaluation process consists of assigning two mutually exclusive hypotheses: that the suspect is the source and that he is not (28). One of the most difficult components of this model is to estimate the within source variability (WSV) (28). This condition would need to be computed when assuming that the suspect is indeed the perpetrator and it is centered on the intra-individual variability distribution of the suspect. In other words, the first hypothesis represents the probability of P being within variability range of S. Contrary

to the original calculation of LR, which is based on the calculation of frequency/distribution of features of the same individual under different image acquisition conditions, this model focuses the attention on determining sources of variation, in order to establish reliable intervals in which the same individual could be considered himself.

This study, together with the two previous ones (Chapters I and II), contributes to providing variability range references. Nonetheless, it is imperative that the validation of present findings through the calculation of “matching” errors in one-to-one situations is carried out. Although metric facial differences were verified, studies that verify matching errors are required to validate the present results for practical forensic casework. Furthermore, the evaluation of intraindividual variability under different image acquisition conditions is also essential to better assist practical examinations. It is also important to highlight that discriminatory findings were reported individually, without considering results of combined measures. Further studies combining measures according to their discriminatory potential would be of great importance to increase distinguishing probabilities.

5 Conclusion

The findings of this study indicate that FPA measures (Euclidean distances, indices and angles) taken from 2D frontal view facial images of monozygotic twins are singular enough to distinguish one from another. Indeed, 20 indices and 20 angles were sufficient to distinguish one from another to the order of less than one twin pair with the same measure in a population of a million MZTs. The most discriminating features between MZTs differ from those found for unrelated individuals, revealing a distinct pattern of facial differences. A strong correlation of measures with age was also observed, especially when using the AN measure.

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Appendix A –

Difference (≠) between facial side (R-right and L-left) for BM (bilateral measure) and CM (cross-side measure).

ED	Female (n = 517)	Male (n = 365)	IN	Female (n = 517)	Male (n = 365)	AN	Female (n = 517)	Male (n = 365)
Al-Ch	47.78	52.60	Spn-Spn/En-En	64.99	67.31	AlR-ChR-Ls	52.80	55.89
Al-Prn	41.78	39.18	Spn-Spn/Ch-Ls	72.34	75.55	AlR-ChR-Li	50.87	55.89
Al-Sn	29.40	30.68	Spn-Spn/Al-Ch	69.44	73.90	ChR-Ls-ChL	69.44	70.88
Ch-Li	57.64	63.56	En-En/En-Al	15.28	18.63	EnR-EnL-AlL	68.86	76.44
Ch-Ls	50.10	51.78	Al-Ch/En-En	54.74	61.37	EnL-EnR-AlR	39.07	46.03
Cph-Cph	58.06	56.16	Ch-Ls/Ch-Li	65.57	67.12	Ls-Li-ChR	60.35	66.30
Cph-Li	63.06	59.73	Ls-Li/N-Sto	63.25	65.48	Li-Ls-ChR	70.02	74.79
En-Al	58.61	62.19	Im-Im/N-Sto	79.69	84.38	Li-Ls-ChL	66.34	73.42
En-En	53.19	47.67	Ls-Li/N-Prn	50.29	57.81	Sto-N-IlL	63.06	62.74
Go-Prn	61.70	58.90	Ls-Li/Ch-Li	73.89	71.23	Sto-N-IlR	68.09	69.32
Il-N	50.68	49.04	Ch-Li/Im-Im	83.37	79.45	AlL-ChL-Ls	67.89	70.14
Im-Im	54.93	53.42	Ch-Ls/En-Al	70.21	71.51	Prn-AlL-Sn	12.77	14.25
Ls-Li	67.89	61.10	Ch-Li/Go-Prn	70.60	67.95	CphL-CphR-Li	63.88	66.03
N-Prn	40.62	53.42	Al-Prn/Il-N	41.97	45.21	CphR-CphL-Li	65.44	66.58
N-Sto	64.02	66.85	Cph-Cph/Im-Im	53.79	57.26	IlR-N-IlL	50.29	50.14
Spn-Spn	72.53	76.10	Cph-Li/Al-Ch	57.64	54.79	CphL-Li-CphR	53.20	59.73
–	–	–	Al-Prn/N-Prn	35.20	45.48	GoL-Prn-N	55.13	69.32
–	–	–	Cph-Cph/Cph-Li	55.15	60.27	GoR-Prn-N	64.41	73.70
–	–	–	Al-Sn/Go-Prn	42.36	44.93	AlR-Prn-AlL	20.31	21.70
–	–	–	Al-Sn/Il-N	31.14	33.97	GoR-Prn-GoL	66.47	79.94
–	–	–	–	–	–	Sn-AlL-ChL	63.25	59.18
Mean	**54.50**	**55.15**		**57.55**	**60.18**		**56.76**	**61.07**

Source: prepared by the author.

5 CONCLUSIONS

The present thesis has led to the conclusion that FPA measures are useful tools for discriminating Brazilian individuals, including even the most challenging population group of identical twins (MZTs). This assertion is based on the comprehensive analysis of standardized frontal view facial images through application of an approach specifically oriented for indirect 2D image analysis (i.e., photo-anthropometry), and all measures were taken as a relation to their iris diameter (i.e., iris ratios). In general, the present study revealed which facial measures are most and less likely to be found between unrelated individuals and MTZs and their discriminatory power (DP). The presence of measures with great DP in compared images is highly suggestive of a positive match or, indeed, lead to exclusion of a suspect, whereas the presence of measures with low DP will be of less forensic significance. Quantitative parameters to qualitative classifications for DP in FPA analysis were also provided, bringing more objectivity to currently expressed categories.

From the first chapter, a total of 16 measures (Euclidean distances) were found to be the least frequent in a population of unrelated individuals, thus indicating the greatest potential for distinguishing human faces: *Al-Ch, Al-Prn*, *Al-Sn*, *Ch-Li*, *Ch-Ls*, *Cph-Cph*, *Cph-Li*, *En-Al*, *En-En*, *Go-Prn*, *Il-N*, *Im-Im*, *Ls-Li*, *N-Prn*, *N-Sto* and *Spn-*Spn. With regards to measure type, vertical measures showed greater potential to discriminate age groups, whereas horizontal ones showed greater potential to discriminate sexes.

The second chapter confirmed the ability of these Euclidean distances, as well as of 20 indices and 21 angles obtained from them, to distinguish unrelated individuals. Indeed, a combination of 15 Euclidean distances and 20 indices was required to achieve a probability of finding less than one individual with duplicate measures in a population of one million. The same probability was obtained using 18 angles in age groups of 15 and 70 YO and even fewer measures were required for the 5, 50 and 60 YO groups (17 AN). In other age groups, 21 angles were necessary to a probability of finding less than one duplicate in a population of 10^5 (100,000). These results strongly support the hypothesis that FPA measures, especially

Euclidean distances, can be used to discriminate human faces of unrelated individuals.

Major differences were observed in measures that include the mouth and nasal region, particularly the *Al* landmark, when images of the same individual were analyzed. Despite these differences, intraindividual variabilities (RAA) were all below an error of 1.003 SD (0.501 mm in actual physical scale). It is important to highlight that since FPA analysis involves consideration of numerous sources of variability, measures variabilities must be considered individually as a result of the distinct behavior of each measure for each age group analyzed. In general, discriminatory power results indicated *Spn-Spn* (ED), *Ls-Li* (ED), *Cph-Li* (ED), *Im-Im/N-Sto* (IN), *Ch-Li/Im-Im* (IN), *Spn-Spn/En-En* (IN), *GoR-Prn-GoL* (AN) and *EnR-EnL-AlL* (AN) have the greatest discriminatory powers for unrelated individuals.

The last chapter confirmed that FPA measures can even distinguish theoretically identical faces (monozygotic twins). Indeed, a combination of 20 indices or 20 angles was sufficient to achieve a probability of finding less than one twin pair with the same measures in a population of one million MZTs (10^6). In contrast to the results for unrelated individuals, good performance of Euclidean distances was not observed for all age groups of MZTs. In fact, 16 EDs were not sufficient to obtain a probability of finding less than one duplicate twin in a population of 10^6 in ages groups of 10, 50 and 60 year olds.

The measures with the greatest discriminatory powers between MZTs were found to be *Spn-Spn* (ED), *N-Sto* (ED), *Ls-Li* (ED), *Cph-Li* (ED), *Ch-Li/Im-Im* (IN), *Im-Im/N-Sto* (IN), *Spn-Spn/Ch-Ls* (IN), *Ls-Li/Ch-Li* (IN), *Li-Ls-ChR* (AN), *GoR-Prn-GoL* (AN), *Li-Ls-ChL* (AN) *and EnR-EnL-AlL* (AN). On the contrary, non-discriminating measures were *Al-Sn* (ED), *Al-Prn* (ED), *N-Prn* (ED), *Il-N* (ED), *En-En/En-Al* (IN), *Al-Sn/Il-N* (IN), *Al-Sn/Go-Prn* (IN), *Al-Prn/N-Prn* (IN), *Prn-AlL-Sn* (AN), *AlR-Prn-AlL* (AN), *EnL-EnR-AlR* (AN) *and IlR-N-IlL* (AN). Compared to unrelated individuals, measures with particular dissimilarities between MZTs were *N-Sto* (ED), *Ls-Li/Ch-Li* (IN) and *Li-Ls-ChL* (AN), whereas *Al-Sn* (ED) showed very low discriminatory power between MZTs, especially in the age groups of 10 and 20 year olds. Measures displaying the greatest similarities between MZTs were *En-En/En-Al* (IN), *Prn-AlL-Sn* (AN) and *AlR-Prn-AlL* (AN). One particular measure demonstrated great discriminatory power for both groups analyzed (unrelated persons and MZTs),

that is *Spn-Spn*. A strong correlation with age was also observed, especially when using the AN measure.

As can also be noted, different discriminatory patterns were observed between MZTs and unrelated individuals, with correlation with age and sex seen in both populations. The use of the horizontal visible iris diameter (HVID) as a calibration factor seemed to enhance the sensitivity for detecting facial differences and improve the potential of FPA as a discriminatory indicator in FFI cases. Future studies in practical contexts, evaluating present findings as well as calculating the probability of "match" errors, are of utmost importance, in order to establish this undervalued tool as a practical implementation for law enforcement agencies and support image comparison examinations. Finally, it is also important to highlight that present findings were achieved within a population of high miscegenation (Brazilian) and inherently large variability. Assessing populations of different ethnicities is essential to provide global information about metric facial patterns.

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APPENDIX A – Ethical Committee Approval

HOSPITAL DAS CLÍNICAS DA FACULDADE DE MEDICINA DE RIBEIRÃO PRETO DA USP -

USP - RIBEIRÃO
assistência · ensino · pesquisa

Plataforma Brasil

PARECER CONSUBSTANCIADO DO CEP

DADOS DA EMENDA

Título da Pesquisa: Análise de parâmetros faciais na população brasileira com finalidade forense a partir de banco de imagens em norma frontal.

Pesquisador: Carlos Eduardo Palhares Machado

Área Temática:

Versão: 2

CAAE: 51448515.0.0000.5440

Instituição Proponente: UNIVERSIDADE DE SAO PAULO

Patrocinador Principal: FUND COORD DE APERFEICOAMENTO DE PESSOAL DE NIVEL SUP

DADOS DO PARECER

Número do Parecer: 1.465.932

Apresentação do Projeto:

A análise de imagens para fins de identificação e classificação humana é um desafio para órgãos investigativos e periciais, uma vez que faltam parâmetros confiáveis e estudos científicos que suportem os resultados dos exames indiretos sobre o corpo humano. A fotoantropometria, conhecida como a análise de distâncias e ângulos formados entre referências anatômicas de um indivíduo por meio de imagens, assim como a análise da morfologia, são consideradas importantes ferramentas de análise facial indireta, podendo ser utilizadas para o levantamento de dados de interesse clínico e/ou cirúrgico, para a determinação de dados antropológicos, como a estimativa de idade, projeções de envelhecimento e, até mesmo, para a comparação de padrões faciais para fins de identificação humana. As contribuições científicas associadas ao tema têm aumentado o interesse de pesquisadores no intuito de desenvolver metodologias de análise e erigir dados populacionais para sua aplicação prática, especialmente da área forense, na qual, muitas vezes, apenas imagens estão disponíveis para a análise pericial, como no caso da pornografia infantil e delitos registrados em circuitos fechados de televisão (CFTV). Apesar da relevância do tema, não existe, atualmente, uma metodologia cientificamente consolidada para se estimar, de forma segura, a idade, o sexo e a ancestralidade de um indivíduo quando examinados unicamente por meio de imagens, tampouco metodologias quantitativas ou qualitativas de

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Identificação Facial Forense. O presente projeto de pesquisa, que é parte de proposta aprovada no âmbito do edital nº 25/2014 da CAPES, tem por objetivo a análise da frequência e distribuição de parâmetros métricos, geométricos e morfológicos da face da população brasileira, por meio de exames qualitativos e quantitativos em imagens presentes no Sistema Nacional de Passaportes da Polícia Federal, por metodologia manual e automatizada, com vistas a criação de bases estatísticas de suporte aos exames de Comparação Facial e Identificação Humana por meio de imagens.

Objetivo da Pesquisa:

São objetivos primários deste projeto:1. Analisar a frequência e distribuição de parâmetros métricos, geométricos e morfológicos da face na população brasileira, com vistas à criação de bases estatísticas de suporte aos exames de Comparação Facial e Identificação Humana por meio de imagens;2. Compreender a forma com que os parâmetros métricos, geométricos e morfológicos variam e se modificam na população brasileira, quando verificados em função do sexo, idade, ancestralidade e naturalidade, para emprego em metodologias forenses.

Avaliação dos Riscos e Benefícios:

Riscos:Os riscos potenciais do presente projeto estão relacionados a uma eventual exposição das imagens ou dos dados biográficos presentes no SINPA,que poderiam levar à identificação dos indivíduos da amostra da pesquisa. Destaca-se, contudo, que serão tomadas as seguintes providências para evitá-los.

Benefícios: Entre os benefícios esperados, podem-se destacar

• Os resultados trarão benefícios à justiça e à coletividade por meio do fortalecimento da prova técnica relacionada aos exames antropológicos faciais realizados em imagens. Com a massificação digital, os exames em imagens são uma

demanda cada vez mais presente nos Organismos Oficiais de Perícia, mas estes ainda carecem de metodologias específicas, cientificamente testadas e validadas, para a produção de seus laudos;

• A comunidade científica é unânime ao afirmar que os estudos antropológicos são fortemente dependentes de fatores e características populacionais. Atualmente, inexistem estudos com o mesmo escopo realizados na população brasileira,

condição que limita e, por vezes, inviabiliza o emprego de métodos cientificamente validados na solução de questões práticas da perícia no Brasil. Espera-se, com o presente estudo, preencher as lacunas relacionadas com tal problemática;

• Espera-se que os resultados do estudo auxiliem na construção de ferramentas aplicáveis à constatação de autoria em diversos crimes associados com imagens, como na identificação de

criminosos flagrados em locais de crime por circuitos fechados de televisão (CFTV) ou por equipamentos portáteis individuais. Também se espera o auxílio na comprovação da materialidade de um dos crimes que mais crescem no mundo, a pornografia infantil, que ainda enfrenta o desafio de contar com metodologias capazes de extrair dados técnicos confiáveis por meio de imagens;

• O projeto cumprirá o objetivo estabelecido pela CAPES, com o Edital PRO-FORENSES, de estimular a realização conjunta de projetos de pesquisa por Instituições de Ensino Superior e Organismos Oficiais de Perícia, possibilitando a produção científica e a formação de recursos humanos relacionados com as Ciências Forenses. Trata-se de estudo inédito, com abordagem não apenas acadêmica, mas voltada à solução de problemas reais;

• A pesquisa contribuirá para o levantamento do perfil fotoantropométrico, biotipológico e morfológico facial da população brasileira, trazendo suporte estatístico para aplicação do conhecimento, não apenas no campo das Ciências Forenses, mas em áreas diversas, como anatomia, artes e ciências ligadas à biometria facial;

• Com a automatização de parte do processo de análise facial, espera-se uma maior difusão e aplicabilidade dos produtos periciais que, para algumas aplicações, poderá
dispensar o conhecimento aprofundado sobre antropologia facial.

Comentários e Considerações sobre a Pesquisa:

Trata-se de um estudo observacional agregado antropológico, com levantamentos de dados transversais e longitudinais retrospectivos, que se utiliza de dados primários de banco de imagens faciais de brasileiros, provenientes do Sistema Nacional de Passaporte (SINPA) gerenciado pela Polícia Federal (PF), utilizando-se variáveis de exposição: a idade, sexo, região de nascimento e ancestralidade; e como variáveis de desfecho: quantitativas contínuas (análise fotoantropométrica) e qualitativas nominais e ordinais (análise morfológica).

Considerações sobre os Termos de apresentação obrigatória:

Trata-se de projeto de pesquisa já analisado e aprovado por este CEP, deacordo com o Parecer número 1.356.054 datado de 08 de Dezembro de 2015.

Em 22/03/2016 os pesquisadores responsável encaminharam uma solicitação de emenda com o objetivo de incluir a Faculdade de Odontologia da Universidade de São Paulo como coparticipante formal da proposta já aprovada.

Recomendações:

Não se aplica.

Conclusões ou Pendências e Lista de Inadequações:

O CEP analisou e aprovou a solicitação de emenda de inclusão da Faculdade de Odontologia da Universidade de São Paulo como Instituição coparticipante.

Considerações Finais a critério do CEP:

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação
Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_670003_E1.pdf	22/03/2016 16:19:22		Aceito
Outros	Carta_de_Esclarecimento_CEP.pdf	22/03/2016 16:15:33	Marta Regina Pinheiro Flores	Aceito
Outros	Protocolo_de_atendimento_MS.pdf	02/03/2016 15:05:47	Marta Regina Pinheiro Flores	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	Solicitacao_dispensa_TCLE.pdf	01/12/2015 02:12:35	Carlos Eduardo Palhares Machado	Aceito
Outros	Edital_25_2014_CAPES_Carta_anuencia_UNB.pdf	28/11/2015 16:17:09	Carlos Eduardo Palhares Machado	Aceito
Outros	Edital_25_2014_CAPES_Carta_anuencia_UNICAMP.pdf	28/11/2015 16:16:32	Carlos Eduardo Palhares Machado	Aceito
Outros	Edital_25_2014_CAPES_Carta_anuencia_PF.pdf	28/11/2015 16:15:37	Carlos Eduardo Palhares Machado	Aceito
Outros	Edital_25_2014_CAPES_Carta_anuencia_USP.pdf	28/11/2015 16:14:32	Carlos Eduardo Palhares Machado	Aceito
Outros	Edital_25_2014_CAPES_RESULTADO_FINAL.pdf	28/11/2015 16:12:42	Carlos Eduardo Palhares Machado	Aceito
Outros	Edital_25_2014_CAPES_PROFORENSES.pdf	28/11/2015 16:11:29	Carlos Eduardo Palhares Machado	Aceito
Outros	Anuencia_POLICIA_FEDERAL_pesquisa_FACE.pdf	28/11/2015 16:09:00	Carlos Eduardo Palhares Machado	Aceito
Orçamento	Orcamento_detalhado_aprovado_pela_UPC_FMRP_USP_e_CAPES.pdf	28/11/2015 16:05:14	Carlos Eduardo Palhares Machado	Aceito
Orçamento	Aprovacao_orcamento_UPC_FMRP_USP.pdf	28/11/2015 16:04:33	Carlos Eduardo Palhares Machado	Aceito
Declaração de Pesquisadores	Declaracao_compromisso_pesquisadores_responsaveis.pdf	28/11/2015 16:02:12	Carlos Eduardo Palhares Machado	Aceito
Folha de Rosto	FOLHA_ROSTO_ASSINADA.pdf	28/11/2015 15:56:24	Carlos Eduardo Palhares Machado	Aceito
Projeto Detalhado / Brochura Investigador	PROJETO_PROFORENSES_FACE_SUBMISSAO_CEP_FINAL_REVISADO.pdf	28/11/2015 13:17:25	Carlos Eduardo Palhares Machado	Aceito

Situação do Parecer:
Aprovado

Necessita Apreciação da CONEP:
Não

RIBEIRAO PRETO, 28 de Março de 2016

Assinado por:
MARCIA GUIMARÃES VILLANOVA
(Coordenador)

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APPENDIX B – Facial photo-anthropometric landmarks

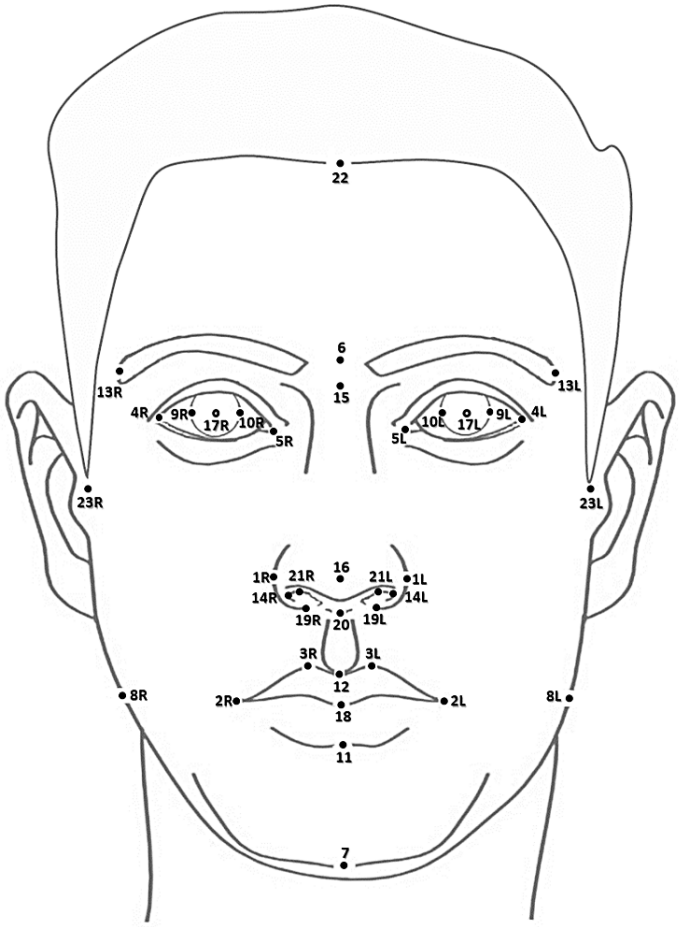
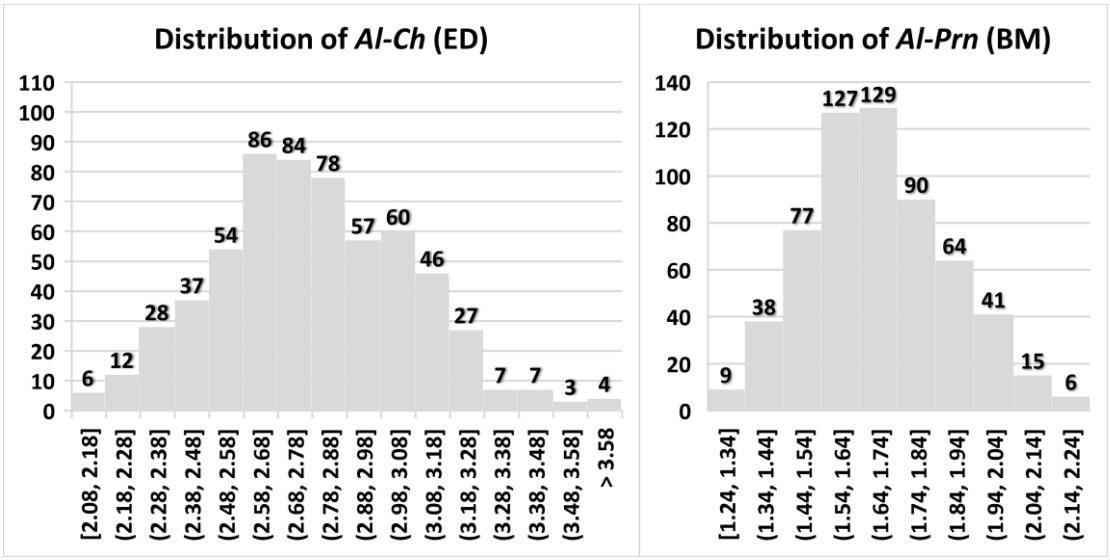
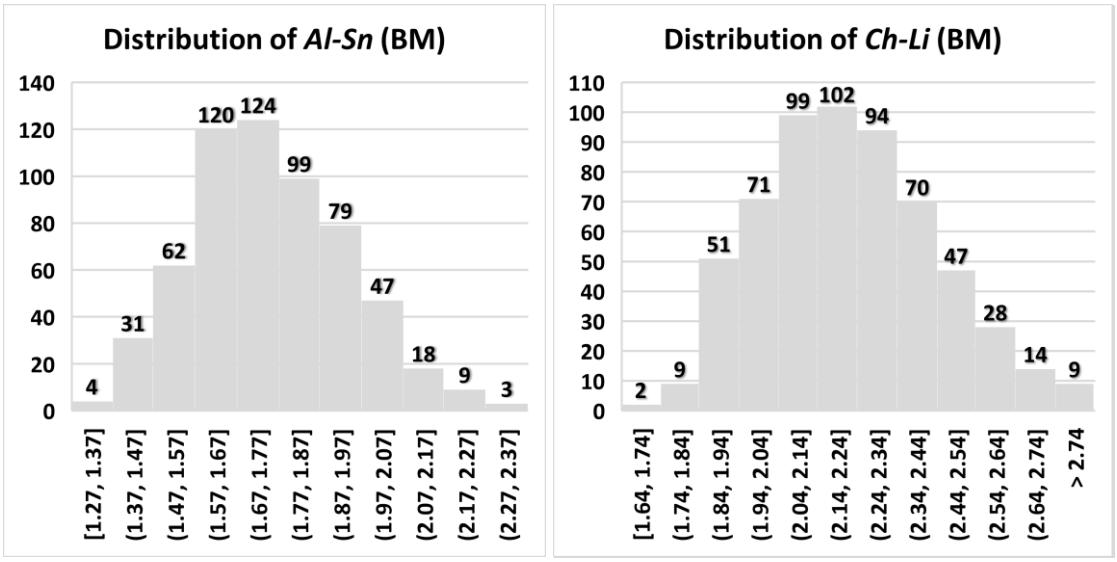


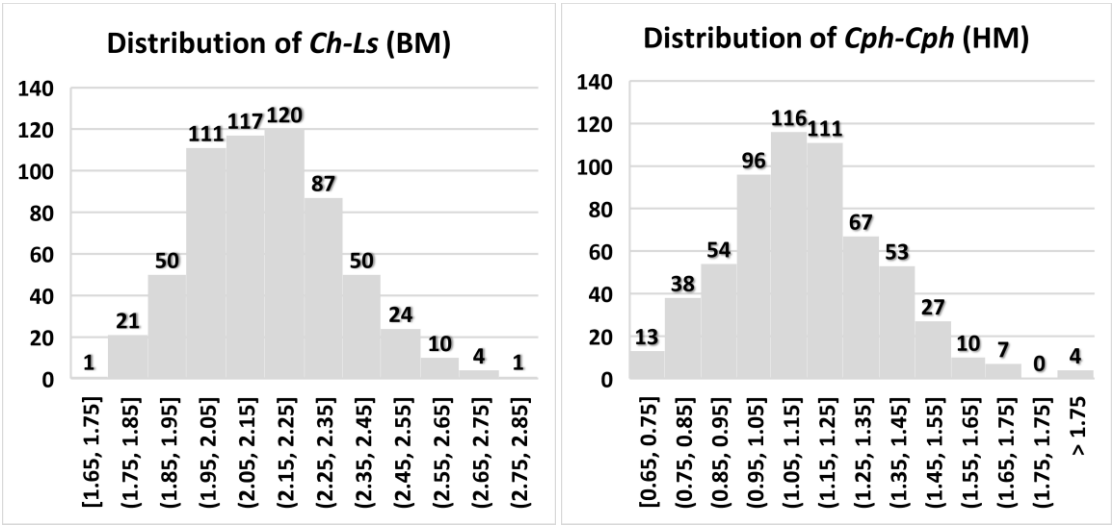
Photo-anthropometric landmarks			
#	Landmark	Laterality	Abbreviation
1	Alare	Bilateral	AlL/AlR
2	Chelion	Bilateral	ChL/ChR
3	Crista Philtre	Bilateral	CphL/CphR
4	Ectocanthion	Bilateral	EcL/EcR
5	Endocanthion	Bilateral	EnL/EnR
6	Glabella	Median	G
7	Gnathion	Median	Gn
8	Gonion	Bilateral	GoL/GoR
9	Iridion Laterale	Bilateral	IlL/IlR
10	Iridion Mediale	Bilateral	ImL/ImR
11	Labiale Inferius	Median	Li
12	Labiale Superius	Median	Ls
13	Laterale Eyebrow	Bilateral	LeL/LeR
14	Laterale Nostril	Bilateral	LnL/LnR
15	Nasion	Median	N
16	Pronasale	Median	Prn
17	Pupil	Bilateral	PuL/PuR
18	Stomion	Median	Sto
19	Subalare	Bilateral	SbalL/SbalR
20	Subnasale	Median	Sn
21	Superius Nostril	Bilateral	SpnL/SpnR
22	Trichion	Median	Tr
23	Zygion	Bilateral	ZyL/ZyR

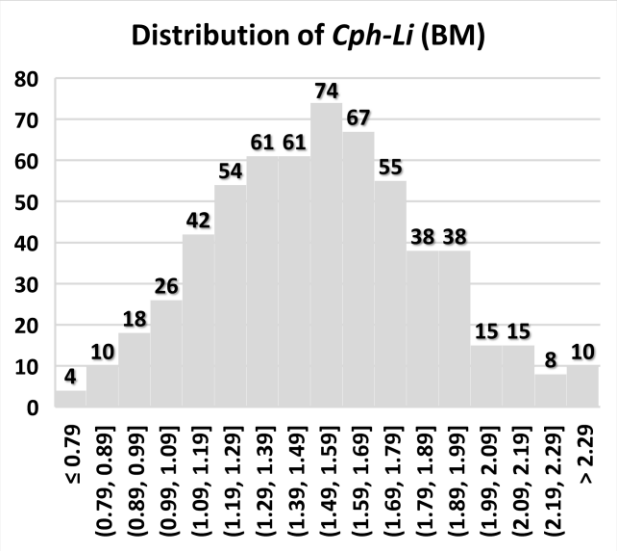
Source: prepared by the author.

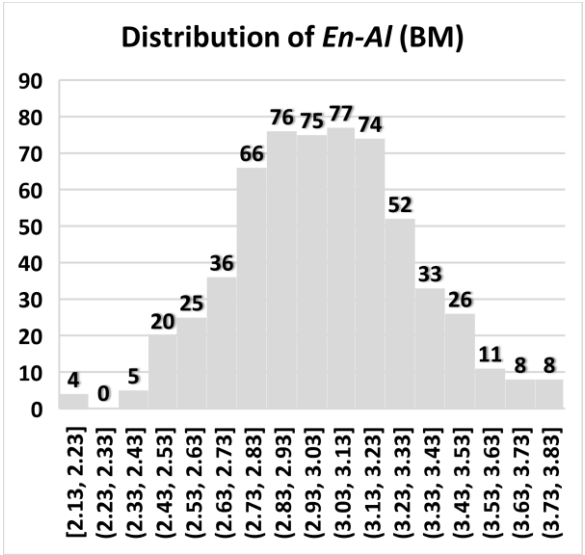
APPENDIX C – Distribution of selected FPA measures (Euclidean distances) within unrelated individuals in ranges of 0.10 (n=596). All sources prepared by the author.








Distribution of *Cph-Li* (BM)
80
70
60
50
40
30
20
10
0
4
10
18
26
42
54
61 61
74
67
55
38 38
15 15
8
10
≤ 0.79
(0.79, 0.89]
(0.89, 0.99]
(0.99, 1.09]
(1.09, 1.19]
(1.19, 1.29]
(1.29, 1.39]
(1.39, 1.49]
(1.49, 1.59]
(1.59, 1.69]
(1.69, 1.79]
(1.79, 1.89]
(1.89, 1.99]
(1.99, 2.09]
(2.09, 2.19]
(2.19, 2.29]
> 2.29


Distribution of *En-Al* (BM)
90
80
70
60
50
40
30
20
10
0
4
0
5
20
25
36
66
76 75 77 74
52
33
26
11
8
8
[2.13, 2.23]
(2.23, 2.33]
(2.33, 2.43]
(2.43, 2.53]
(2.53, 2.63]
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(3.03, 3.13]
(3.13, 3.23]
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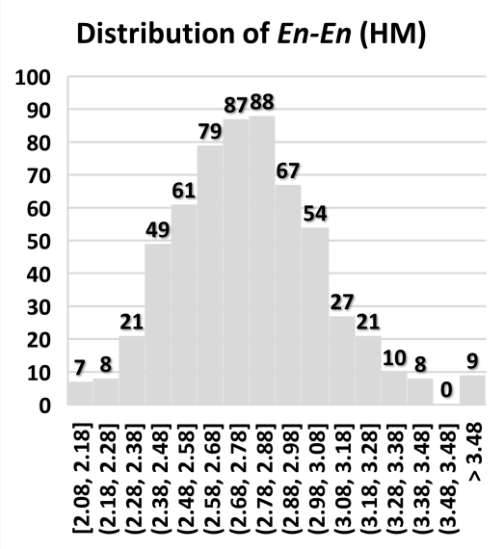
Distribution of *En-En* (HM)
100
90
80
70
60
50
40
30
20
10
0
7
8
21
49
61
79
87 88
67
54
27
21
10
8
0
9
[2.08, 2.18]
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(2.28, 2.38]
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(2.98, 3.08]
(3.08, 3.18]
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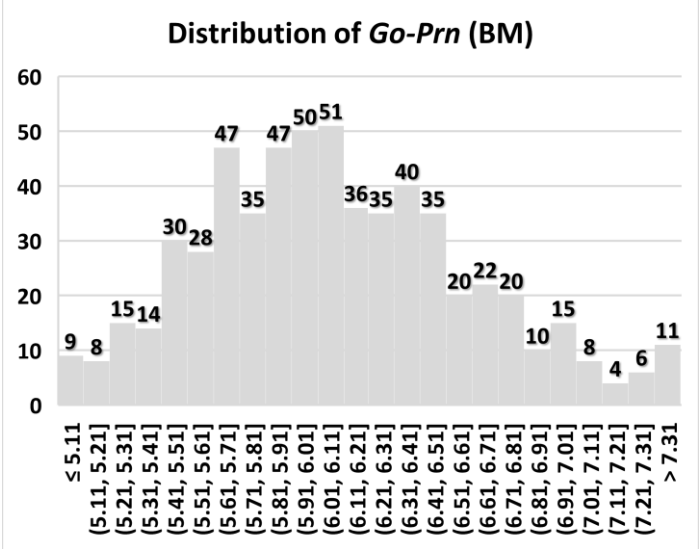
(3.28, 3.38]
(3.38, 3.48]
(3.48, 3.48]
> 3.48


Distribution of *Go-Prn* (BM)
60
50
40
30
20
10
0
9
8
15
14
30
28
47
35
47
50
51
36
35
40
35
20
22
20
10
15
8
4
6
11
≤ 5.11
(5.11, 5.21]
(5.21, 5.31]
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(6.01, 6.11]
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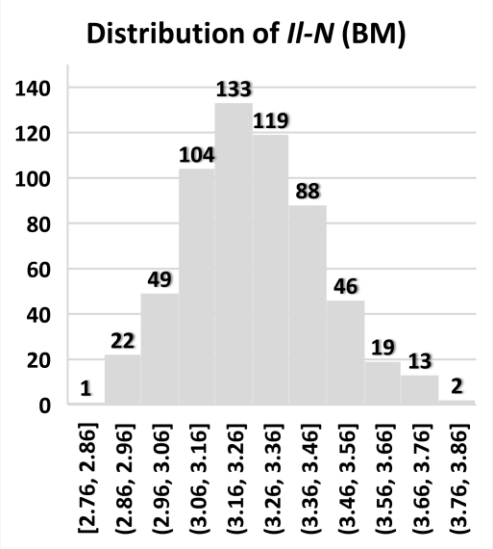
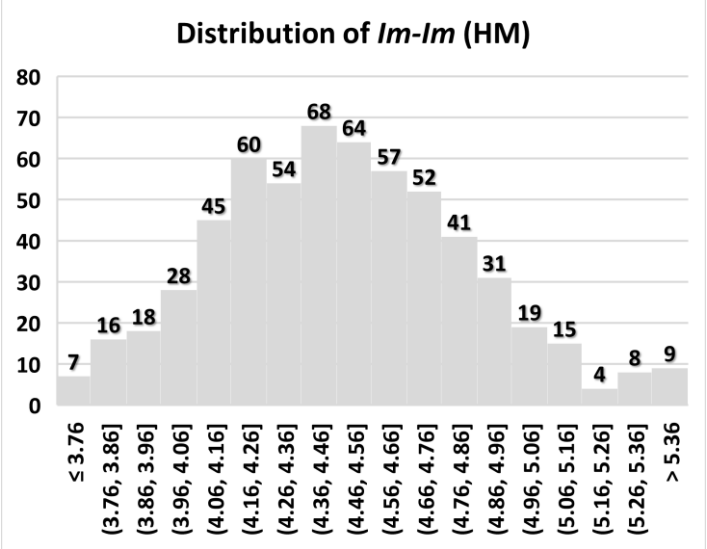
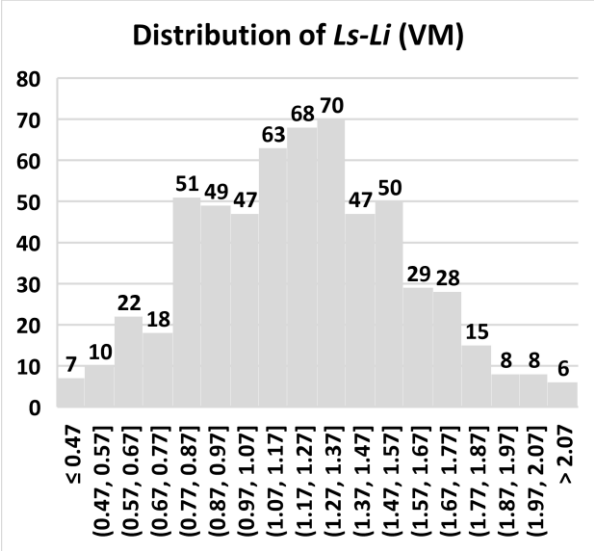
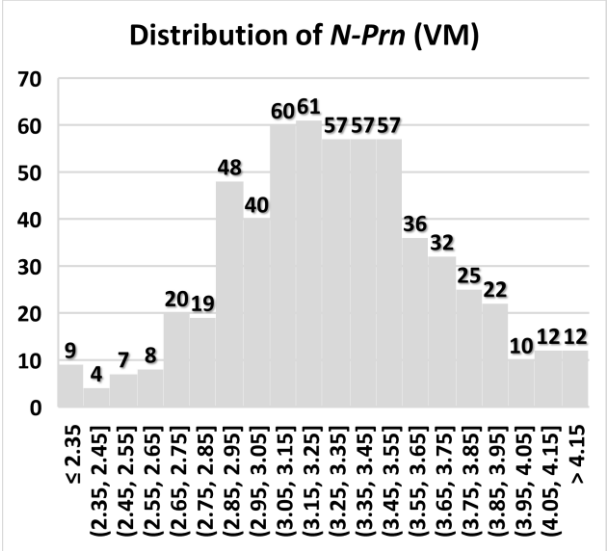
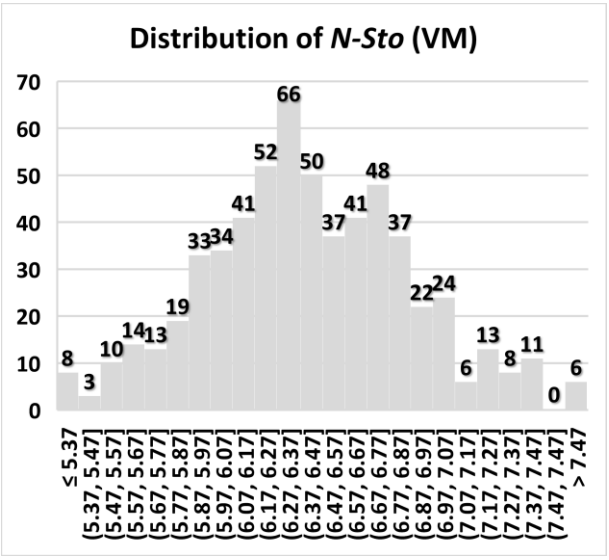
(6.91, 7.01]
(7.01, 7.11]
(7.11, 7.21]
(7.21, 7.31]
> 7.31

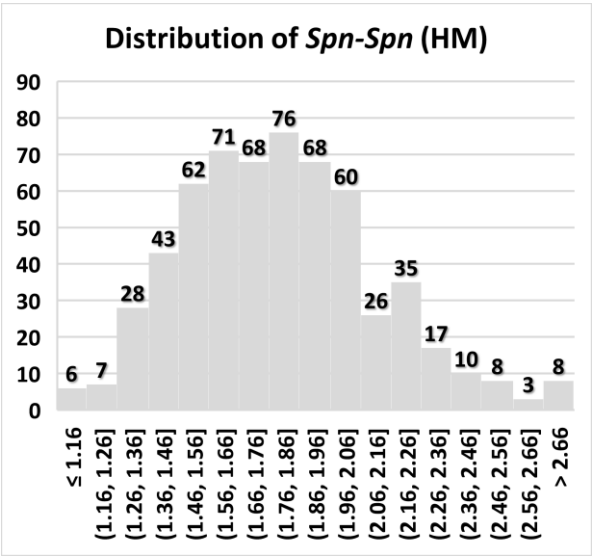

Distribution of *Il-N* (BM)
140
120
100
80
60
40
20
0
1
22
49
104
133
119
88
46
19
13
2
[2.76, 2.86]
(2.86, 2.96]
(2.96, 3.06]
(3.06, 3.16]
(3.16, 3.26]
(3.26, 3.36]
(3.36, 3.46]
(3.46, 3.56]
(3.56, 3.66]
(3.66, 3.76]
(3.76, 3.86]


Distribution of *Im-Im* (HM)
80
70
60
50
40
30
20
10
0
7
16
18
28
45
60
54
68
64
57
52
41
31
19
15
4
8
9
≤ 3.76
(3.76, 3.86]
(3.86, 3.96]
(3.96, 4.06]
(4.06, 4.16]
(4.16, 4.26]
(4.26, 4.36]
(4.36, 4.46]
(4.46, 4.56]
(4.56, 4.66]
(4.66, 4.76]
(4.76, 4.86]
(4.86, 4.96]
(4.96, 5.06]
(5.06, 5.16]
(5.16, 5.26]
(5.26, 5.36]
> 5.36

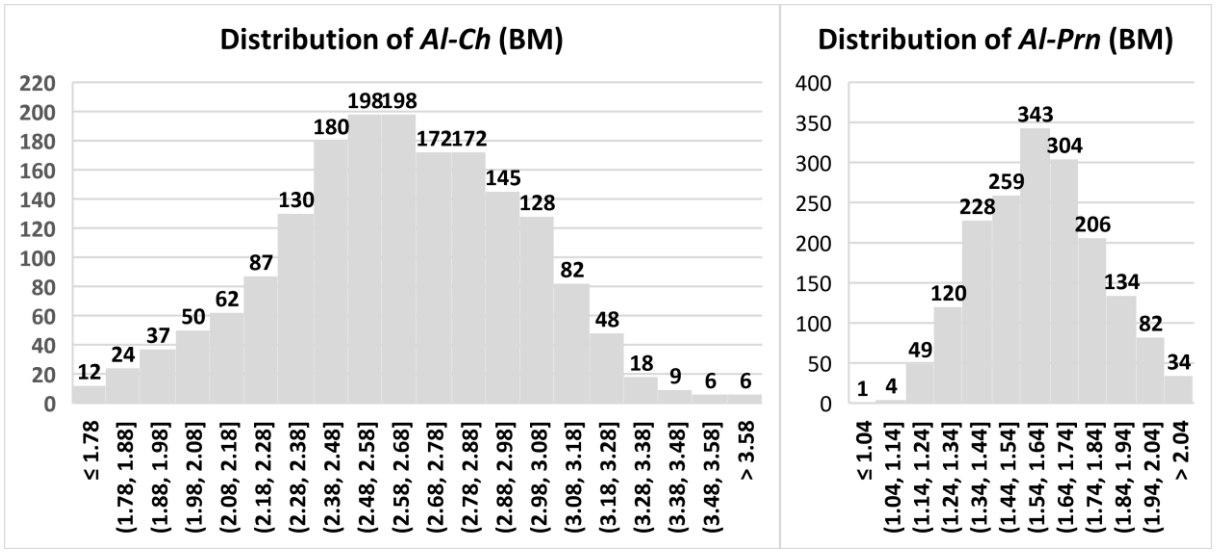

Distribution of *Ls-Li* (VM)
80
70
60
50
40
30
20
10
0
7
10
22
18
51
49
47
63
68
70
47
50
29
28
15
8
8
6
≤ 0.47
(0.47, 0.57]
(0.57, 0.67]
(0.67, 0.77]
(0.77, 0.87]
(0.87, 0.97]
(0.97, 1.07]
(1.07, 1.17]
(1.17, 1.27]
(1.27, 1.37]
(1.37, 1.47]
(1.47, 1.57]
(1.57, 1.67]
(1.67, 1.77]
(1.77, 1.87]
(1.87, 1.97]
(1.97, 2.07]
> 2.07

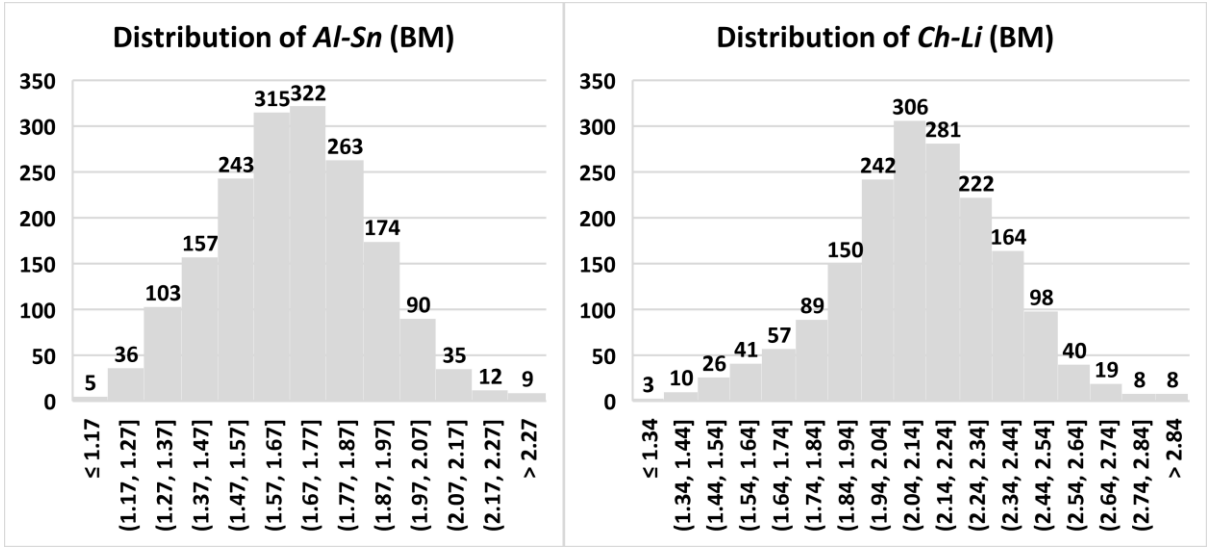

Distribution of *N-Prn* (VM)
70
60
50
40
30
20
10
0
9
4
7
8
20
19
48
40
60
61
57
57
57
36
32
25
22
10
12
12
≤ 2.35
(2.35, 2.45]
(2.45, 2.55]
(2.55, 2.65]
(2.65, 2.75]
(2.75, 2.85]
(2.85, 2.95]
(2.95, 3.05]
(3.05, 3.15]
(3.15, 3.25]
(3.25, 3.35]
(3.35, 3.45]
(3.45, 3.55]
(3.55, 3.65]
(3.65, 3.75]
(3.75, 3.85]
(3.85, 3.95]
(3.95, 4.05]
(4.05, 4.15]
> 4.15

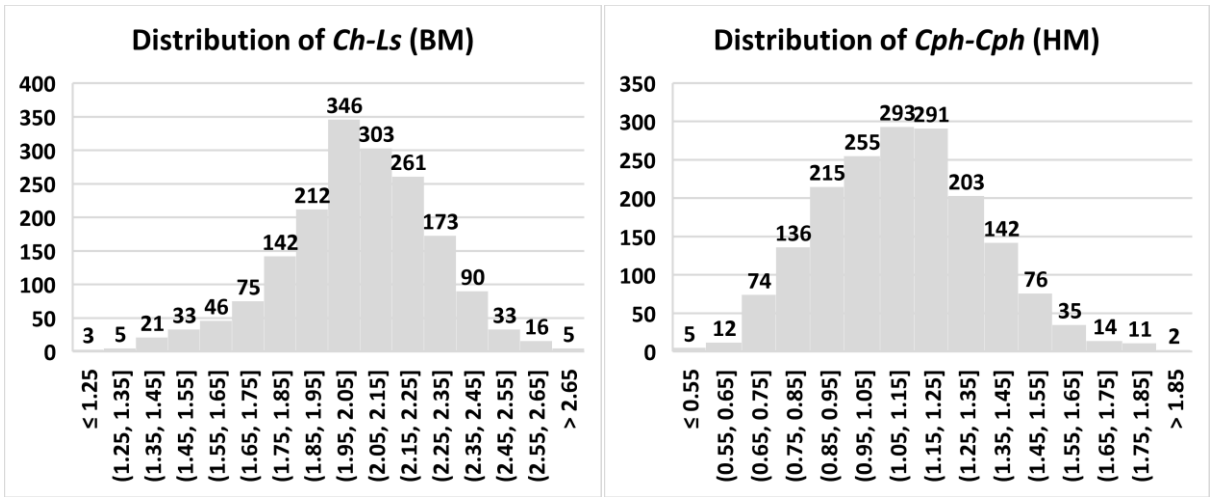

Distribution of *N-Sto* (VM)
70
60
50
40
30
20
10
0
8
3
10
14
13
19
33
34
41
52
66
50
37
41
48
37
22
24
6
13
8
11
0
6
≤ 5.37
(5.37, 5.47]
(5.47, 5.57]
(5.57, 5.67]
(5.67, 5.77]
(5.77, 5.87]
(5.87, 5.97]
(5.97, 6.07]
(6.07, 6.17]
(6.17, 6.27]
(6.27, 6.37]
(6.37, 6.47]
(6.47, 6.57]
(6.57, 6.67]
(6.67, 6.77]
(6.77, 6.87]
(6.87, 6.97]
(6.97, 7.07]
(7.07, 7.17]
(7.17, 7.27]
(7.27, 7.37]
(7.37, 7.47]
(7.47, 7.47]
> 7.47

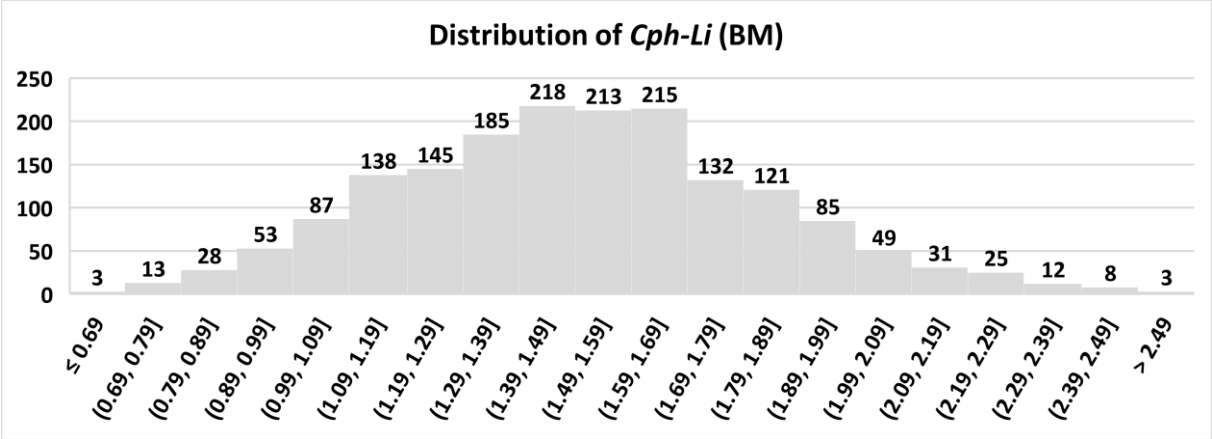

Distribution of *Spn-Spn* (HM)
90
80
70
60
50
40
30
20
10
0
6
7
28
43
62
71
68
76
68
60
26
35
17
10
8
3
8
≤ 1.16
(1.16, 1.26]
(1.26, 1.36]
(1.36, 1.46]
(1.46, 1.56]
(1.56, 1.66]
(1.66, 1.76]
(1.76, 1.86]
(1.86, 1.96]
(1.96, 2.06]
(2.06, 2.16]
(2.16, 2.26]
(2.26, 2.36]
(2.36, 2.46]
(2.46, 2.56]
(2.56, 2.66]
> 2.66

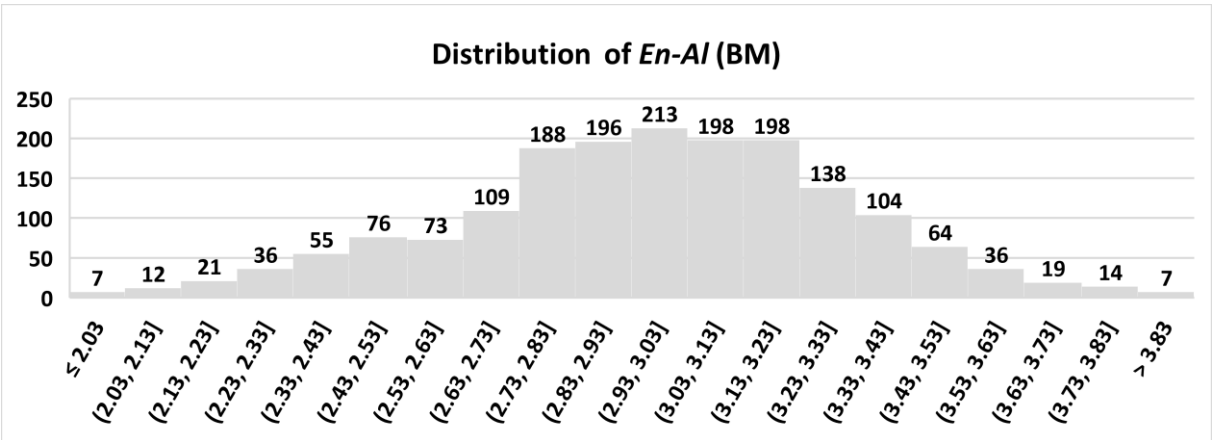
APPENDIX D – Distribution of selected FPA measures (Euclidean distances) within MZT in ranges of 0.10 (n=1764). All sources prepared by the author.

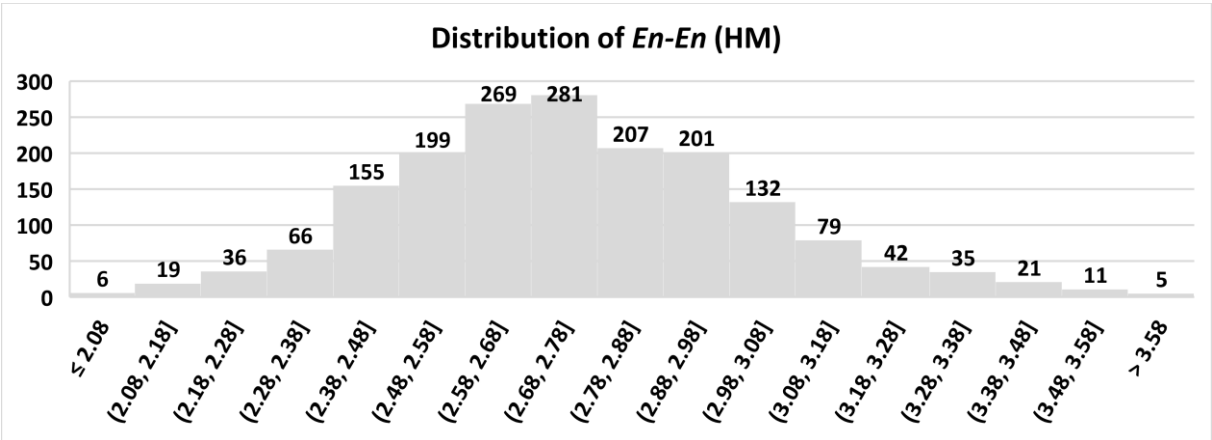


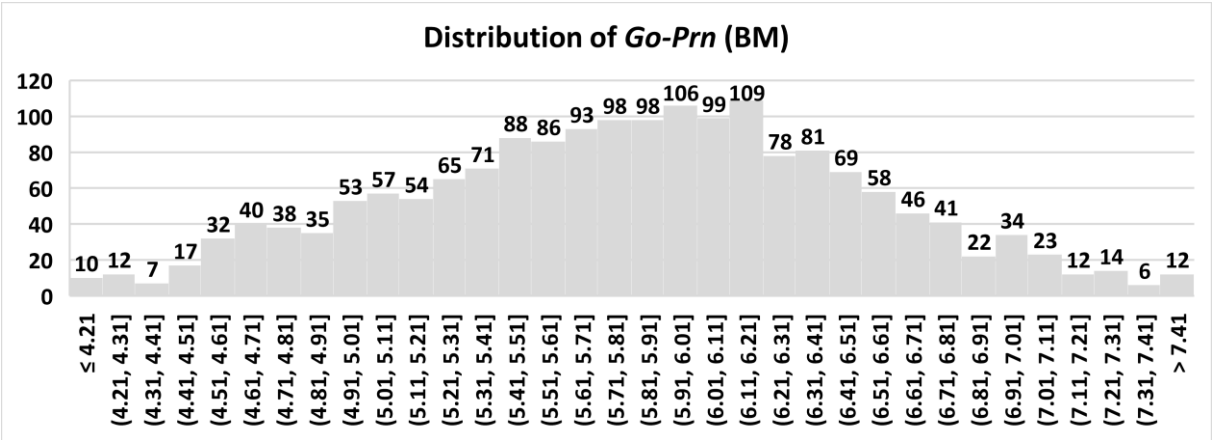


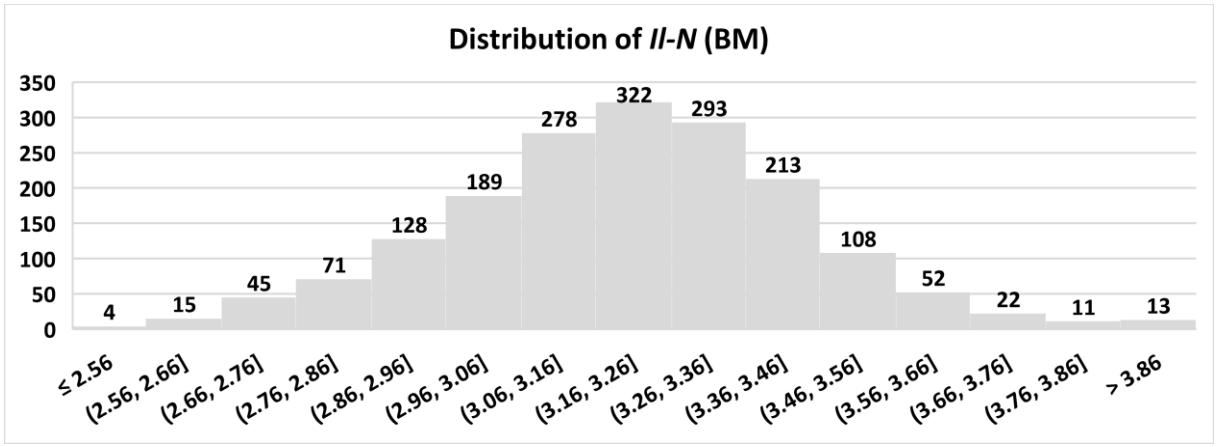


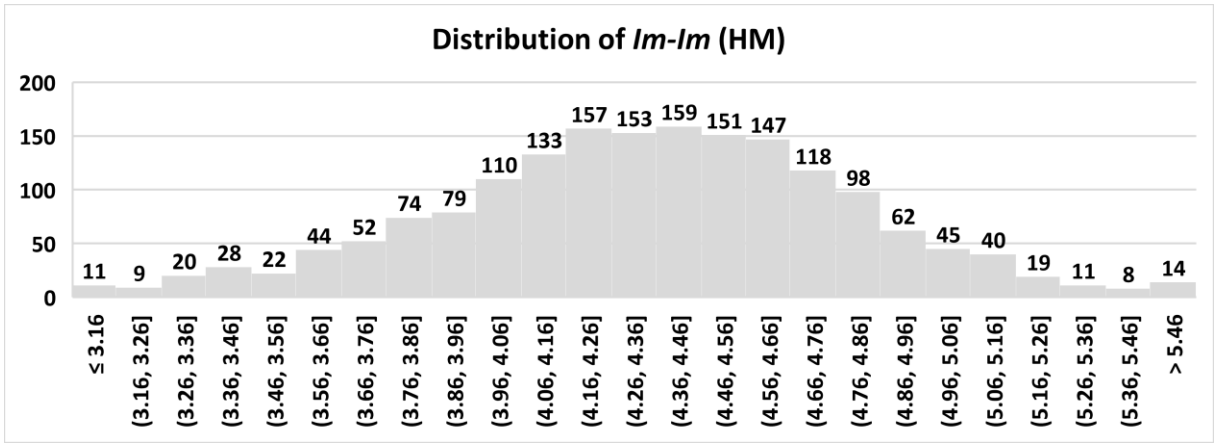

Distribution of *Cph-Li* (BM)
250
200
150
100
50
0
3 13 28 53 87 138 145 185 218 213 215 132 121 85 49 31 25 12 8 3
≤ 0.69
(0.69, 0.79]
(0.79, 0.89]
(0.89, 0.99]
(0.99, 1.09]
(1.09, 1.19]
(1.19, 1.29]
(1.29, 1.39]
(1.39, 1.49]
(1.49, 1.59]
(1.59, 1.69]
(1.69, 1.79]
(1.79, 1.89]
(1.89, 1.99]
(1.99, 2.09]
(2.09, 2.19]
(2.19, 2.29]
(2.29, 2.39]
(2.39, 2.49]
> 2.49

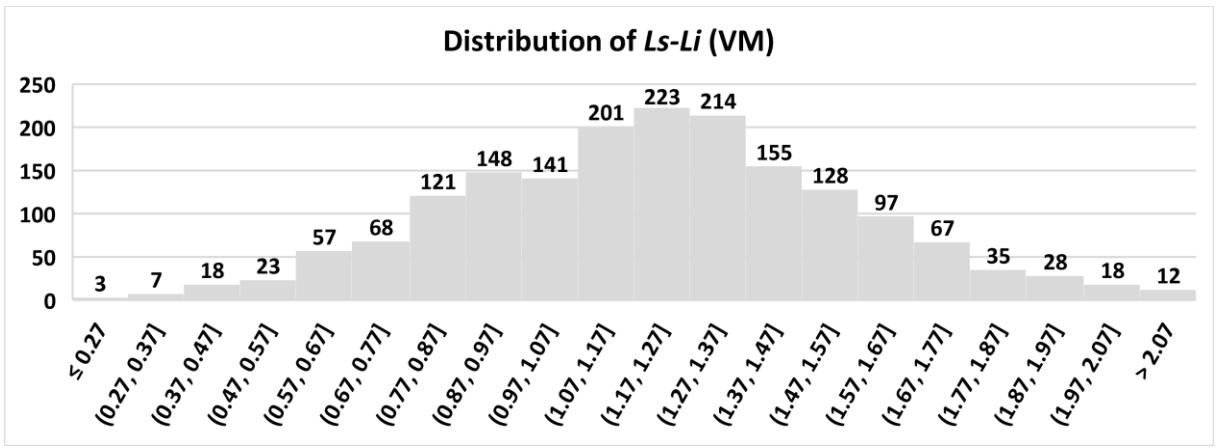

Distribution of *En-Al* (BM)
250
200
150
100
50
0
7 12 21 36 55 76 73 109 188 196 213 198 198 138 104 64 36 19 14 7
≤ 2.03
(2.03, 2.13]
(2.13, 2.23]
(2.23, 2.33]
(2.33, 2.43]
(2.43, 2.53]
(2.53, 2.63]
(2.63, 2.73]
(2.73, 2.83]
(2.83, 2.93]
(2.93, 3.03]
(3.03, 3.13]
(3.13, 3.23]
(3.23, 3.33]
(3.33, 3.43]
(3.43, 3.53]
(3.53, 3.63]
(3.63, 3.73]
(3.73, 3.83]
> 3.83

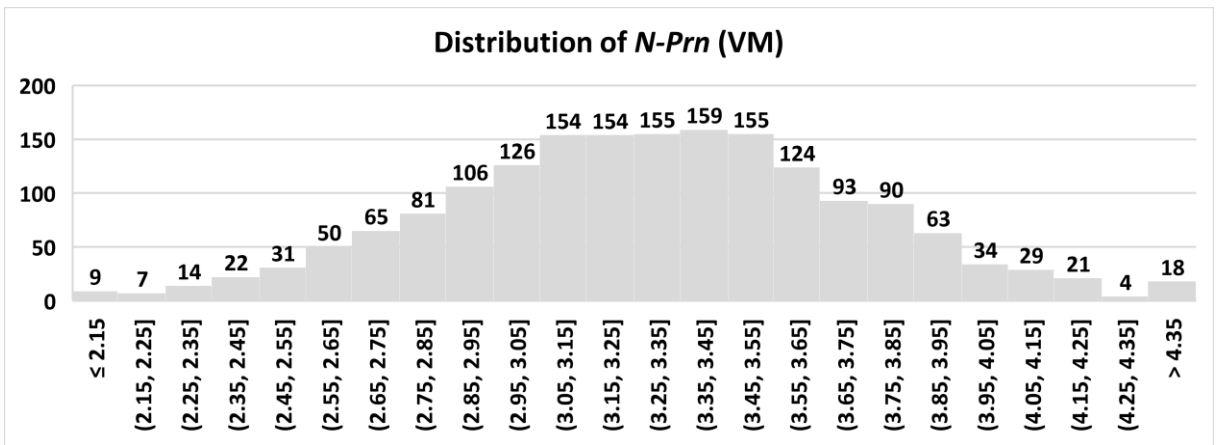

Distribution of *En-En* (HM)
300
250
200
150
100
50
0
6 19 36 66 155 199 269 281 207 201 132 79 42 35 21 11 5
≤ 2.08
(2.08, 2.18]
(2.18, 2.28]
(2.28, 2.38]
(2.38, 2.48]
(2.48, 2.58]
(2.58, 2.68]
(2.68, 2.78]
(2.78, 2.88]
(2.88, 2.98]
(2.98, 3.08]
(3.08, 3.18]
(3.18, 3.28]
(3.28, 3.38]
(3.38, 3.48]
(3.48, 3.58]
> 3.58

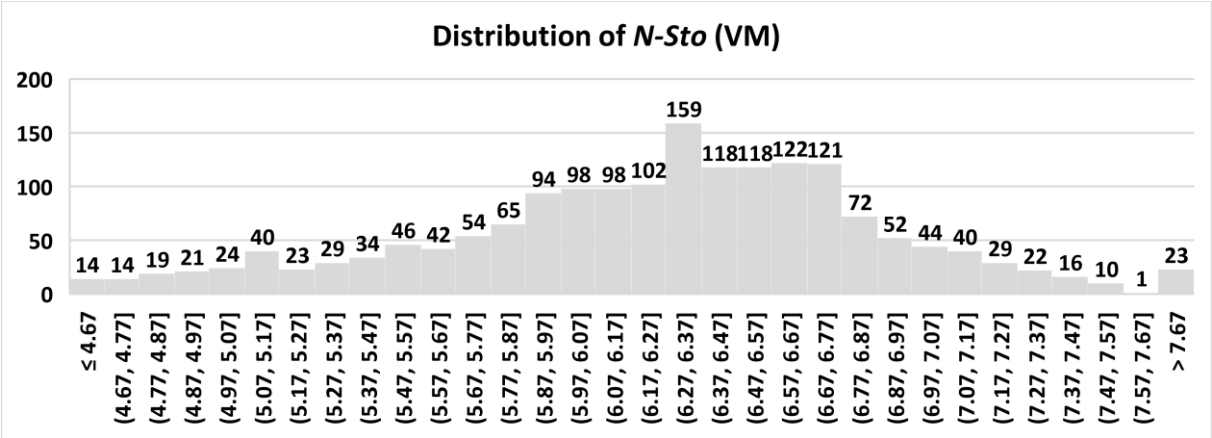

Distribution of *Go-Prn* (BM)
120
100
80
60
40
20
0
10 12 7 17 32 40 38 35 53 57 54 65 71 88 86 93 98 98 106 99 109 78 81 69 58 46 41 22 34 23 12 14 6 12
≤ 4.21
(4.21, 4.31]
(4.31, 4.41]
(4.41, 4.51]
(4.51, 4.61]
(4.61, 4.71]
(4.71, 4.81]
(4.81, 4.91]
(4.91, 5.01]
(5.01, 5.11]
(5.11, 5.21]
(5.21, 5.31]
(5.31, 5.41]
(5.41, 5.51]
(5.51, 5.61]
(5.61, 5.71]
(5.71, 5.81]
(5.81, 5.91]
(5.91, 6.01]
(6.01, 6.11]
(6.11, 6.21]
(6.21, 6.31]
(6.31, 6.41]
(6.41, 6.51]
(6.51, 6.61]
(6.61, 6.71]
(6.71, 6.81]
(6.81, 6.91]
(6.91, 7.01]
(7.01, 7.11]
(7.11, 7.21]
(7.21, 7.31]
(7.31, 7.41]
> 7.41

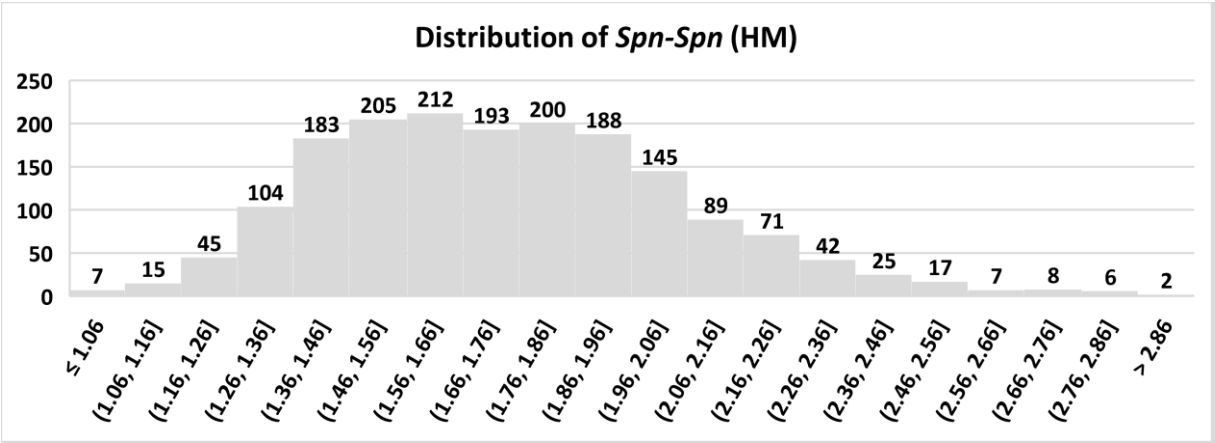

Distribution of *Il-N* (BM)
350
300
250
200
150
100
50
0
4
15
45
71
128
189
278
322
293
213
108
52
22
11
13
≤ 2.56
(2.56, 2.66]
(2.66, 2.76]
(2.76, 2.86]
(2.86, 2.96]
(2.96, 3.06]
(3.06, 3.16]
(3.16, 3.26]
(3.26, 3.36]
(3.36, 3.46]
(3.46, 3.56]
(3.56, 3.66]
(3.66, 3.76]
(3.76, 3.86]
> 3.86


Distribution of *Im-Im* (HM)
200
150
100
50
0
11
9
20
28
22
44
52
74
79
110
133
157
153
159
151
147
118
98
62
45
40
19
11
8
14
≤ 3.16
(3.16, 3.26]
(3.26, 3.36]
(3.36, 3.46]
(3.46, 3.56]
(3.56, 3.66]
(3.66, 3.76]
(3.76, 3.86]
(3.86, 3.96]
(3.96, 4.06]
(4.06, 4.16]
(4.16, 4.26]
(4.26, 4.36]
(4.36, 4.46]
(4.46, 4.56]
(4.56, 4.66]
(4.66, 4.76]
(4.76, 4.86]
(4.86, 4.96]
(4.96, 5.06]
(5.06, 5.16]
(5.16, 5.26]
(5.26, 5.36]
(5.36, 5.46]
> 5.46


Distribution of *Ls-Li* (VM)
250
200
150
100
50
0
3
7
18
23
57
68
121
148
141
201
223
214
155
128
97
67
35
28
18
12
≤ 0.27
(0.27, 0.37]
(0.37, 0.47]
(0.47, 0.57]
(0.57, 0.67]
(0.67, 0.77]
(0.77, 0.87]
(0.87, 0.97]
(0.97, 1.07]
(1.07, 1.17]
(1.17, 1.27]
(1.27, 1.37]
(1.37, 1.47]
(1.47, 1.57]
(1.57, 1.67]
(1.67, 1.77]
(1.77, 1.87]
(1.87, 1.97]
(1.97, 2.07]
> 2.07


Distribution of *N-Prn* (VM)
200
150
100
50
0
9
7
14
22
31
50
65
81
106
126
154
154
155
159
155
124
93
90
63
34
29
21
4
18
≤ 2.15
(2.15, 2.25]
(2.25, 2.35]
(2.35, 2.45]
(2.45, 2.55]
(2.55, 2.65]
(2.65, 2.75]
(2.75, 2.85]
(2.85, 2.95]
(2.95, 3.05]
(3.05, 3.15]
(3.15, 3.25]
(3.25, 3.35]
(3.35, 3.45]
(3.45, 3.55]
(3.55, 3.65]
(3.65, 3.75]
(3.75, 3.85]
(3.85, 3.95]
(3.95, 4.05]
(4.05, 4.15]
(4.15, 4.25]
(4.25, 4.35]
> 4.35


Distribution of *N-Sto* (VM)
200
150
100
50
0
14 14 19 21 24 40 23 29 34 46 42 54 65 94 98 98 102 159 118 118 122 121 72 52 44 40 29 22 16 10 1 23
≤ 4.67
(4.67, 4.77]
(4.77, 4.87]
(4.87, 4.97]
(4.97, 5.07]
(5.07, 5.17]
(5.17, 5.27]
(5.27, 5.37]
(5.37, 5.47]
(5.47, 5.57]
(5.57, 5.67]
(5.67, 5.77]
(5.77, 5.87]
(5.87, 5.97]
(5.97, 6.07]
(6.07, 6.17]
(6.17, 6.27]
(6.27, 6.37]
(6.37, 6.47]
(6.47, 6.57]
(6.57, 6.67]
(6.67, 6.77]
(6.77, 6.87]
(6.87, 6.97]
(6.97, 7.07]
(7.07, 7.17]
(7.17, 7.27]
(7.27, 7.37]
(7.37, 7.47]
(7.47, 7.57]
(7.57, 7.67]
> 7.67


Distribution of *Spn-Spn* (HM)
250
200
150
100
50
0
7 15 45 104 183 205 212 193 200 188 145 89 71 42 25 17 7 8 6 2
≤ 1.06
(1.06, 1.16]
(1.16, 1.26]
(1.26, 1.36]
(1.36, 1.46]
(1.46, 1.56]
(1.56, 1.66]
(1.66, 1.76]
(1.76, 1.86]
(1.86, 1.96]
(1.96, 2.06]
(2.06, 2.16]
(2.16, 2.26]
(2.26, 2.36]
(2.36, 2.46]
(2.46, 2.56]
(2.56, 2.66]
(2.66, 2.76]
(2.76, 2.86]
> 2.86