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TECHNICAL NOTE

ANTHROPOLOGY

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Key Parameters of Face Shape Variation in 3D in a Large Sample*

ABSTRACT: Improvement of methods for evidential facial comparison for the Courts relies on the collection of large databases of facial images that permit the analysis of face shape variation and the development of statistical tools. In this paper, we present a short description and key findings of an anthropometric study of face shape variation in three-dimensions. We used Statistical Shape Analysis to investigate a large database sample (n = 1968), classified by age and gender. We found that size, shape of the bilateral features and midline contributed successively to overall variation. Face size is associated with age. Sexual dimorphism is evident in size and shape, and shows patterns that affect male and female subjects differently. We anticipate this approach will lend itself to the development of methods for analysis of variation within subject groups and the establishment of the relative uniqueness or abundance of facial measurements within them.

KEYWORDS: forensic science, facial comparison, biometrics, anthropometry, principal components analysis, shape analysis

In forensic science, the face is interesting from investigative and probative perspectives, including both recognition and identification. Biometric methods of facial recognition have been part of a plethora of computer science-based applications used in the verification of identity (1) and novel computerized techniques for the construction of facial composites have been developed (2).

New technology also offers a route to improve scientific methods for facial comparison for the Courts, where the development of both databases and statistical methods are important in ascertaining evidential value. Here, we present a short description and key findings of an anthropometric investigation of face shape variation in three-dimensions (3D) in a large sample, with the aim of developing methods for the analysis of variation within subject groups and the establishment of the relative uniqueness or abundance of specific facial measurements in various populations.

Methods

Stereophotogrammetry offers the potential for rapid and precise measurement of facial morphology in 3D in large samples. As part of a large multi-disciplinary collaboration and following ethical approval, we collected a database (3) of facial images of healthy volunteers using a Geometrix FaceVision® FV802 Biometric Camera (ALIVE Tech, Cumming, GA). Subjects in the database are predominantly—94.77%—of White ancestry (3). We used a software tool (ForensicAnalyzer®; ALIVE Tech) to locate the 3D coordinates of anthropometric landmarks with high precision. A set of 30 landmarks (Fig. 1 and Table 1) demonstrating most between-subject relative to within-subject variation was selected for the analysis of patterns of 3D face shape variation in a sample of 1968 individuals aged 14 years or over, classified by age and gender, of whom 1286 were landmarked in duplicate. We used Procrustes alignment to remove differences attributable to translation and rotation, to reveal underlying differences in size and shape (4). After Procrustes registration, principal components (PC) analysis of size and shape was carried out by eigen-decomposition of the sample covariance matrix. Centroid size (S) was used as the size measure. This is the square root of the sum of squared Euclidean distances from each landmark to the centroid. Procrustes shape distance (ρ) was used to measure the distance between shapes where position, rotation, and scale were ignored. Root mean square shape distance rms(ρ) was used to measure shape variability in the sample where location, rotation, and scale were again ignored—rms(ρ) is approximately equal to the root mean square distance of individual shapes to the overall mean shape after scaling to unit size and Procrustes registration (4).

Results and Discussion

PC analysis (Fig. 2) yields a first PC representing size. The second PC represents bilateral variation at the ears, eyes, nose, and mouth. The third PC represents variation in the sagittal plane of the midline and eye structures.

Mean size is greater in male than female subjects, and increases with age in both (Fig. 3 and Table 2; $\bar{S}_{\mathrm{M}}$ and $\bar{S}_{\mathrm{F}}$). Standard deviation in size (Table 2; $\mathrm{sd}(S)_{\mathrm{M}}$ and $\mathrm{sd}(S)_{\mathrm{F}}$) indicates that size

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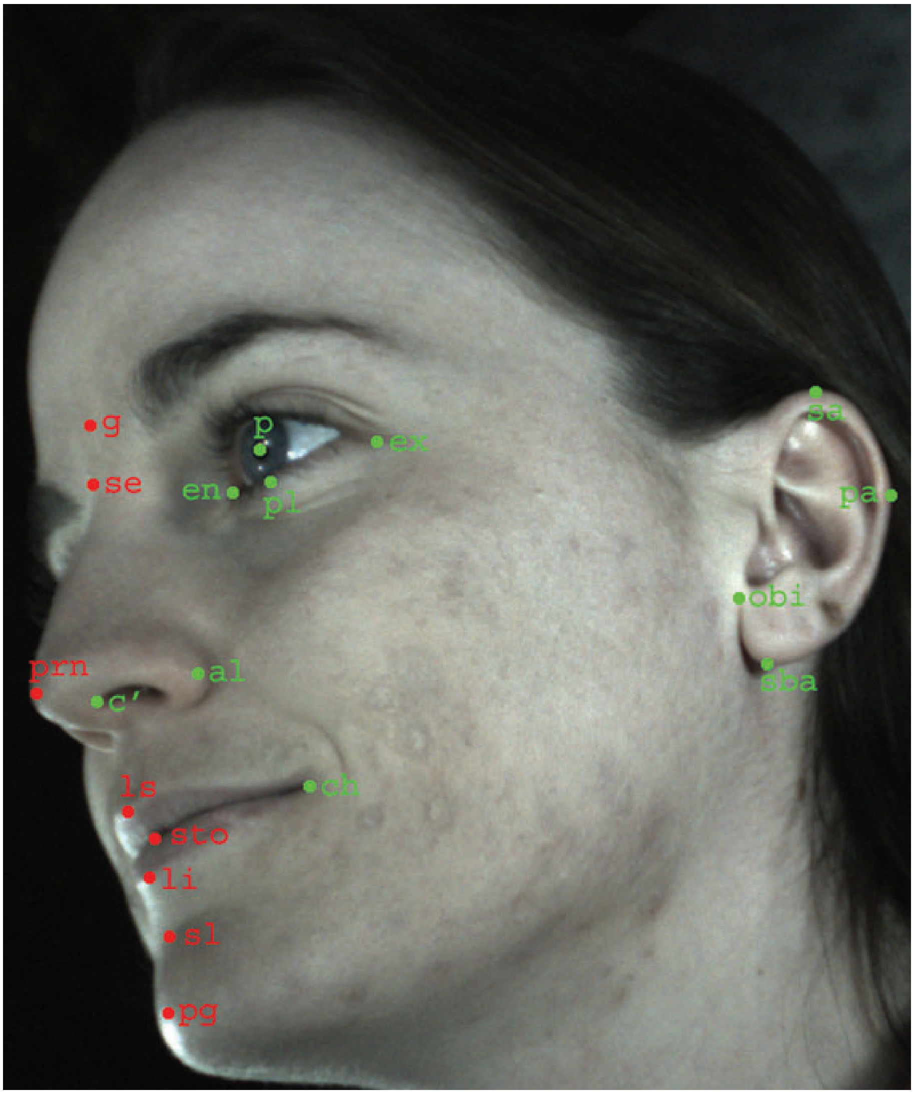

FIG. 1—*Illustration of the 30 landmark sites collected from volunteers using the Geometrix® FaceVision equipment (see Table 1). Bilateral landmarks are in green.*

TABLE 1—*List of the 30 landmarks used in the Geometrix® study and shown in Fig. 1.*

Label	Name	Description (see Farkas [12])
g	Glabella	The most prominent midline point between the eyebrows
sl	Sublabiale	Determines the lower border of the lower lip and upper border of the chin
pg	Pogonion	The most anterior midpoint of the chin
en	Endocanthion (l, r)	The point at the inner commissure of the eye fissure
ex	Exocanthion (l, r)	The point at the outer commissure of the eye fissure
p	Pupil (l, r)	Determined when the head is in the rest position and the eye is looking straight forward
pi	Palpebrale inferius (l, r)	The lowest point in the mid portion of the free margin of each lower eyelid
se	Sellion	The deepest landmark located in the bottom of the nasofrontal angle
prn	Pronasale	The most protruded point of the apex nasi
al	Alar (l, r)	The most lateral point on each alar contour
c'	Highest point of columella (l, r)	The point on each columella crest, level with the tip of the corresponding nostril
ls	Labiale superius	The midpoint of the upper vermillion line
li	Labiale inferius	The midpoint of the lower vermillion line
sto	Stomion	The imaginary point at the crossing of the vertical facial midline and the horizontal labial fissure between gently closed lips, with the teeth shut in the natural position
ch	Cheilion (l, r)	The point located at each labial commissure
sa	Superaurale (l, r)	The highest point on the free margin of the auricle
sba	Subaurale (l, r)	The lowest point on the free margin of the ear lobe
pa	Postaurale (l, r)	The most posterior point on the free margin of the ear
obi	Otobasion inferius (l, r)	The point of attachment of the ear lobe to the cheek

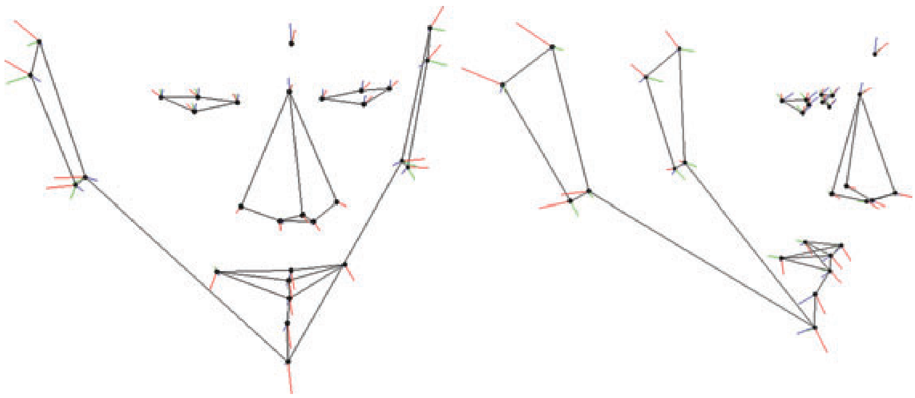

FIG. 2—*Principal components analysis of overall size and shape variation in 3254 landmarkings. Mean face: black; PC1: red; PC2: green; PC3: blue. Each vector is drawn to the configuration at the mean + 3 SD along each PC.*

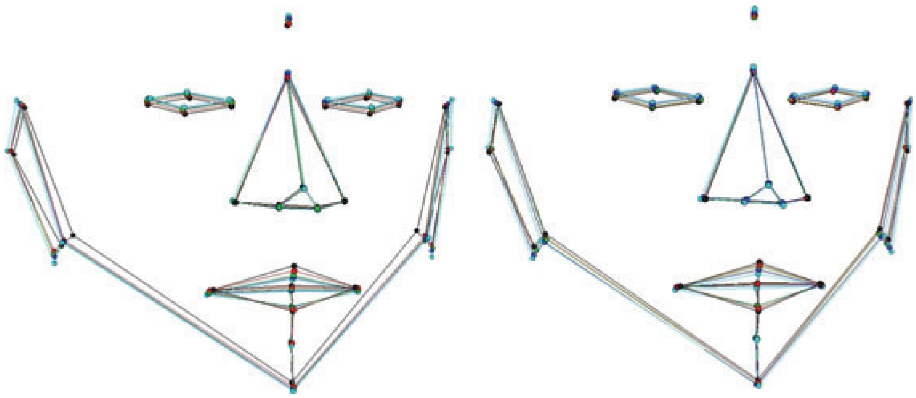

FIG. 3—*Procrustes mean face in male subjects (left) and female subjects (right) of different age groups. 15–24: black; 25–34: red; 35–44: green; 45–54: blue; 55+: cyan.*

TABLE 2—*Summary statistics by age group.*

Age (years)	n_M	n_F	$\overline{S}_M$	sd$(S)_M$	$\overline{S}_F$	sd$(S)_F$	$\rho(\hat{\mu}_M, \hat{\mu}_F)$	rms$(\rho)_M$	rms$(\rho)_F$
15–24	260	174	402.4	13.6	381.5	10.8	0.016	0.065	0.065
25–34	448	229	412.4	12.5	383.3	12.2	0.020	0.068	0.064
35–44	979	362	415.6	11.9	382.9	11.5	0.020	0.065	0.065
45–54	353	118	415.2	12.6	385.8	12.1	0.024	0.068	0.066
55+	254	77	417.1	12.4	389.2	9.2	0.021	0.071	0.066

n, number of landmarkings; $\overline{S}$, mean centroid size; sd(S), standard deviation; $\rho(\hat{\mu}_M, \hat{\mu}_F)$, Procrustes shape distance between means; rms(ρ), root mean squared shape distance; subscript M, male; F, female.

variability is similar irrespective of sex and age group, although female subjects are a little less variable in the 15–24 and 55+ groups, and male subjects are more variable in the 15–24 group. The distance between the mean shapes of male and female subjects (Table 2; $\rho(\hat{\mu}_M, \hat{\mu}_F)$) is least in the 15–24 groups. Root mean square shape distances (Table 2; rms$(\rho)_M$ and rms$(\rho)_F$) indicates little difference in overall shape variability between genders and age groups. Examination of the facial features (Figs. 3 and 4) shows a relative increase in size in the ears and the mental eminence—or chin—with age in both genders, whereas the lips become narrower in height and wider with increasing age.

Anthropometric methods of forensic facial comparison are the subject of investigation by a number of authors (5–10). Knowledge of size and shape variation in faces related to age and gender offer potential means of subdividing or intelligently searching large biometric databases, and of developing an empirical model of face shape variation for use in forensic facial comparison. Both scientific investigations and Court judgments have been alert to the requirement for databases. Without them, as one attorney observed (11), "it is impossible to know how many others may look the same as a particular accused."

Recognizing the requirement for a database and for statistical analysis, Mardia et al. (5) completed an analysis of a database (the VIAS database) consisting of the landmarked anterior and lateral profile photographic images of 358 individuals. These authors also employed PC analysis, which revealed high correlations between certain measurements. Their analysis was in 2D, however, and—although some correspondence may be evident—is not directly intercomparable with our own. Furthermore, given that the VIAS sample consisted entirely of young White male subjects, no analysis by age and gender could be undertaken. These authors concluded that investigation of face shape variation within subject groups—at least by age, gender, ancestry—will be essential, and that it will be necessary to discover the relative uniqueness or abundance of various facial features, perhaps by combining 2D anterior and profile data.

We anticipate that by collecting a database of 3D measurements categorized by age, gender, and ancestry (3), we have gone some way in furthering these prescient goals and that in identifying the key parameters of face shape variation in 3D presented here, we have detected candidate areas of relative uniqueness or abundance in variation. Furthermore, our database—subject to ethical and law-

FIG. 4—*Procrustes mean faces registered by rotation and translation, with (right) and without (left) scaling, in male subjects (black) and female subjects (red) of different age groups.*

enforcement related considerations—is freely available to other researchers in crime prevention and detection.

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