Towards a method for determining age ranges from faces of juveniles on photographs

M. Cummaudo [a], M. Guerzoni [a], D. Gibelli [a,d], A. Cigada [b], Z. Obertovà [c], M. Ratnayake [c], P. Poppa [a], P. Gabriel [c], S. Ritz-Timme [c], C. Cattaneo [a,c,*]

[a] LABANOF, Laboratorio di Antropologia e Odontologia Forense, Sezione di Medicina Legale, Dipartimento di Scienze Biomediche per la Salute, Università degli Studi di Milano, Italy

[b] Dipartimento di Meccanica, Sezione Misure Meccaniche e Termiche, Politecnico di Milano, Italy

[c] Institut für Rechtsmedizin, Universitätsklinikum Düsseldorf, Moorenstraße 5, 40225 Düsseldorf, Germany

[d] SVSeD, Soccorso Violenza Sessuale e Domestica, Fondazione IRCCS Cà Granda, Ospedale Maggiore Policlinico di Milano, Milan, Italy

Received 8 February 2013
Received in revised form 27 January 2014
Accepted 29 January 2014
Available online 12 February 2014

1. Introduction

In recent years a steady increase in the distribution of child pornography material has been observed, due to the ease with which it can be exchanged through the web [1]. Various institutions and non-profit organizations (www.savethechildren.it; www.stop-it.org) estimated that between 2002 and 2004 there had been an increase of 93% of sites representing pedo-pornographic images in Italy. Likewise in Germany the number of websites with pedo-pornographic contents had increased by 94% between 2006 and 2007 [2], reflecting a common trend in many other countries.

For this reason, the assessment of the victim's age on 2D material has a crucial role for ascertaining the crime of child pornography. However, most experts still use the assessment of sexual characteristics for ageing even though this has proven to be too subjective and deceiving for age estimation [3–9].

Recently forensic experts have begun to assess the feasibility of using morphological parameters other than secondary sexual characteristics in order to estimate the age (or at least obtain an approximate age range) of an individual from 2D images [10–12]. In general, sexual morphological traits may prove useful when they are applied to pre-pubertal individuals; however, recent studies [3–5] have proven the inadequacy of the use of morphological

* Corresponding author at: LABANOF, Laboratorio di Antropologia e Odontologia Forense, Sezione di Medicina Legale, Dipartimento di Scienze Biomediche per la Salute, Università degli Studi di Milano, V. Mangiagalli 37, Milan, Italy.
Tel.: +39 02 50315679; fax: +39 02 50315724.
E-mail address: cristina.cattaneo@unimi.it (C. Cattaneo).

Table 1
Distribution of subjects taking part in the study within different age ranges: number of images in frontal and lateral view included in the experiment divided between males and females and according to different age ranges.

Age class	Frontal view		Lateral view	
	No. of males	No. of females	No. of males	No. of females
3–5 years	92	64	92	62
6–8 years	20	21	20	21
9–11 years	86	98	86	98
12–14 years	261	154	261	155
15–17 years	163	119	164	117
18–20 years	211	416	210	417
21–24 years	27	192	28	191
Total	860	1064	861	1061

parameters as valid criteria to evaluate suspect juvenile pornographic material in the pubertal and post-pubertal stage. In addition to the variability between populations [13–15], individual biology, environmental and pathological factors such as obesity [16–18] lead to a great inter-individual variability in sexual maturation.

Therefore at the present stage there is a lack of scientifically valid methods to determine the age of a person from 2D images, but recent studies [19,20] concerning a possible correlation between certain anthropometric indices of the face and the age of an individual have shown some potential. Actually, the need to age children on photos can occur in other scenarios where one may have only the represented face, such as in the case of photographs of children who have gone missing or have been abducted.

The present study, inspired by a previous EU project involving Italy, Germany and Lithuania [19], aims at verifying whether it is possible to use certain anthropometric indices of the face of an individual to determine his or her age; this may provide a useful tool for assessing the age range of children depicted on 2D images in case of juvenile pornography, but also in cases of missing children issues or other instances of child maltreatment and abuse.

2. Materials and methods

The experimental study was based on 1924 standardized photographs in frontal view and 1921 in lateral view taken from Caucasoid subjects aged between 3 and 24 years without relevant pathologies and facial deformities (Table 1). For each subject, standardized photographs were taken at 1.5 m distance with the head of the person oriented according to the Frankfurt plane. The minimum acceptable photographic resolution was 640×480 pixels, although higher resolutions around 1000×700 pixels are recommended [21]. The photographs underwent analysis by software specifically developed at the Politecnico of Milano for this purpose, initially allowing the operators to place 22 landmarks on faces taken in the frontal view (Fig. 1a) and 11 in the lateral view [22] (Fig. 1b). The landmarks were identified according to the descriptions by Knussmann [23]. Landmarks which are easily and reliably found on photographs must be chosen; a recent study on the reliability of the positioning of facial landmarks on photographs has in fact confirmed that greater inaccuracy relates to the identification of zygion, gonion and frontotemporale in the frontal view images and pogonion, gnathion and praeaurale in the lateral view [24,25].

Of all indices, 18 were chosen in frontal view (al-al/ch-ch, al-al/se-sn, al-al/se-sto, ch-ch/ex-ex, ch-ch/ft-ft, ch-ch/pu-pu, en-en/ch-ch, en-en/se-sn, en-en/se-sto, pu-pu/se-sto, se-sn/ex-ex, se-sn/ft-ft, se-sn/pu-pu, se-sn/se-sto, se-sn/zy-zy, se-sto/ex-ex, se-sto/ft-ft, se-sto/zy-zy) and five in lateral view (prn-sn/se-sto, se-prn/se-sn, se-prn/se-sto, se-sn/se-sto, pra-pa/sa-sba). These indices were chosen on the basis of previous results obtained within the same research project relating to a pilot study on 6, 10, 14 and 18 year olds [19]. Each index was defined as the ratio between two linear measurements (for example, en-en/se-sn is the ratio between the distance endocanthion–endocanthion and the distance selion–subnasale). Indices were used instead of direct measurements in order to overcome the issue of possibly different distances from the camera since they are often unknown in real forensic cases. Subsequently, the correlation index (CI) of the indices with age was evaluated.

3. Results

After positioning facial landmarks on all the images in the available database and calculating distances between all of them, the obtained measurements were stored in matrices from which they could be retrieved for an automatic evaluation.

Results point out that 7 anthropometric indices show a correlation with age higher than 0.7, and in detail ch-ch/ex-ex, ch-ch/pu-pu, en-en/ch-ch and se-sto/ex-ex in frontal view (Figs. 2

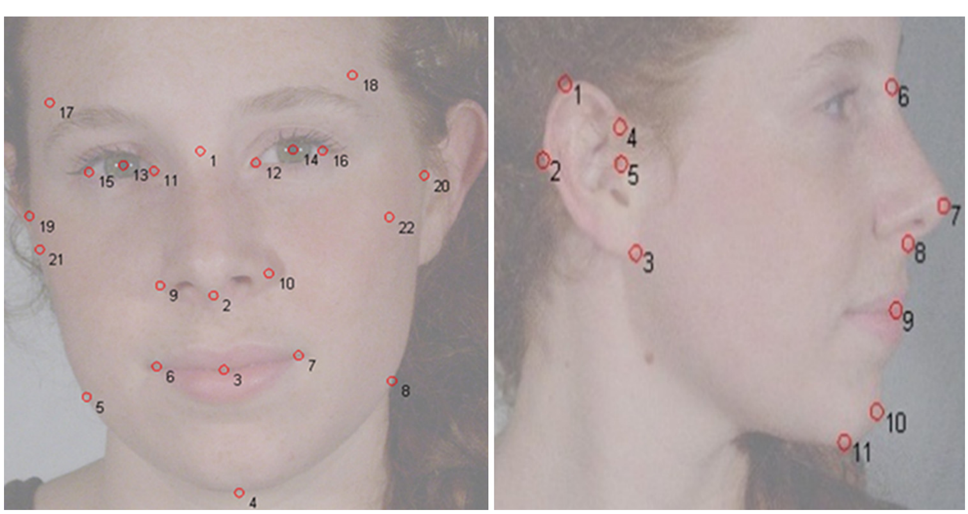

Fig. 1. Landmarks chosen for the experimental project: (a) 1 – Sellion (se); 2 – Subnasale (sn); 3 – Stomion (sto); 4 – Gnathion (gn); 5 and 8 – Gonion (go); 6 and 7 – Chelion (ch); 9 and 10 – Alare (al); 11 and 12 – Endocanthion (en); 13 and 14 – Pupillare (pu); 15 and 16 – Exocanthion (ex); 17 and 18 – Frontotemporale (ft); 19 and 20 – Tragion (t); 21 and 22 – Zygion (zy) and (b) 1 – Superaurale (sa); 2 – Postaurale (pa); 3 – Subaurale (sba); 4 – Preaurale (pra); 5 – Tragion (t); 6 – Selion (se); 7 – Pronasale (prn); 8 – Subnasale (sn); 9 – Stomion (sto); 10 – Pogonion (pg); 11 – Gnathion (gn).

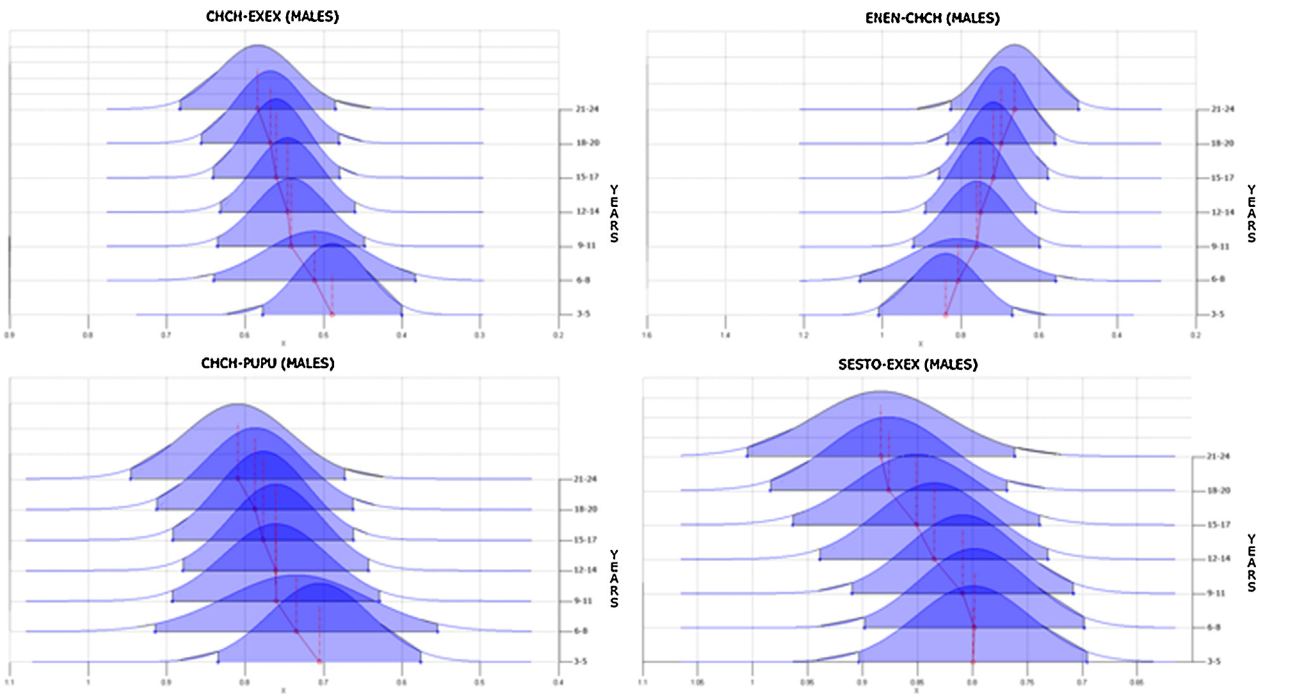

Fig. 2. Modification of facial indices taken in frontal view in males in the chosen age ranges: ch-ch/ex-ex: ratio between the distance chelion–chelion and exocanthion–exocanthion; en-en/ch-ch: ratio between the distance endocanthion–endocanthion and chelion–chelion; ch-ch/pu-pu: ratio between chelion–chelion and pupillare–pupillare; se-sto/ex-ex: ratio between distance selion–stomion and exocanthion–exocanthion; ch-ch/ex-ex, ch-ch/pu-pu and se-sto/ex-ex increase with age, whereas en-en/ch-ch decreases.

and 3), se-prn/se-sn, se-prn/se-sto and se-sn/se-sto in lateral view (Figs. 4 and 5).

In the frontal view, ch-ch/ex-ex showed a range between 0.489 in the 3–5 year age class and 0.584 in the 21–24 year class in males, between 0.493 and 0.584 in females; ch-ch/pu-pu was between 0.705 and 0.809 in males, between 0.709 and 0.799 in females. En-en/ch-ch was between 0.839 and 0.664 in males, between 0.843 and 0.722 in females; se-sto/ex-ex was included

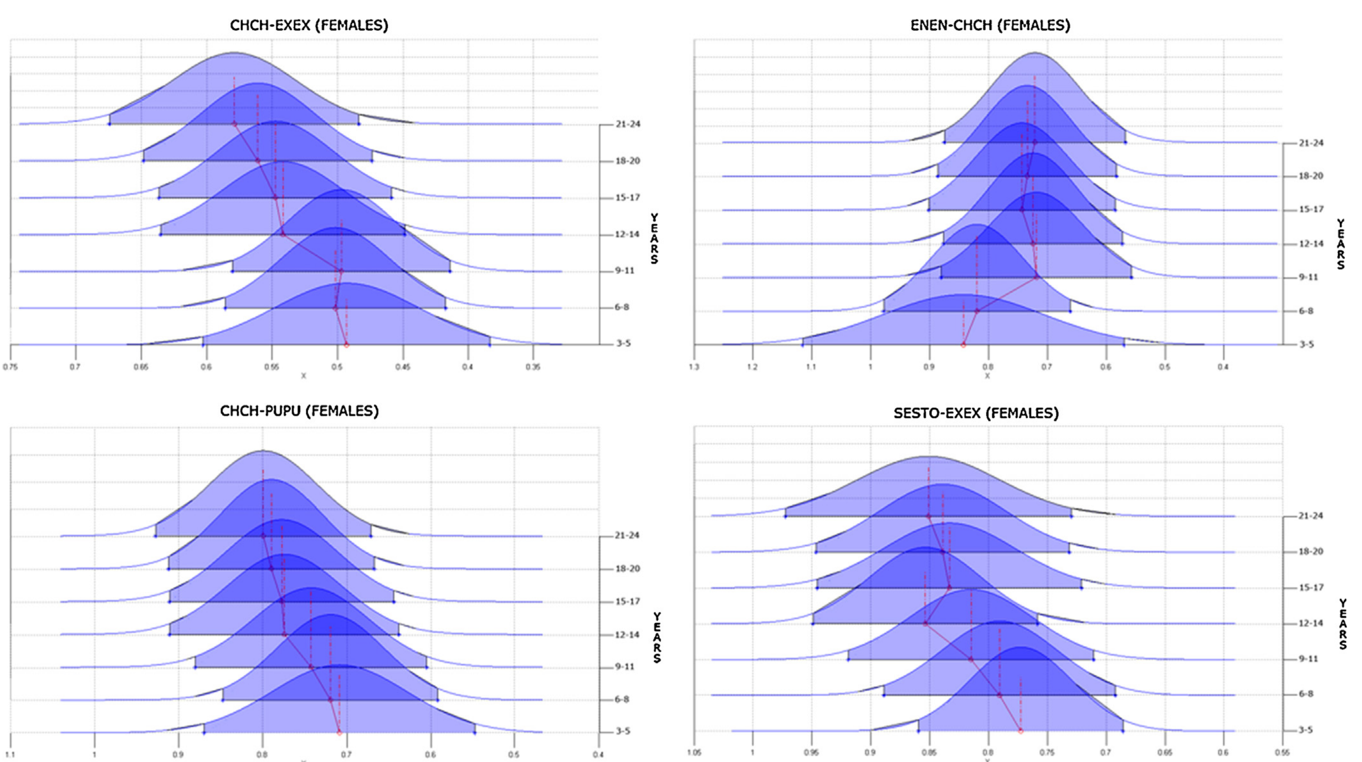

Fig. 3. Modification of facial indices taken in frontal view in females in the chosen age ranges: ch-ch/ex-ex: ratio between the distance chelion–chelion and exocanthion–exocanthion; en-en/ch-ch: ratio between the distance endocanthion–endocanthion and chelion–chelion; ch-ch/pu-pu: ratio between chelion–chelion and pupillare–pupillare; se-sto/ex-ex: ratio between distance selion–stomion and exocanthion–exocanthion; ch-ch/ex-ex, ch-ch/pu-pu and se-sto/ex-ex increase with age, whereas en-en/ch-ch decreases.

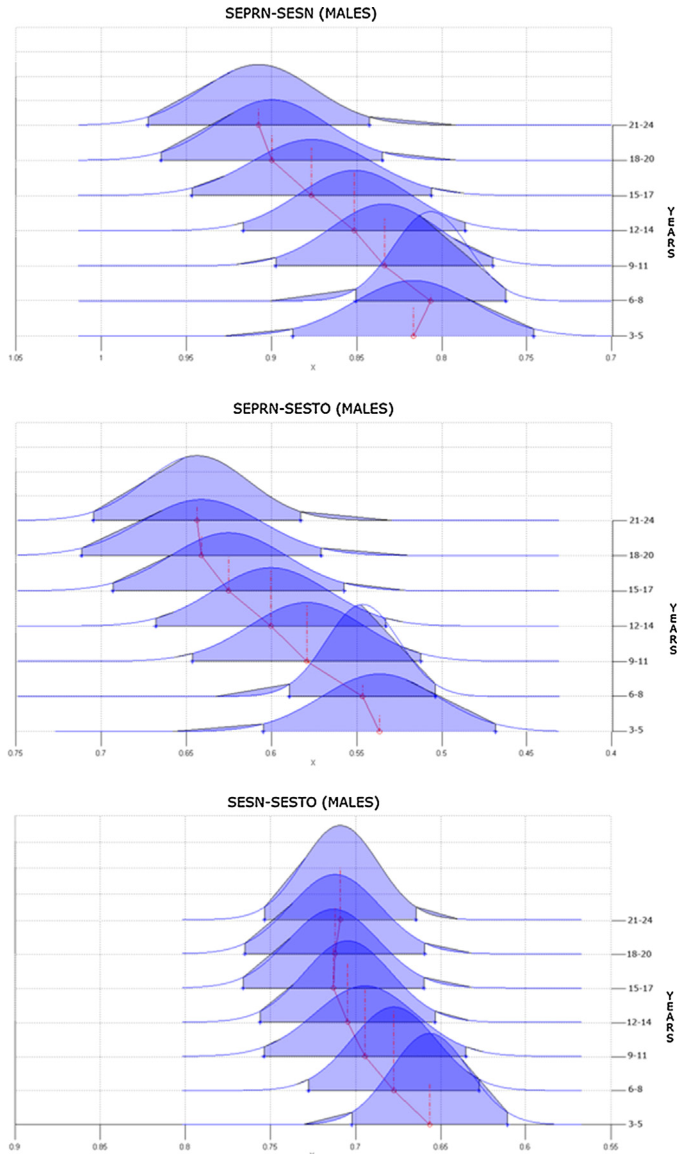

Fig. 4. Modification of facial indices taken in lateral view in males in the chosen age ranges: se-prn/se-sn: ratio between distance selion–pronasale and selion–subnasale; se-prn/se-sto: ratio between distance selion–pronasale and selion–stomion; se-sn/se-sto: ratio between distance selion–subnasale and selion–stomion; se-prn/se-sn and se-prn/se-sto constantly increase with age, whereas se-sn/se-sto only up to 15–17 years circa.

between 0.799 and 0.883 in males, 0.773 and 0.851 in females (Table 2).

As far as the lateral view is concerned, se-prn/se-sn was between 0.817 in the 3–5 year class and 0.907 in the 21–24 year class in males, 0.828 and 0.904 in females; se-prn/se-sto was between 0.537 and 0.644 in males, 0.551 and 0.646 in females: se-sn/se-sto was between 0.657 and 0.709 in males, 0.671 and 0.714 in females (Table 3).

Frontal indices ch-ch/ex-ex, ch-ch/pu-pu and se-sto/ex-ex constantly increased with age, whereas en-en/ch-ch decreased: this trend was observed both in males and females. For what concerns lateral indices, se-prn/se-sn and se-prn/se-sto constantly increased with age, whereas se-sn/se-sto increased only up to 15–17 in males, 18–20 in females. Also, for what concerns parameters in the lateral view, between males and females no appreciable differences were observed.

4. Discussion

Due to the alarming increase in pedo-pornographic videos and photographs currently available in the web, and consequent common legal requests to assess such images and estimate the age of the involved persons, the development of suitable methods to verify the age of children and adolescents represented on pornographic images and/or tapes has an obvious importance. Currently the assessment of sexual characteristics is still used as a method of ageing although it proved to be unreliable due to the large inter- and intra-individual variability observed for sexual maturation [5–9]. For this reason, recent research in Europe has been oriented towards the study of facial parameters as age indicators [19,20]. Such an approach can also be helpful in verifying the age of faces of minors on photographs in cases of missing children and/or cases of child identification.

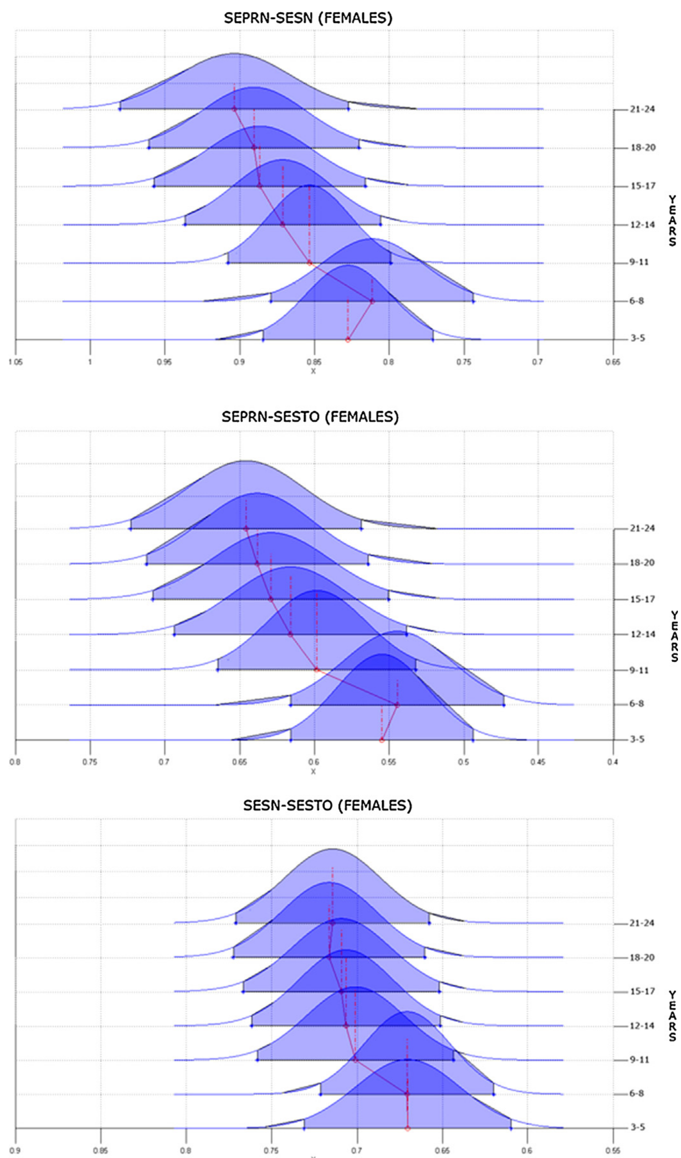

Fig. 5. Modification of facial indices taken in lateral view in females in the chosen age ranges: se-prn/se-sn: ratio between distance selion–pronasale and se-subnasale; se-prn/se-sto: ratio between distance selion–pronasale and selion–stomion; se-sn/se-sto: ratio between distance selion–subnasale and selion–stomion; se-prn/se-sn and se-prn/se-sto constantly increase with age, whereas se-sn/se-sto only up to 18–20 years circa.

In the past most anthropometric studies concerning craniofacial growth described the normal development of the head and face in order to provide a tool for identifying anomalies in growth and development of children [26–29]. However, the possibility of using facial indices for ageing is a field which has been explored only recently [19,20]. Literature provides a severe caveat against the application of photo-anthropometry to personal identification; in fact this specific field actually lacks of an adequate standardization, and moreover requires to be analyzed in depth for what concerns the impact of low resolution and different angulation [30–32]. The analysis of indices as ratio between measurements was therefore preferred, since the linear measurements may provide a bias due to the facial orientation and distance from the camera.

From this point of view the repeatability of the measurements has a relevant importance: the evaluation of inter- and intra-observer error was considered in an article linked to the same experimental project, which showed that the error in positioning facial landmarks involved in measurements vary according to the different point [33]. The inter-observer dispersion was evaluated by 25 operators who were requested to lay down facial landmarks on the photos of the same person. The landmarks with the lowest inter-observer dispersion in frontal view were both pupillare, the stomion, and both cheilions, in lateral view stomion and pronasale; for what concerns intra-observer error, the points affected by the least variability were both pupillare, cheilion, endocanthion, stomion in frontal view, selion, pronasale, subnasale and stomion in lateral view. The article showed that the highest dispersion was reached by selion in frontal view, both for what concerns the inter- and intra-observer repeatability. The other landmarks included in measurements which had the highest correlation with age showed an intermediate error. The only index including a landmark affected by a high inter- and intra-observer error is se-sto/ex-ex: from this point of view, the results of the previous study suggests caution in applying this ratio to age assessment.

For what concerns the relation between facial measurements and age, all the indices but for en-en/ch-ch show an increase with age, without differences between males and females: however, the exact trend of each measurement can be hardly reconstructed, since the facial assessment focused on the ratio between different linear values. However, data report that with age, distance

Table 2
Mean value and standard deviation of indices in frontal view in males and females (ch-ch/ex-ex: ratio between chelion–chelion and exocanthion–exocanthion; ch-ch/pu-pu: ratio between chelion–chelion and pupillare–pupillare; en-en/ch-ch: ratio between endocanthion–endocanthion and chelion–chelion; se-sto/ex-ex: ratio between selion–stomion and exocanthion–exocanthion).

		ch-ch/ex-ex		ch-ch/pu-pu		en-en/ch-ch		se-sto/ex-ex	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
0–5 years	M	0.489	0.044	0.705	0.064	0.839	0.085	0.799	0.052
	F	0.493	0.055	0.709	0.080	0.843	0.014	0.773	0.043
6–8 years	M	0.512	0.064	0.735	0.089	0.809	0.012	0.798	0.005
	F	0.502	0.042	0.719	0.064	0.820	0.079	0.791	0.049
9–11 years	M	0.542	0.047	0.761	0.066	0.761	0.080	0.809	0.050
	F	0.497	0.041	0.742	0.069	0.719	0.081	0.815	0.052
12–14 years	M	0.546	0.043	0.761	0.059	0.751	0.071	0.835	0.052
	F	0.542	0.047	0.774	0.068	0.725	0.076	0.854	0.048
15–17 years	M	0.560	0.040	0.777	0.057	0.718	0.069	0.851	0.056
	F	0.548	0.044	0.777	0.066	0.744	0.079	0.833	0.056
18–20 years	M	0.568	0.044	0.787	0.062	0.698	0.068	0.876	0.054
	F	0.561	0.044	0.789	0.061	0.735	0.076	0.839	0.053
21–24 years	M	0.584	0.049	0.809	0.068	0.664	0.081	0.883	0.061
	F	0.579	0.047	0.799	0.064	0.722	0.077	0.851	0.061

between the angles of the mouth increases in comparison to ex-ex and pu-pu distance; in addition, en-en distance decreases in comparison to ch-ch. These results show that the lower part of the face seems to be more affected by the growth process, rather than the middle-upper portion. The longitudinal diameter se-sto seems to increase more than ex-ex. For what concerns the lateral indices, se-prn increases more than se-sn and se-sto: this may suggest that during the chosen age range the nose is more affected by growth, especially for what concerns the length and protrusion from the facial plane. In addition, se-sn distance increases more than se-sto: this result suggests once again that the longitudinal diameters show a progression up to 24 years.

The variation of indices with age observed in this study confirmed on a large-scale basis (over 1900) a previous pilot study which suggested that some facial anthropometric indices on photographs can be used as age indicators. This previous study in fact had underlined the possible correlation between facial indices and age on a sample of 373 individuals (photos) for 18 indices in frontal view and five indices in lateral view [19]. A higher number of indices seemed to be suitable for age estimation; however, in that case the analysis was performed at four different ages only (6, 10, 14 and 18 years), and therefore there was a higher probability of finding statistically significant differences. In the present study indices that showed correlation with age were ch-ch/ex-ex, ch-ch/pu-pu, ch-ch/ft-ft, en-en/ch-ch and se-sto/ex-ex in the frontal view, se-prn/se-sn, se-prn/se-sto and se-sn/se-sto in the lateral view; however in this case the correlation with age was assessed in the entire age group ranging between 3 and 24 years. Of course. landmarks which show the least inter- and intra-observer differences need to be used, in particular pupillare, cheilion, endocanthion and stomion in the frontal view and selion, pronasale, subnasale and stomion in the lateral view [33]. Unfortunately, although the entire experiment took into consideration a high number of images, the number of samples for age stages was not homogeneous and in some cases amounted to only 20 images: the low number of samples in different age groups prevents us from performing a statistical analysis of the significance of the obtained results, which will be ascertained by further analyses on a larger population. This study provides just a first step useful for developing a mathematical formula for age estimation:

Table 3
Mean value and standard deviation of indices in lateral view in males and females (se-prn/se-sn: ratio between selion–pronasale and se-subnasale; se-prn/se-sto: ratio between selion–pronasale and selion–stomion; se-sn/se-sto: ratio between selion–subnasale and selion–stomion).

		se-prn/se-sn		se-prn/se-sto		se-sn/se-sto	
		Mean	SD	Mean	SD	Mean	SD
0–5 years	M	0.817	0.035	0.537	0.034	0.657	0.028
	F	0.828	0.028	0.551	0.030	0.671	0.030
6–8 years	M	0.807	0.022	0.547	0.021	0.678	0.025
	F	0.811	0.034	0.545	0.035	0.671	0.025
9–11 years	M	0.834	0.032	0.579	0.033	0.695	0.029
	F	0.853	0.027	0.598	0.033	0.701	0.028
12–14 years	M	0.851	0.032	0.600	0.037	0.705	0.026
	F	0.871	0.033	0.616	0.039	0.707	0.027
15–17 years	M	0.876	0.035	0.625	0.034	0.713	0.026
	F	0.887	0.035	0.629	0.039	0.709	0.029
18–20 years	M	0.899	0.032	0.641	0.035	0.712	0.026
	F	0.890	0.035	0.638	0.037	0.717	0.028
21–24 years	M	0.907	0.032	0.644	0.030	0.709	0.022
	F	0.904	0.038	0.646	0.038	0.714	0.028

the obtained data may provide a preliminary indication concerning the age of the subject which may be reached by placing the results of facial measurements on the different Gaussian distributions and verifying to which one the individual corresponds. This is clearly far from representing a novel method for age assessment, but represents a way to practically apply the obtained results in forensic practice.

Another aspect which deserves future research is related to the head orientation of the subject depicted on the photograph. Tanner and Weiner [34] pointed out that the greatest single source of error seems to be attributable to the subject's position. Thus in theory, what has been stated in this article may be true only for frontal and lateral projections (and not faces photographed at other angles). Future studies are needed in order to verify if a subject's pose on a photograph can affect these indices for what concerns ageing. Finally, the quality of the photograph needs to be taken into account. The minimum acceptable resolution is 640×480 pixels since lower resolutions make it very difficult to detect facial landmarks. In fact, during the positioning of facial landmarks on photographs the application of the zoom function to cases of low-resolution images may reduce many details.

In conclusion, the obtained results have provide for every index a Gaussian distribution whereby one can place the individual and verify the age group to which he or she corresponds to best; this clearly is not yet a valid method for age estimation, but it may give a first indication concerning the concordance of a specific ratio with a given age range. As one can observe, the Gaussian distributions in all indices show large areas of superimposition between different age ranges, and this detail gives an indication concerning the high error range provided by this approach. However, although this study provides only the preliminary data of the experimental project, initial information seem interesting and represents a first step towards the assessment of an age group from a picture – a tool which is actually lacking in the forensic field.

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