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Age assessment by using facial photo-anthropometry in a Brazilian population

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ABSTRACT

This study aimed to test the discriminant power of the photoanthropometric analysis of the human face for distinguishing females and males aged below or above 14 and 18. The sample consisted of 1354 photographs taken in frontal view of the Brazilian females and males aged between 10 and 22 years. Using SAFF-2D® software (Department of Federal Police, Brasília, Brazil), fourteen examiners positioned 35 landmarks in each of the photographs. The landmark positioning led to the quantification of 110 indices and 51 iridian ratios. These variables were tested into logistic regression models designed to distinguish females and males older or not than 14 and 18 years. Receiver Operating Characteristics (ROC) curves were used to assess the distinctive power of the models and the inherent Area Under the Curve (AUC) founded inferences about accuracy. The model was able to distinguish females that were not older than 14 in 129 cases (64.5 %) and females that were older than 14 in 359 cases (75.42 %). The females that were not older than 18 years were distinguished in 250 cases (60.83 %), while the females older than 18 years were distinguished in 199 cases (74.53 %). Males that were not older than 14 were distinguished in 175 cases (84.95 %) and males that were older than 14 were distinguished in 381 cases (81.06 %). Males that were not older than 18 years were distinguished in 280 cases (68.97 %), while males older than 18 years were distinguished in 224 cases (83.58 %). The female model reached 76 % and 73 % of distinctive accuracy for the thresholds of 14 and 18 years, respectively. The male model reached 90 % and 83 % for the same thresholds, respectively. Facial photoanthropometry is a useful tool for age estimation in criminal cases that involve the legal age thresholds of 14 and 18 years.

Introduction

Child pornography is a billionaire business and one of the fastest growing crimes in the black market worldwide [1]. Estimating the age of the victims through photographic or dynamic video materials, as well as classifying them into children and adolescents, is essential to support police investigations [2]. In many countries, such as Brazil, Hungary and Italy, the age threshold established for legal majority is 18 years [3]. While the threshold for the age of sexual consent is 14 [4]. Particularly, in Brazil, reports from SaferNet (new.safernet.org.br) – a dedicated non-governmental organization (NGO) – indicate that child and juvenile pornography is ranked top amongst the most common cybercrimes in the country. According to the Federal Prosecution Service of Brazil, the leading position of this modality of crime persisted at least up to 2019. More specifically, in 2018, the National Centre for the Denunciation of Cybernetic Crimes registered nearly 60 thousand reports. Despite the fact this is possibly an underreported crime, the quantity of cases in that year represented an increase of nearly 80 %. From a criminal perspective, the national Law classify as pedo-pornography the acquisition, storage and distribution of any kind of material (static or dynamic). Penalties might extend up to eight years of reclusion (with possible aggravating circumstances).

Recommendations for the age estimation of the living from images and video footages are provided by the interdisciplinary Study Group on

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Forensic Age Diagnostics (SGFAD) [2]. However, there is no scientific protocol exclusively established to estimate age from photographs of the human face applicable to the thresholds of legal interest (e.g. 18 and 14 years). The photoanthropometric analysis of the human face emerged as an alternative tool for assessing facial traits and in association with age intervals [5]. This approach is founded on the positioning of anatomical landmarks in photographs and the calculation of ratios between anatomic structures. In general, the photoanthropometric analysis applied to age estimation does not describe in detail the morphological alterations of the human face over the time. For this reason it may not be an accurate tool for distinguishing age in short intervals [6]. However, it may be tested as a tool with dichotomic response to infer if a child is under or over the age of sexual consent or if an adolescent is younger or older than the age of legal majority.

This study tested the discriminant power of the photoanthropometry of the human face for distinguishing individuals younger or older than 14 and 18 years of age.

Material and methods

This cross-sectional study was designed according to the Standards of the Scientific Group of Forensic Facial Identification (FACISGroup). The research protocol was approved by the local committee of ethics in human research (protocol: CAAE-51448515.0.3002.0075).

The sample consisted of 1354 photographs of the human face of Caucasian Brazilian individuals, with European ancestry, aged between 10 and 22 years homogeneously distributed based on sex (Table 1). The photographs were standardly taken in frontal view following the recommendations of the International Civil Aviation Organization (ICAO). The same model of camera, lenses and flash were used to take all the photographs. The distance between the lenses and the face of the participants was set in 150 mm. The obtained images had a pixels resolution of 640 × 480 and were stored in. png 24-bit format. During the photographic acquisition, the participants had to express a neutral face, with closed lips and the head positioned towards the camera. Photographs that did not enable a complete visualization of the face due to hair position, eyeglasses, make-up and jewelry were excluded. Participants with evident facial asymmetries or deformations, as well those with misaligned face in the sagittal, axial and coronal planes, were also excluded.

Fourteen examiners were trained and calibrated for using a software specifically designed for landmark positioning (SAFF-2D®, Department of Federal Police, Brasília, Brazil). With the software 35 anatomic landmarks (23 bilateral and 12 in the median plane) were positioned [7] (Fig. 1, Table 2). The landmark positioning led to the quantification of 160 measurements (variables). The measurements led to the calculation of 110 indices (IND) [8] and 50 iridian ratios (IR) [5]. Comparisons of the mean IND and IR between females and males were performed with Mann-Whitney test. In order to assess the influence of the 160 quantitative variables over the age (to distinguish participants aged below or above 14 and 18), a logistic regression model [9] was separately designed for females (F) and males (M), as well as for the general sample (F + M). Firstly, the model was adjusted with all the variables. Next it was investigated for multicolinearity. Variance Inflation Factor (VIF) [10] was applied. Variables with VIF above 10 were removed from the model. Backward approach [11] with a level of significance of 5% was used. Within this approach, the variables with higher p-value are sequentially removed and only those with $p < 0.05$ are maintained. The quality of the adjustment of the logistic regression was assessed with Hosmer-Lemeshow test [12] and R^2. The Receiver Operating Characteristics curve (ROC) [13] was used to classify the positive (sensibility) and false-positive (specificity) outcomes. Additionally, the area under the curve (AUC) was used to make inferences in accuracy. The statistical analysis was performed within R® 3.4.2. (The R Foundation, Vienna, Austria) software package.

Intra- and inter-examiner agreement for placing landmarks was quantified by repeating the landmarking procedure on 10 photographs, three times, within intervals of 15 days and in a double-blind set-up. Quantification was performed with Intraclass Correlation Coefficient (ICC).

Table 1
Sample distribution based on age.

Age (years)	n	Frequency (%)
10−10.99	94	6.9
11−11.99	103	7.6
12−12.99	108	8.0
13−13.99	101	7.5
14−14.99	107	7.9
15−15.99	105	7.8
16−16.99	103	7.6
17−17.99	97	7.2
18−18.99	100	7.4
19−19.99	110	8.1
20−20.99	110	8.1
21−21.99	107	7.9
22−22.99	109	8.0
Total	**1354**	**100.0**

n: number of participants.

Results

Out of the total sample, 678 (50.07 %) were females and 676 (49.93 %) were males. The distribution of females and males based on age showed that 200 (29.5 %) females and 206 (30.47 %) males were under 14, while 411 (60.62 %) females and 407 (60.21 %) males were under 18 (Table 3).

A descriptive analysis of the variables showed that 41 IND and 2 RI were higher in females ($p < 0.05$), while 42 IND and 40 IR were higher in males ($p < 0.05$) (Table 4).

In females, the variables that had significant influence in age estimation were IND_002, IND_048, IND_050, IND_059, IND_072, IND_077, IND_078, IND_082, IND_091, IND_097, IND_102, IR_11 e IR_23 for the age threshold of 14 years and IND_048, IND_050, IND_059, IND_078, IND_082, IR_11, IND_029, IND_058, IND_073, IR_01, IR_22 for the age threshold of 18 years (Table 5). The following regression formula resulted from statistic modeling the data from females:

Females aged >14 years:

$$\gamma = 25,01 - 0,09 \times IND_{002}) - 0,12 \times \mathrm{IND}_{048}) - 0,03 \times \mathrm{IND}_{050}) + 0,21 \times \mathrm{IND}_{059}) + 0,02 \times \mathrm{IND}_{072}) + 0,06 \times \mathrm{IND}_{077}) - 0,11 \times \mathrm{IND}_{078}) - 0,05 \times \mathrm{IND}_{082}) - 0,34 \times \mathrm{IND}_{091}) - 0,03 \times \mathrm{IND}_{097}) - 0,10 \times \mathrm{IND}_{102}) - 2,06 \times \mathrm{RI}_{11}) + 5,20 \times \mathrm{RI}_{23})$$

$$ProbAge > 14) = \frac{\exp(\gamma)}{1 + \exp(\gamma)}$$

Females aged >18 years:

$$\gamma = 13,78 - 0,14 \times \mathrm{IND}_{048}) - 0,04\mathrm{IND}_{050}) + 0,22\mathrm{IND}_{059}) - 0,16\mathrm{IND}_{078}) + 0,03\mathrm{IND}_{082}) - 3,32\mathrm{RI}_{11}) + 0,07\mathrm{IND}_{029}) - 0,03\mathrm{IND}_{058}) - 0,09\mathrm{IND}_{073}) + 0,13\mathrm{RI}_{01}) + 3,96(\mathrm{RI}_{22})$$

$$ProbAge > 18) = \frac{\exp(\gamma)}{1 + \exp(\gamma)}$$

The ROC outcomes showed that the model was able to distinguish the females that were not aged >14 in 129 cases (64.5 %) and the females that were aged >14 in 359 cases (75.42 %) (Fig. 2). The females that were not aged >18 years were distinguished in 250 cases (60.83 %), while the females aged >18 years were distinguished in 199 cases (74.53 %) (Fig. 3).

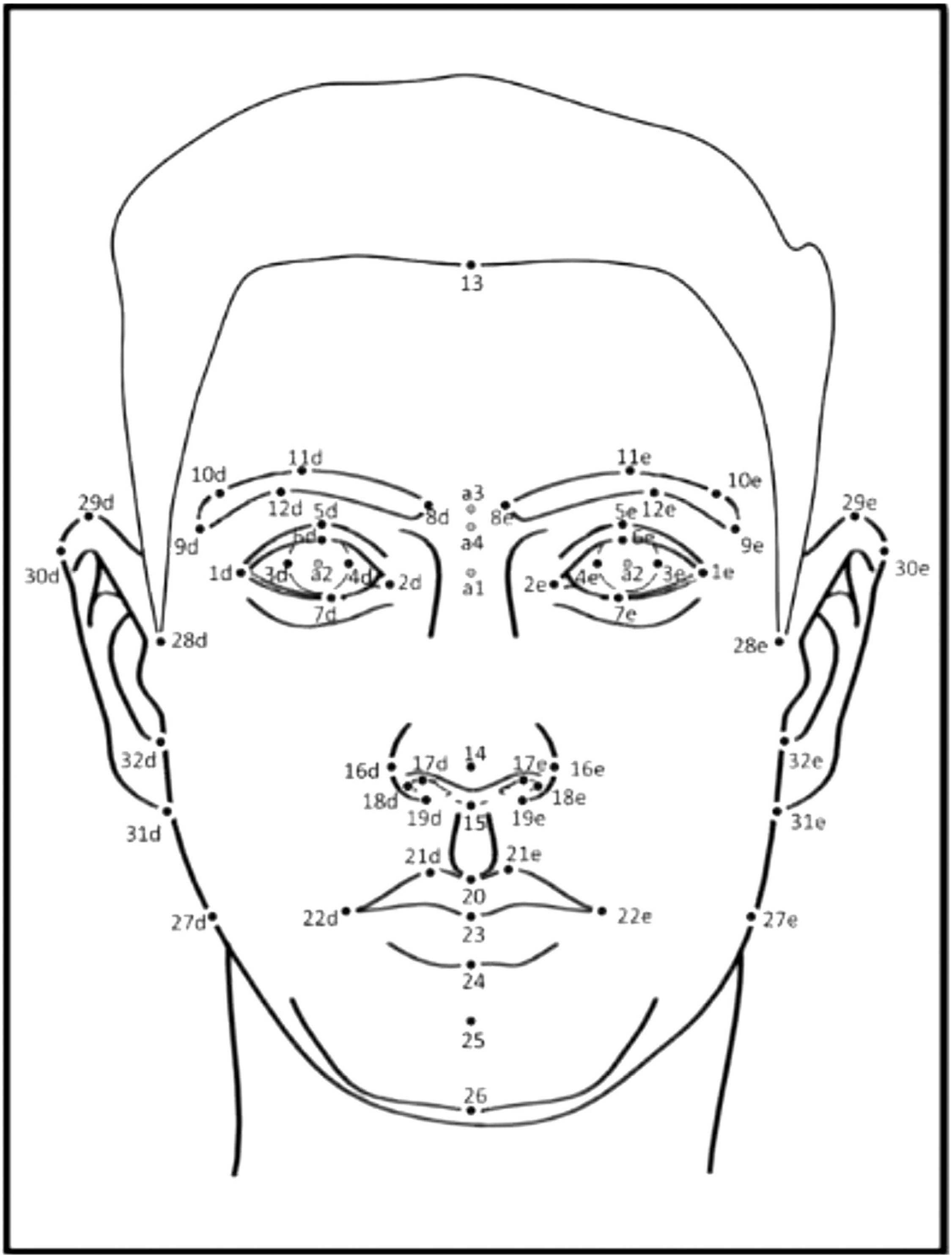

Fig. 1. Facial landmarks used in the present study.
Legend: A description of the landmarks is provided in Table 2.

In males, the variables that had significant influence in age estimation were IND_022, IND_073, IND_091, IND_097, IR_10, IR_22, IR_49 for the age threshold of 14 years and IR_22, IND_006, IND_050, IND_058, IND_059, IND_072, IND_084, IND_091, IR_01, IR_11, IR_50 for the age threshold of 18 years (Table 6). The following regression formula resulted from statistic modeling the male data:

Males aged >14 years:

$$\gamma = -14,06 - 0,04 \times \mathrm{IND}_{022}) + 0,14 \times \mathrm{IND}_{073}) + 0,43 \times \mathrm{IND}_{091}) - 0,11 \times \mathrm{IND}_{097}) + 5,92 \times \mathrm{RI}_{10}) + 8,62 \times \mathrm{RI}_{22}) - 0,48 \times (\mathrm{RI}_{49})$$

$$ProbAge > 14) = \frac{\exp(\gamma)}{1 + \exp(\gamma)}$$

Table 2
Photoanthropometric landmarks used in the present study.

#	Landmark	Distribution	Code
1	Ectocanthion	bilateral	ec_d / ec_e
2	Endocanthion	bilateral	en_d / en_e
3	Iridion laterale	bilateral	il_d / il_e
4	Iridion mediale	bilateral	im_d / im_e
5	Upper palpebral groove	bilateral	sps_d / sps_e
6	Upper palpebra	bilateral	ps_d / ps_e
7	Lower palpebra	bilateral	pi_d / pi_e
8	Medial eyebrow	bilateral	sm_d / sm_e
9	Lateral eyebrow	bilateral	sl_d / sl_e
10	Frontotemporal	bilateral	ft_d / ft_e
11	Upper eyebrow	bilateral	ss_d / ss_e
12	Lower eyebrow	bilateral	si_d / si_e
13	Trichion	median	tr
14	Pronasale	median	prn
15	Subnasale	median	sn
16	Alare	bilateral	al_d / al_e
17	Upper nostril	bilateral	nas_d / nas_e
18	Lateral nostril	bilateral	nal_d / nal_e
19	Subalare	bilateral	sbal_d / sbal_d
20	Labiale superior	median	ls
21	Crista philtrum	bilateral	cph_d / cph_e
22	Chelion	bilateral	ch_d / ch_e
23	Stomion	median	sto
24	Labiale inferior	median	li
25	Labiomentale	median	lm
26	Gnathion	median	gn
27	Gonion	bilateral	go_d / go_e
28	Zygion	bilateral	zy_d / zy_e
29	Supra-auriculare	bilateral	sa_d / sa_e
30	Post-auriculare	bilateral	pa_d / pa_e
31	Subauriculare	bilateral	sba_d / sba_e
32	Supralobulare	bilateral	slb_d / slb_e
a1	Midnasale	median	mid
a2	Pupil	bilateral	pu_d / pu_e
a3	Glabela	median	g
a4	Nasion	median	n

Table 3
Distribution of females and males based on the ages of 14 and 18.

Age		Total		Sex			
				Females		Males	
		n	%	n	%	N	%
>14	No	406	29.99 %	200	29.50 %	206	30.47 %
	Yes	948	70.01 %	478	70.50 %	470	69.53 %
>18	No	818	60.41 %	411	60.62 %	407	60.21 %
	Yes	536	39.59 %	267	39.38 %	269	39.79 %

n: absolute frequency; %: relative frequency.

Males aged >18 years:

$$\gamma = -31,82 + 6,70 \times \mathrm{RI}_{22}) + 0,13\mathrm{IND}_{006}) - 0,02 \times \mathrm{IND}_{050}) + 0,06 \times \mathrm{IND}_{058}) + 0,12 \times \mathrm{IND}_{059}) + 0,02 \times \mathrm{IND}_{072}) + 0,07 \times \mathrm{IND}_{084}) + 0,26 \times \mathrm{IND}_{091}) - 0,20 \times \mathrm{RI}_{01}) + 3,59 \times (\mathrm{RI}_{11}) - 2,39 \times (\mathrm{RI}_{50})$$

$$ProbAge > 18) = \frac{\exp(\gamma)}{1 + \exp(\gamma)}$$

The ROC outcomes showed that the model was able to distinguish the males that were not aged >14 in 175 cases (84.95 %) and the males that were aged >14 in 381 cases (81.06 %) (Fig. 4). The males that were not aged >18 years were distinguished in 280 cases (68.97 %), while the males aged >18 years were distinguished in 224 cases (83.58 %) (Fig. 5).

Intra- and inter-examiner agreement outcomes were excellent (ICC > 0.9, $p < 0.001$).

Discussion

The International Crime Police Organization (INTERPOL) describes the concept of child pornography as the visual representation of sexual exploitation with major focus in child sexual behavior and genitals – including audio records and written material [14]. In Europe, critical thresholds of legal interest for child and juvenile pornography are mainly found in the ages of 14, 16 and 18. The European Union legislation (Council Framework Decision 2004/68/JHA) indicates the term “child pornography” may be used not only to describe the sexual exploitation of real minors, but also to described cases that involve pseudo-minority (i.g. adults simulating minors in sexual behavior) [2]. As many other countries, Brazil establishes as children those individuals aged below 14 years, while adolescents are those aged between 14 and 18 [15]. Criminal cases that involve children and adolescents with unknown or uncertain age require the participation of forensic experts and their knowledge to estimate the age [16]. In this context, this study aimed to test the discriminant power of the photoanthropometry of the human face as an age estimation tool to distinguish victims and/or perpetrators of sexual crimes based on the age thresholds of 14 and 18 years.

Despite the existing methods for the photoanthropometric study of facial growth in many fields of science, few approaches were adapted for forensic applications. Recently, authors from Europe showed that clinically-visible facial alterations related to age could be detected and studied for age estimation in photographs. More specifically, the authors quantified morphological facial alterations over the time into photo-anthropometric indices strongly correlated with age [1]. Similarly, the current study investigated anthropometric indices obtained from landmark positioning in photographs. However, it is important to note that the quality of the photographs, the distance between the camera and the subject and the angulation of the camera may influence and hamper the photoanthropometric analysis [17]. For this reason, ICAO photographic protocol was followed in the present study. With a proper sample of images and a methodological set up designed according to the previous scientific literature, this study tested the discriminant power of photo-anthropometry as a tool to distinguish subjects based on the legal age thresholds of 14 and 18 years.

The logistic regression model to distinguish females aged above 14 showed good adjustment (via Hosmer-Lemeshow test; $p = 0.514$). In this model, the variables were able to explain 22.88 % of the classification based on age (via Pseudo R^2). The ROC curve cutoff was 0.66, which means that subjects are classified above 14 years when the estimated probability of the model reaches 0.66 or higher. The AUC showed an accuracy of 75 %, with sensitivity and specificity of 75 % and 65 %, respectively. Good adjustment was also observed within the logistic regression model to distinguish females aged above 18 ($p = 0.494$). In this model, the variables were able to explain 19.9 % of the classification based on age. The cutoff value of the ROC curve for this model was 0.35, while the accuracy was 73 % (AUC), with sensitivity of 75 % and specificity of 61 %.

In males, the logistic regression models to distinguish those aged above 14 also had a good adjustment (via Hosmer-Lemeshow test; $p = 0.289$). In this case, the variables were able to explain 54.84 % of the classification based on age (Pseudo R^2). The ROC curve cutoff was 0.71, while the accuracy was 90 % (AUC), with sensitivity of 81 % and specificity of 85 %. For distinguishing males aged above 18, the logistic regression model had a good adjustment ($p = 0.122$), in which the variables were able to explain 40.52 % (Pseudo R^2) of the classification based on age. The ROC curve cutoff was 0.35, while the accuracy was 83 % (AUC), with sensitivity and specificity of 84 % and 69 %, respectively.

In comparison, the outcomes of the logistic model designed based on the threshold of 14 were more accurate than those based on the age

Table 4
Mean and standard deviation of the indices (IND) and iridian ratios (IR) in females and males.

Variables	Total		Sex				p
			Female		Male		
	Mean	SD	Mean	SD	Mean	SD	
IND_001	81.10	10.92	82.33	7.11	79.87	13.61	0.000
IND_002	86.41	5.98	86.23	5.36	86.58	6.54	0.189
IND_003	65.66	7.80	64.45	7.11	66.87	8.27	0.000
IND_004	45.47	4.28	45.41	4.10	45.54	4.47	0.903
IND_005	55.67	6.60	56.40	4.31	54.93	8.23	0.000
IND_006	79.90	4.78	79.78	4.37	80.02	5.16	0.432
IND_007	71.99	9.42	69.56	7.16	74.43	10.70	0.000
IND_008	49.86	5.37	49.05	4.32	50.68	6.13	0.000
IND_009	75.73	8.26	76.28	6.63	75.19	9.60	0.000
IND_010	51.98	4.26	52.26	3.93	51.71	4.55	0.036
IND_011	70.14	8.02	69.51	7.22	70.77	8.71	0.025
IND_012	76.81	8.78	74.99	6.88	78.62	10.01	0.000
IND_013	37.05	6.27	37.37	4.01	36.73	7.90	0.000
IND_014	53.17	6.98	52.85	4.78	53.49	8.63	0.318
IND_015	69.63	6.66	70.67	3.18	68.59	8.75	0.000
IND_016	69.41	10.86	70.54	6.86	68.29	13.67	0.000
IND_017	96.13	7.10	96.00	6.38	96.26	7.76	0.543
IND_018	76.97	10.13	75.40	9.14	78.56	10.81	0.000
IND_019	50.59	4.95	50.56	4.70	50.63	5.19	0.772
IND_020	47.66	6.90	48.33	4.38	46.98	8.67	0.000
IND_021	71.87	4.77	71.70	4.38	72.04	5.13	0.188
IND_022	84.38	11.89	81.36	9.14	87.40	13.46	0.000
IND_023	55.47	6.06	54.60	4.92	56.33	6.92	0.000
IND_024	31.71	6.01	32.02	3.74	31.41	7.62	0.000
IND_025	47.82	6.40	47.49	4.42	48.15	7.89	0.149
IND_026	66.23	7.85	67.35	3.64	65.12	10.37	0.000
IND_027	85.63	11.79	83.60	7.17	87.66	14.79	0.000
IND_028	128.71	10.08	126.22	6.53	131.22	12.17	0.000
IND_029	120.74	10.61	118.14	6.47	123.36	13.03	0.000
IND_030	80.32	11.50	78.24	6.78	82.41	14.50	0.000
IND_031	84.27	11.95	82.61	6.94	85.92	15.25	0.000
IND_032	98.85	9.90	99.11	7.12	98.58	12.07	0.015
IND_033	105.45	10.72	105.92	7.75	104.99	13.02	0.002
IND_034	39.10	13.24	37.24	3.21	40.96	18.28	0.000
IND_035	62.22	3.24	63.25	2.53	61.19	3.53	0.000
IND_036	59.69	3.44	60.73	2.70	58.65	3.77	0.000
IND_037	57.11	7.71	55.32	3.11	58.90	10.14	0.000
IND_038	60.88	7.81	59.12	3.35	62.65	10.24	0.000
IND_039	38.09	6.71	36.76	2.55	39.41	8.96	0.000
IND_040	40.58	6.43	39.28	2.72	41.89	8.49	0.000
IND_041	62.04	20.39	58.37	6.14	65.72	27.72	0.000
IND_042	69.02	22.67	65.00	7.11	73.05	30.77	0.000
IND_043	66.63	4.18	66.46	3.05	66.80	5.07	0.831
IND_044	36.19	2.46	36.10	2.32	36.28	2.59	0.278
IND_045	99.85	0.46	99.82	0.18	99.88	0.62	0.000
IND_046	88.95	8.73	89.32	8.96	88.57	8.48	0.189
IND_047	99.08	8.13	98.70	3.54	99.46	10.94	0.049
IND_048	41.37	2.79	41.54	2.54	41.19	3.01	0.003
IND_049	31.98	1.15	32.04	1.17	31.93	1.13	0.084
IND_050	108.31	10.36	106.65	9.11	109.98	11.23	0.000
IND_051	66.56	7.45	66.27	5.20	66.85	9.16	0.526
IND_052	45.47	4.28	45.41	4.10	45.54	4.47	0.903
IND_053	50.59	4.95	50.56	4.70	50.63	5.19	0.772
IND_054	119.98	752.10	92.79	8.84	147.34	1064.86	0.000
IND_055	70.14	8.02	69.51	7.22	70.77	8.71	0.025
IND_056	21.29	2.48	21.24	1.88	21.34	2.96	0.455
IND_057	39.60	5.69	40.94	3.33	38.26	7.08	0.000
IND_058	98.55	6.90	99.07	6.71	98.02	7.05	0.004
IND_059	2.15	6.51	1.93	2.49	2.37	8.87	0.218
IND_060	26.44	4.08	25.86	2.75	27.02	5.01	0.000
IND_061	37.05	6.27	37.37	4.01	36.73	7.90	0.000
IND_062	31.71	6.01	32.02	3.74	31.41	7.62	0.000
IND_063	43.38	5.16	44.72	3.09	42.03	6.34	0.000
IND_064	76.96	11.90	81.43	10.41	72.48	11.62	0.000
IND_065	65.88	11.00	69.80	9.76	61.96	10.78	0.000
IND_066	34.62	6.53	34.05	6.00	35.20	6.98	0.002
IND_067	33.51	3.56	33.60	3.09	33.41	3.97	0.815
IND_068	154.59	14.15	153.43	13.20	155.76	14.96	0.004
IND_069	74.37	6.91	74.04	7.63	74.70	6.08	0.009
IND_070	26.19	6.45	26.71	6.83	25.67	6.01	0.005

(continued on next page)

Table 4 ***(continued)***

Variables	Total		Sex				p
			Female		Male		
	Mean	SD	Mean	SD	Mean	SD	
IND_071	36.08	11.37	36.88	11.32	35.27	11.37	0.005
IND_072	56.01	16.37	54.94	17.70	57.07	14.85	0.000
IND_073	96.36	2.79	96.95	2.53	95.77	2.92	0.000
IND_074	91.53	3.38	91.10	3.21	91.95	3.49	0.000
IND_075	105.46	5.55	106.58	5.22	104.33	5.65	0.000
IND_076	98.14	10.80	97.77	7.99	98.52	13.02	0.553
IND_077	26.68	4.82	25.48	3.99	27.88	5.27	0.000
IND_078	2.07	2.29	1.99	2.33	2.15	2.25	0.062
IND_079	34.59	5.01	34.62	3.57	34.56	6.13	0.087
IND_080	30.85	9.52	29.44	3.29	32.28	12.92	0.000
IND_081	34.33	10.56	32.78	3.76	35.88	14.30	0.000
IND_082	51.02	16.78	50.94	8.46	51.10	22.19	0.820
IND_083	44.52	8.08	41.95	6.60	47.11	8.58	0.000
IND_084	52.23	10.00	49.11	8.34	55.35	10.55	0.000
IND_085	93.13	8.49	94.44	7.92	91.81	8.84	0.000
IND_086	26.64	2.09	27.20	1.78	26.08	2.23	0.000
IND_087	108.03	719.45	82.39	7.15	133.82	1018.67	0.000
IND_088	61.93	5.42	61.65	4.95	62.22	5.84	0.284
IND_089	16.43	1.52	16.59	1.47	16.27	1.55	0.001
IND_090	6.69	1.02	6.86	0.96	6.52	1.04	0.000
IND_091	8.03	1.07	8.08	1.03	7.98	1.11	0.087
IND_092	39.74	4.01	39.04	3.15	40.43	4.61	0.000
IND_093	31.51	3.60	31.37	3.14	31.65	4.00	0.002
IND_094	33.04	3.53	33.12	2.90	32.97	4.06	0.525
IND_095	37.92	6.75	38.94	4.97	36.89	8.02	0.000
IND_096	110.31	13.58	108.91	11.90	111.71	14.95	0.001
IND_097	138.22	15.86	144.17	12.74	132.26	16.44	0.000
IND_098	41.37	2.79	41.54	2.54	41.19	3.01	0.003
IND_099	93.09	13.38	97.94	11.78	88.23	13.13	0.000
IND_100	43.25	4.05	44.32	3.58	42.16	4.21	0.000
IND_101	13.22	0.77	13.30	0.72	13.13	0.81	0.000
IND_102	36.68	3.26	37.00	3.31	36.36	3.19	0.000
IND_103	28.04	2.96	27.70	2.56	28.37	3.28	0.000
IND_104	18.45	1.36	18.59	1.23	18.30	1.47	0.000
IND_105	11.00	0.93	11.28	0.72	10.73	1.02	0.000
IND_106	31.98	1.15	32.04	1.17	31.93	1.13	0.084
IND_107	88.95	8.73	89.32	8.96	88.57	8.48	0.189
IND_108	67.94	7.32	66.82	6.28	69.07	8.08	0.000
IND_109	44.69	3.23	44.84	3.02	44.53	3.43	0.093
IND_110	26.64	2.09	27.20	1.78	26.08	2.23	0.000
IR_01	11.53	1.57	11.49	1.62	11.56	1.51	0.001
IR_02	9.63	1.06	9.42	0.75	9.84	1.26	0.000
IR_03	7.59	0.45	7.54	0.42	7.64	0.47	0.000
IR_04	2.75	0.25	2.73	0.25	2.77	0.26	0.000
IR_05	6.22	0.35	6.18	0.32	6.26	0.37	0.000
IR_06	4.25	0.37	4.18	0.32	4.32	0.40	0.000
IR_07	5.23	0.38	5.18	0.34	5.28	0.40	0.000
IR_08	2.43	0.16	2.42	0.15	2.44	0.17	0.003
IR_09	3.02	0.34	2.94	0.26	3.09	0.39	0.000
IR_10	1.64	0.58	1.60	0.15	1.69	0.81	0.000
IR_11	1.67	0.53	1.62	0.16	1.72	0.73	0.000
IR_12	0.11	0.36	0.10	0.13	0.13	0.50	0.114
IR_13	3.94	0.36	3.94	0.32	3.95	0.39	0.335
IR_14	1.05	0.21	1.00	0.17	1.10	0.23	0.000
IR_15	2.02	0.20	2.00	0.17	2.04	0.21	0.000
IR_16	2.07	0.22	2.06	0.20	2.08	0.23	0.010
IR_17	1.98	0.18	1.97	0.16	1.98	0.20	0.261
IR_18	1.98	0.18	1.98	0.16	1.98	0.20	0.327
IR_19	2.16	0.20	2.17	0.19	2.15	0.21	0.449
IR_20	2.15	0.20	2.16	0.18	2.14	0.21	0.434
IR_21	1.40	0.64	1.31	0.22	1.48	0.87	0.000
IR_22	0.89	0.13	0.87	0.12	0.92	0.13	0.000
IR_23	1.50	0.15	1.47	0.13	1.53	0.16	0.000
IR_24	5.11	0.53	5.11	0.37	5.11	0.66	0.271
IR_25	6.48	0.48	6.42	0.43	6.53	0.52	0.000
IR_26	6.95	0.48	6.88	0.42	7.02	0.52	0.000
IR_27	7.83	0.55	7.75	0.49	7.91	0.59	0.000
IR_28	10.65	0.90	10.38	0.63	10.92	1.04	0.000
IR_29	0.61	0.09	0.61	0.08	0.61	0.09	0.899
IR_30	4.22	0.53	4.25	0.33	4.19	0.67	0.000
IR_31	5.59	0.42	5.55	0.38	5.62	0.45	0.001
IR_32	6.06	0.42	6.01	0.37	6.11	0.46	0.000
IR_33	6.94	0.49	6.88	0.45	7.00	0.53	0.000

Table 4 *(continued)*

Variables	Total		Sex				p
			Female		Male		
	Mean	SD	Mean	SD	Mean	SD	
IR_34	9.77	0.89	9.51	0.58	10.02	1.06	0.000
IR_35	3.61	0.55	3.64	0.33	3.59	0.70	0.000
IR_36	4.98	0.41	4.95	0.37	5.01	0.44	0.001
IR_37	5.45	0.40	5.40	0.36	5.50	0.43	0.000
IR_38	6.33	0.48	6.27	0.43	6.39	0.51	0.000
IR_39	9.16	0.92	8.90	0.56	9.42	1.11	0.000
IR_40	1.40	0.64	1.31	0.22	1.48	0.87	0.000
IR_41	1.87	0.64	1.77	0.22	1.97	0.87	0.000
IR_42	2.75	0.67	2.64	0.29	2.86	0.89	0.000
IR_43	5.61	1.33	5.27	0.49	5.95	1.75	0.000
IR_44	0.49	0.13	0.47	0.14	0.50	0.13	0.000
IR_45	1.36	0.25	1.34	0.23	1.38	0.27	0.001
IR_46	4.23	1.29	3.96	0.42	4.50	1.74	0.000
IR_47	0.88	0.17	0.88	0.16	0.89	0.18	0.095
IR_48	3.76	1.31	3.50	0.36	4.02	1.79	0.000
IR_49	2.89	1.41	2.63	0.36	3.14	1.93	0.000
IR_50	−0.10	0.12	−0.14	0.11	−0.06	0.11	0.000

p: Mann-Whitney test outcomes considering a significance level of 5%.

Table 5
Factors that influence on distinguishing females aged above 14 and 18 years.

Variables	>14 years						>18 years					
	β	β Pad.	SE	OR	CI - 95 %	p	β	β Pad.	SE	OR	CI - 95 %	p
Intercept	25.01	15.33	5.43	–	–	0.000	13.78	−2.27	5.65	–	–	0.015
IND_002	−0.09	−0.09	0.02	0.91	[0.87; 0.95]	0.000	–	–	–	–	–	–
IND_048	−0.12	−0.05	0.05	0.89	[0.80; 0.99]	0.031	−0.14	−0.12	0.05	0.87	[0.79; 0.95]	0.002
IND_050	−0.03	−0.03	0.01	0.97	[0.94; 0.99]	0.005	−0.04	−0.03	0.01	0.96	[0.94; 0.98]	0.000
IND_059	0.21	0.11	0.07	1.23	[1.08; 1.41]	0.002	0.22	0.15	0.05	1.25	[1.12; 1.39]	0.000
IND_072	0.02	0.01	0.01	1.02	[1.00; 1.03]	0.009	–	–	–	–	–	–
IND_077	0.06	0.03	0.02	1.06	[1.01; 1.11]	0.014	–	–	–	–	–	–
IND_078	−0.11	−0.09	0.06	0.90	[0.80; 1.00]	0.048	−0.16	−0.07	0.05	0.85	[0.76; 0.95]	0.003
IND_082	−0.05	−0.03	0.02	0.95	[0.92; 0.98]	0.001	0.03	0.03	0.01	1.03	[1.00; 1.05]	0.024
IND_091	−0.34	−0.30	0.10	0.71	[0.58; 0.88]	0.001	–	–	–	–	–	–
IND_097	−0.03	−0.03	0.01	0.97	[0.95; 0.98]	0.000	–	–	–	–	–	–
IND_102	−0.10	−0.09	0.04	0.90	[0.84; 0.97]	0.007	–	–	–	–	–	–
IR_11	−2.06	−0.21	0.84	0.13	[0.02; 0.67]	0.015	−3.32	−1.04	0.77	0.04	[0.01; 0.16]	0.000
IR_23	5.20	6.69	1.16	181.99	[18.85; 1757.10]	0.000	–	–	–	–	–	–
IND_029	–	–	–	–	–	–	0.07	0.08	0.01	1.07	[1.04; 1.10]	0.000
IND_058	–	–	–	–	–	–	−0.03	0.00	0.01	0.97	[0.94; 0.99]	0.015
IND_073	–	–	–	–	–	–	−0.09	−0.03	0.04	0.91	[0.84; 0.98]	0.017
IR_01	–	–	–	–	–	–	0.13	0.04	0.06	1.14	[1.02; 1.27]	0.020
IR_22	–	–	–	–	–	–	3.96	3.60	0.92	52.34	[8.58; 319.28]	0.000
R^2 (Negelkerke)					22.88 %		19.90 %					
Hosmer-Lemeshow (p-value)					0.514		0.494					
Area Under the Curve (AUC)					0.76		0.73					
Sensibility					0.75		0.75					
Specificity					0.65		0.61					

SE: standard error; OR: Odds Ratio; CI: confidence interval.

threshold of 18. In both age thresholds, the outcomes for males were more accurate than those for females. The difference between females and males may be justified by the development timing. In particular, the facial development in females is limited to a shorter age interval, in which a developmental slowdown is evident around the age of 13. In males, the developmental process extends throughout the adolescence up to the early adulthood [18]. In practice, the continuous and accumulative morphological changes in the human face with age culminate in more accurate estimates of the model for males for both the legal age thresholds of 14 and 18.

In the scientific literature, higher accuracy rates were previously (and recently) reported from estimating age using photoanthropometric analyses. Authors used Joint Mutual Information (JMI) calculated from morphological changes in the human face to distinguish participants that were younger or older than 10, 14 and 18 years. By means of ROC curve analysis they obtained accuracy rates of 0.971, 0.969 and 0.903, respectively [6]. The reduced accuracy rates obtained in the present study is justified, firstly, by the development of two logistic regression models for each age threshold – one for females and one for males. In the previous study, the authors did not designed models specifically based on sex. It is estimated that their mean accuracy rate would decrease nearly 22 % by splitting their model for females and males. A second factor that also played an important part in the present study is the sample selection based on the ancestry of the participants – which were all Caucasian Brazilians with European ancestry. In the previous study, sampling strategies based on (uniform) ancestry were not applied.

The accuracy of an age estimation method that is designed to make forensic inferences related to the age threshold of 14 and 18 is extremely relevant for application in practice. Lack of justice and wrongful convictions are the consequence of incorrectly classifying crime victims and perpetrators based on age [19]. From a forensic point of view, there are two main types of errors that may occur from the application of a

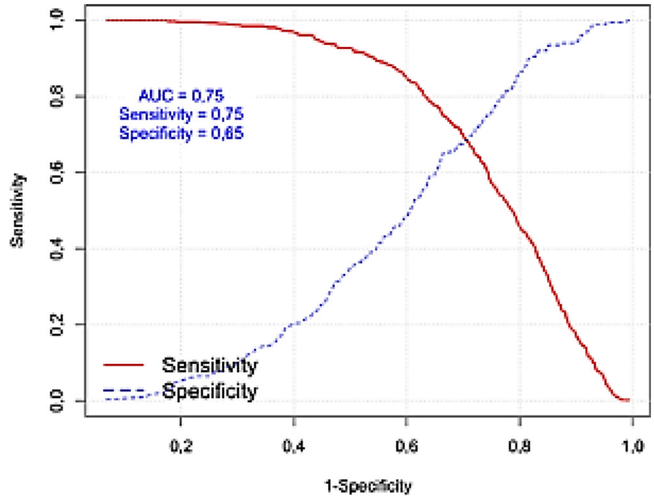

Fig. 2. Receiver Operating Characteristics curve (ROC) outcomes of the statistic model designed to distinguish females aged >14 years.

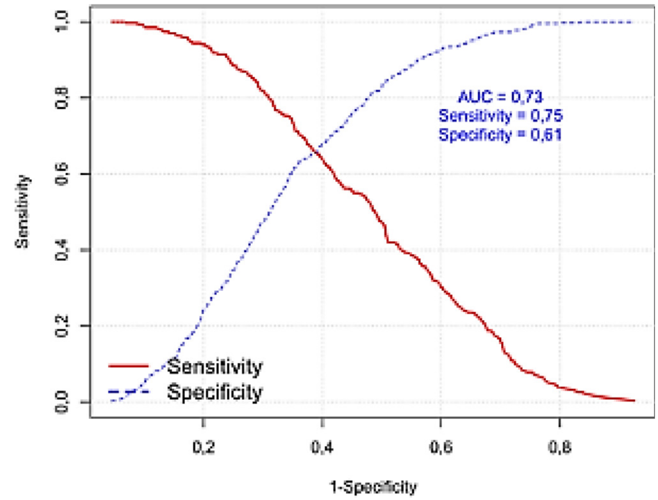

Fig. 3. Receiver Operating Characteristics curve (ROC) outcomes of the statistic model designed to distinguish females aged >18 years.

specific technical expertise: false positives and false negatives. In the context of the present study, the first is translated as those participants that were younger than 14 or 18 and were classified above these age thresholds. In practice, false positives will induce a less severe judgment of perpetrators because the victims were classified above the age of sexual consent. On the other hand, false negatives represent the participants that were classified below the age of legal consent (<14) and age of majority (<18) when in fact they were older. In these cases, the judgment of perpetrators is more severe because of their sexual involvement with minors. In the worst scenario, the false negative outcomes may lead to the conviction of an innocent based on the crime of child pornography. In the present study, false negatives among females reached 25 % for both the age threshold of 14 and 18, while in males it reached 19 % and 16 % for the ages of 14 and 18, respectively.

The present study was innovative because it resulted in outcomes from a large and standardized database. The photoanthropometric analysis of the human face figured as an available tool for studying the morphological alterations that occur in females and males and their relation with the legal age threshold of 14 and 18 years. In females, the accuracy of this method reached 76 % (for the threshold of 14) and 73 % (for the threshold of 18), while in males it reached 90 % and 83 % for the age threshold of 14 and 18, respectively. Future studies in the Field should investigate the facial morphological changes over the time in different populations – especially because sexually dimorphic features may be influenced by internal and external factors, such as socioeconomic status [20], nutrition and hormonal behavior. Forensic experts must understand that the application of the present technique and findings may be extrapolated toward needs other than the analysis of pedo-pornographic material. For instance, it may provide knowledge to understand how males and females differ based on facial traits (sexual dimorphism), and to point out possible facial age progression of persons reported missing for a long time. Studies dedicated to clarify the application of the technique to these fields are encouraged.

Table 6
Factors that influence on distinguishing males aged above 14 and 18 years.

Variables	> 14 years						> 18 years					
	β	β Pad.	SE	OR	CI - 95 %	p	β	β Pad.	SE	OR	CI - 95 %	p
Intercept	−14.06	−2.21	4.68	–	–	0.003	−31.82	−14.72	3.63	–	–	0.000
IND_022	−0.04	−0.05	0.01	0.96	[0.94; 0.98]	0.001	–	5.66	–	–	–	–
IND_073	0.14	0.03	0.04	1.15	[1.06; 1.26]	0.001	–	–	–	–	–	–
IND_091	0.43	0.31	0.11	1.53	[1.23; 1.90]	0.000	–	–	–	–	–	–
IND_097	−0.11	−0.06	0.01	0.90	[0.88; 0.92]	0.000	–	–	–	–	–	–
IR_10	5.92	3.83	0.93	373.73	[60.37; 2313.68]	0.000	–	–	–	–	–	–
IR_22	8.62	6.33	1.10	5540.78	[641.12; 47884.94]	0.000	6.70	5.66	0.97	812.14	[121.33; 5436.02]	0.000
IR_49	−0.48	−0.24	0.09	0.62	[0.51; 0.74]	0.000	–		–	–	–	–
IND_006	–	–	–	–	–	–	0.13	0.09	0.02	1.14	[1.09; 1.19]	0.000
IND_050	–	–	–	–	–	–	−0.02	−0.03	0.01	0.98	[0.96; 0.99]	0.009
IND_058	–	–	–	–	–	–	0.06	0.01	0.02	1.06	[1.03; 1.10]	0.000
IND_059	–	–	–	–	–	–	0.12	0.09	0.05	1.13	[1.03; 1.24]	0.010
IND_072	–	–	–	–	–	–	0.02	0.01	0.01	1.02	[1.01; 1.04]	0.004
IND_084	–	–	–	–	–	–	0.07	0.05	0.01	1.08	[1.05; 1.10]	0.000
IND_091	–	–	–	–	–	–	0.26	0.14	0.12	1.30	[1.02; 1.65]	0.033
IR_01	–	–	–	–	–	–	−0.20	0.05	0.09	0.82	[0.69; 0.97]	0.024
IR_11	–	–	–	–	–	–	3.59	−0.11	0.78	36.30	[7.81; 168.81]	0.000
IR_50	–	–	–	–	–	–	−2.39	−1.59	1.24	0.09	[0.01; 1.03]	0.053
R^2 (Negelkerke)					54.84 %		40.52 %					
Hosmer-Lemeshow (p-value)					0.289		0.122					
Area Under the Curve (AUC)					0.90		0.83					
Sensibility					0.81		0.84					
Specificity					0.85		0.69					

SE: standard error; OR: Odds Ratio; CI: confidence interval.

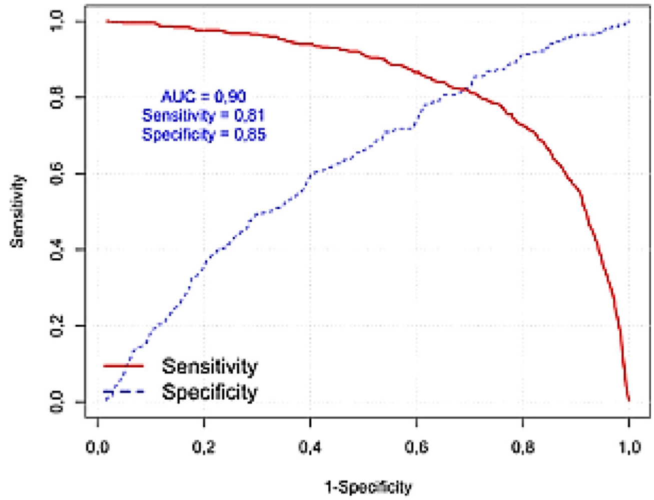

Fig. 4. Receiver Operating Characteristics curve (ROC) outcomes of the statistic model designed to distinguish males aged >14 years.

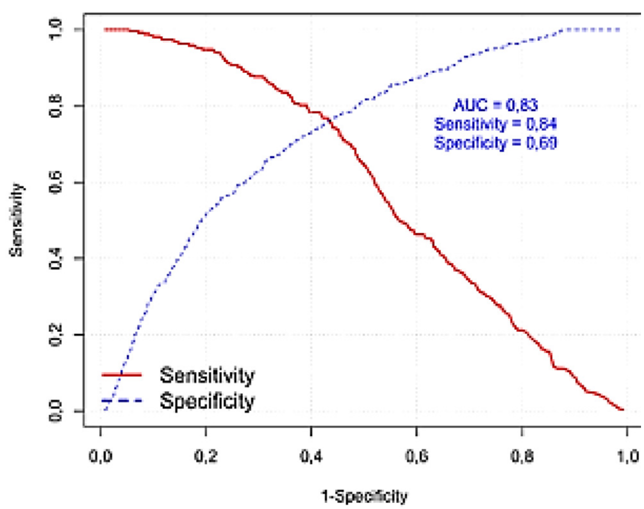

Fig. 5. Receiver Operating Characteristics curve (ROC) outcomes of the statistic model designed to distinguish males aged >18 years.

Compliance with ethical standards

Ethical approval from the Institutional Committee of Ethics in Human Research was obtained for this study (protocol: CAAE-51448515.0.3002.0075), and properly included aspects related with informed consent.

Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.fsir.2020.100131.

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