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ORIGINAL ARTICLE

The juvenile face as a suitable age indicator in child pornography cases: a pilot study on the reliability of automated and visual estimation approaches

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Abstract
Objective In cases of suspected child pornography, the age of the victim represents a crucial factor for legal prosecution. The conventional methods for age estimation provide unreliable age estimates, particularly if teenage victims are concerned. In this pilot study, the potential of age estimation for screening purposes is explored for juvenile faces. In addition to a visual approach, an automated procedure is introduced, which has the ability to rapidly scan through large numbers of suspicious image data in order to trace juvenile faces.
Methods Age estimations were performed by experts, non-experts and the Demonstrator of a developed software on frontal facial images of 50 females aged 10–19 years from Germany, Italy, and Lithuania. To test the accuracy, the mean absolute error (MAE) between the estimates and the real ages was calculated for each examiner and the Demonstrator.
Results The Demonstrator achieved the lowest MAE (1.47 years) for the 50 test images. Decreased image quality had no significant impact on the performance and classification results. The experts delivered slightly less accurate MAE (1.63 years). Throughout the tested age range, both the manual and the automated approach led to reliable age estimates within the limits of natural biological variability.
Conclusions The visual analysis of the face produces reasonably accurate age estimates up to the age of 18 years, which is the legally relevant age threshold for victims in cases of pedo-pornography. This approach can be applied in conjunction with the conventional methods for a preliminary age estimation of juveniles depicted on images.

Keywords Age estimation · Automated age estimation · Child pornography · Juvenile pornography

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Introduction

The lives of children victimized through child pornography are forever affected, not only by the abuse, but also by the permanent record of exploitation [1, 2]. The progress of new technologies, particularly the Internet, facilitates relatively anonymous dissemination of and access to child pornographic material leading to a profitable criminal business which is increasingly spreading around the world. Several thousands of search queries for images of sexually abused children are carried out daily [3–5]. It is estimated that more than 1,000 new pedo-pornographic images and videos are

uploaded to the Internet every week [6, 7]. In Germany, the number of cases concerning production, possession, and distribution of child pornography increased by 94 % between 2006 and 2007 [8]. A similar trend (93 %) has also been observed by an Italian non-profit organization, which focuses on the protection of minors [9, 10].

In addition to the large number of images that have to be examined by the investigating authorities in cases of suspected child pornography, another major challenge presents itself, which is to determine the age of the depicted victims. Article 1 of the UNCRC, the United States Federal Child Exploitation Law, and the Framework Decision 2004/68/JHA of the European Union Council on combating the sexual exploitation of children and child pornography jointly define a "child" as any person below the age of 18 years. In some European countries such as Germany, depictions of children younger than 14 years are termed as child pornography and depictions of adolescents under the age of 18 years as juvenile pornography.

Since investigators are usually not able to identify the individuals depicted in the images, it is often very difficult to ascertain whether the image contains a child or an adult, especially when pubescent children and adolescents are concerned. Due to this uncertainty, cases involving pornographic depictions of adolescents are less likely to be prosecuted. Paradoxically, teenagers are more frequent victims of commercial pornography than younger children, and they are equally often subjected to sexual abuse by family members and acquaintances [2, 3, 11]. Moreover, Steel [5] showed that in peer-to-peer networks, 76 % of age-specific searches in connection with pornography focused on victims aged between 11 and 16 years. Similarly, Wolak et al. [12] found that 75 % of images secured from arrested possessors of child pornography displayed children between 13 and 17 years of age.

However, until now, there has been no scientifically established method for age assessment based solely on images. Particularly, if the pubescent children up to 18 years are considered, the application of the conventional methods (i.e., the assessment of secondary sexual characteristics and dental status) will not provide reliable age estimates [13–15].

Because of the shortcomings of the existing methods, a group of European researchers has focused its attention on the face, in order to verify if the age-related information can be obtained from the growth changes of the facial proportions of children and juveniles [16–18]. For this purpose, a large data set including facial photographs and anthropometric data from 3–21-year-old males and females were acquired. As an important outcome of this project, an automated software Demonstrator was developed to assist the investigating officers in the stressful and time-consuming task of scanning huge numbers of suspicious images. The Demonstrator automatically extracts facial sub-images from the scanned data sets and sorts these images according to the estimated age in an ascending order.

The aims of this pilot study include (1) testing the human ability to estimate the age of 10–19-year-old females based on their frontal facial images and (2) comparing the results of age estimation performed by forensic experts, laymen, and the Demonstrator, particularly, with respect to the legally significant age thresholds (i.e., 14 and 18 years). As a measure of accuracy of the age estimation, the mean absolute error between the real age of the test person and the estimated age was used.

Methods

The standardized facial images were collected during the implementation of the EU-funded international project AGIS 2005. The project has explored the possibility of extracting age-related information from the changes in facial proportions of children and juveniles [17]. For this purpose, a large data set including facial photographs and anthropometric data from 10–19-year-old females was acquired. The study was approved by the Ethics Committees of the three participating countries (Germany, Italy, and Lithuania). Moreover, the subjects and their parents (in the case of minors) signed an informed consent prior to their participation.

For each subject, five standardized photographs were acquired with the focus on seilion (the deepest point of the nasal root depression), and the distance between the test person and the camera equal to 1.5 m. A constant distance was assured by using a mat with fixed marks for the position of the chair and the camera stand. The head of the test person was oriented in the Frankfurt plain and photographed with a digital camera in the following positions: left lateral (90 °), 45 ° left, frontal, 45 ° right, and right lateral (90 °). In this initial study, only the frontal images were used. The exact age of the test person was defined in months counted from the birth date to the examination date.

The visual approach

The age estimations were performed on frontal facial images of 50 females from Germany, Italy, and Lithuania. The subjects on the images were between 10 to19 years old, which was however, not known to the examiners. The examiners were presented with a scoring sheet where they selected the most likely age category and noted the absolute age as a natural number for each female. The choice of age categories were: younger than 12 years, 12–14 years, 14–16 years, 16–18 years, and older than 18 years.

The information available about the examiners were professional status, sex, age (younger/older than 40 years), and the country of origin. There were 14 professionals (anthropologists and forensic pathologists) and 31 non-experts participating in the test. Out of these, 17 were males and 28 were females; 33 (73.3 %) were younger than 40 years. Most examiners are from Germany (23), while 10 are from Italy and 12 from Lithuania.

Statistical analysis was performed using IBM SPSS Statistics 18 software. The mean absolute error of the age estimates for 50 images was calculated for each examiner and for the Demonstrator software. The mean absolute error was used as a measure of accuracy, showing how close the estimate is to the actual value without reference to over- or under-prediction.

The automated approach (using "Demonstrator" software)

One of the aims of the study was to develop a method for automated age estimation based on facial proportions of juveniles and to evaluate the performance and the limitations of this method under optimal conditions by using laboratory image data.

Automatic extraction of facial features

The first step of the procedure was to automatically detect faces on images. To extract facial regions from huge image data sets, the developers employed their core face recognition technology. One of the approaches includes the application of patented hierarchical graph matching technology [19, 20]. As the name implies, a critical ingredient of this method is the use of a graph, i.e., a set of nodes and connecting edges, which represents the facial geometry. During the process, the graph locates itself onto the face in a way that its nodes converge to predefined salient points, so-called landmarks. The flexibility of the graph further allows an adjustment to the size, pose, and facial expression. This process runs fully automated and thus solves the face-finding problem. Instead of using the raw image pixels, graph matching transforms the image information to features more suitable for automatic recognition than the gray-level information. Graph matching makes use of specialized kernel functions, which are robust against undesirable influencing factors such as changes in illumination and contrast. For feature generation, a set of these filter functions is applied to each node of the graph, providing a facial template that forms an abstract representation of a human face.

Age estimation

Age estimation was done by determining the similarity between the facial templates of an individual of unknown age with facial templates that belong to individuals of known age. In a statistical sense, the similarity values resulting from the comparison of facial templates of individuals of the same age would be higher than similarity values resulting from the comparison of facial templates of individuals of a different age.

In order to estimate the age of a person, the relevant age range of 10–19 years was divided into several disjoint age classes. For each class, a number of reference images of persons with known age were selected. Several state-of-the-art classifiers (i.e., linear and non-linear, Fisher's Linear Discriminant Analysis (Fischer LDA) [21, 22], Neural Networks [21, 22], and Support Vector Machines [21, 22]) were implemented and trained with these reference data and fused by an Adaptive Boosting (AdaBoost) [21, 22] approach in the sequel. As a result, the software Demonstrator was developed for the automated age estimation and sorting by age based on facial images of juveniles.

Results

Table 1 shows the values for the mean absolute error (MAE) by country of the test person and by expert status and country of the examiners. The MAE for all 50 images was 1.47 years for the Demonstrator, 1.63 years for the experts, and 1.84 years for the laymen. The mean absolute error of the age estimations was significantly different between the experts and the non-experts (t test, p <0.045). The differences between the experts and the non-experts within the three countries follow a similar pattern, that is smaller mean absolute errors were observed for the experts (see Table 1). It is important to note that the indicated mean error is an averaged error in a statistical sense. The error of the age estimate for a given individual may differ from this mean value.

In the European Union, any person under the age of 18 years is defined as being a child in the context of child pornography. However, some legal systems distinguish two crucial age thresholds, namely, depictions of children younger than 14 years are termed as child pornography, depictions of adolescents between the age of 14 and under the age of 18 years as juvenile pornography. Concerning these age categories, the Demonstrator was able to identify all females that were younger than 18 years (10–18 years) correctly. Experts recognized 93.7 % of under 18-year-old females as such, while non-experts categorized 87.4 % of these girls correctly. To estimate, the age group of girls younger than 14 years correctly proved to be more difficult; the Demonstrator classified 88.0 % of these females correctly, the experts 66.6 %, and the laymen only 56.0 %.

These results were achieved on images acquired under laboratory conditions with a resolution of about 2,000×

Table 1 Mean absolute errors (MAE) in years and standard deviations for the age estimation based on facial images of 50 females from Germany, Italy, and Lithuania

	Examiner (country)	Number	Total MAE (SD)	Number	Experts MAE (SD)	Number	Non-experts MAE (SD)	Demonstrator MAE (SD)
All images	Germany	23	1.70 (0.2)	8	1.57 (0.2)	15	1.77 (0.3)	1.47
	Italy	10	2.02 (0.4)	1	2.00	9	2.03 (0.4)	
	Lithuania	12	1.70 (0.3)	5	1.66 (0.1)	7	1.73 (0.4)	
	Total	45	1.77 (0.3)	14	1.63 (0.2)	31	1.84 (0.4)	
German test persons	Germany	23	1.64 (0.3)	8	1.55 (0.2)	15	1.68 (0.4)	1.56
	Italy	10	2.04 (0.7)	1	1.15	9	2.14 (0.7)	
	Lithuania	12	1.79 (0.5)	5	1.62 (0.2)	7	1.92 (0.7)	
	Total	45	1.77 (0.5)	14	1.55 (0.2)	31	1.87 (0.6)	
Italian test persons	Germany	23	1.93 (0.4)	8	1.78 (0.4)	15	2.00 (0.4)	1.31
	Italy	10	2.05 (0.4)	1	1.93	9	2.07 (0.5)	
	Lithuania	12	1.73 (0.3)	5	1.73 (0.3)	7	1.73 (0.4)	
	Total	45	1.90 (0.4)	14	1.77 (0.4)	31	1.96 (0.4)	
Lithuanian test persons	Germany	23	1.57 (0.2)	8	1.39 (0.2)	15	1.66 (0.2)	1.21
	Italy	10	1.96 (0.5)	1	2.63	9	1.89 (0.4)	
	Lithuania	12	1.52 (0.3)	5	1.50 (0.3)	7	1.53 (0.4)	
	Total	45	1.64 (0.4)	14	1.52 (0.4)	31	1.70 (0.4)	

2,000 pixels (portrait photo style). Therefore, it was necessary to test the influence of lower quality images on the classification results of the Demonstrator. From the large spectrum of possible influencing factors that lead to low-image quality, different head poses, lower image resolution, and blurring were selected for testing. The tests revealed that moderate head poses of less than 20 °, reduction of the original image resolution from about 2,000×2,000 pixels (portrait photo style) to about 128×128, and artificial blurring of the original images with a smoothing operator of pixel width less than 40 pixels does not have a significant impact on the computed classification errors. It needs to be acknowledged though that image data in real cases often depict faces in arbitrary head poses including facial expressions and partial occlusions. Such images may only be thumbnails with a resolution of about 20×20 pixels. Such variations are not covered by the Demonstrator and will need conceptual extensions.

The Demonstrator consists of two parts. The front-end and the classifiers were implemented within the study. The underlying technology for face detection, feature extraction, and the computation of a facial template formed pre-existing know-how and was only made available to the project. The demonstrator runs on a standard PC and was only available to the partners of the study.

Discussion

In the past two decades, international organizations and law enforcement agencies around the world have focused substantial attention on the issue of child pornography in order to achieve suitable national legislations and an international harmonization of legal procedures. Although national criminal codes concerning (pedo)-pornography differ in some respects, in general, any visual depiction of sexually explicit conduct involving a person younger than 18 years of age is considered illegal [7, 11, 23].

In some countries, the degree of the offense, and simultaneously, the sentence, depend on the age of the victim; the younger the portrayed child, the greater the offense and the stricter the judicial sentence [2, 6]. Therefore, the assessment of the victim's age has significant legal implications in cases of suspected child pornography. Moreover, an accurate age estimate might be of crucial importance for the identification of the victim depicted on the images and for establishing the time intervals during which the abuse took place. In order to assess the victim's age on images or videos, gynecologists, pediatricians, or more often, forensic pathologists and forensic anthropologists are consulted by the magistrates as expert advisors [23–27].

The conventional method used for age estimation on images is largely based on the evaluation of secondary sexual characteristics of the victims. This approach shows two main shortcomings: (1) the ill use of Tanner stages for the estimation of chronological age and (2) the limitation of the application in cases of pubescent and adolescent victims. The use of Tanner stages for the development of pubic hair, genitalia, and breasts for aging individuals on images has been severely criticized considering the large inter-individual and inter-population variability observed in sexual maturation [28–33]. In addition, this method proved to

be highly inaccurate when tested, mainly because it is impossible to compare the evaluation of photographic staging with a complete medical examination [13–15, 32]. Similarly, although the evaluation of dental status is of crucial importance in the age assessments of living individuals on images, it is very difficult to obtain enough information to correctly evaluate the developmental stage of the dentition even if the subject's mouth happens to be open [26, 27].

Another problem for the investigating authorities represents the sheer amount of image data that have to be viewed and analyzed. Offenders may possess collections consisting of over a million images of sexually exploited children [7, 12]. Therefore, there is a demand for innovative computer-based tools that would support investigating authorities in the strenuous task of scanning through the seized image material.

In the present study, the potential of the face as an age indicator was tested, particularly with regard to the legally relevant age thresholds (i.e., 14 and 18 years). Facial images of 10–19-year-old females were the object of the age estimation performed by experts, laymen, and an automated software Demonstrator. As a measure of accuracy of the age estimation, the mean absolute error between the real age of the test person and the estimated age was used.

The results show that the visual analysis of the face leads to reasonable age estimations within the limits of natural biological variability. The software Demonstrator achieved on average slightly better results in the age estimation than the experts and non-experts, on top of the incomparable scanning speed of more than 1,000 images per minute. In addition, experts performed on average better than non-experts. Therefore, the involvement of expert advisors for age estimation of victims in cases of suspected child pornography is recommended.

The performance of the Demonstrator was tested on laboratory data and also evaluated on lower quality photographs since, in practice, the retrieved images are often of lower resolution, blurred, or the head positions of the depicted persons vary. The results showed that the classification errors were not notably altered compared to those computed for images taken under laboratory conditions.

Based on the results of this pilot study, the analysis of age-related changes of the craniofacial complex is proposed as a complementary method in establishing the age of victims depicted on images or videos. Particularly, if pubescent or adolescent victims are concerned, this method provides satisfactory results outside the domain of conventional methods.

The ability of the automated procedure to perform a fast and successful search for faces of minors will be beneficial in cases where large data sets have been seized by the law enforcement with the suspicion that they might contain child pornography. This, by no means, signifies that it should be used as an instrument for expert testimony. It should only be used as a preliminary step to age assessment which, in the case of an indication of an age younger than 18, should then be followed by a more thorough examination of the image with methods which may develop through further research [16].

Conclusions

This pilot study points out an innovative way towards a more precise method of age estimation of juvenile subjects portrayed on suspected pedo-pornographic material by using the face as an age indicator. The results of the accuracy tests on the age estimations showed that the automated approach performs on average slightly better than the visual approach, when applied by professionals. Non-experts deliver the least accurate age estimates. In addition, the substantial advantage of the automated procedure is its scanning speed. Therefore, this method can be applied as a quick and reliable method of screening for young faces. Moreover, by using this approach, more accurate age estimates are possible for pubescent and adolescent victims, who in legal proceedings represent the most difficult ones with evident consequences [2, 11].

The final aim of the project is to develop a refined method for age estimation based on a morphometric analysis of the juvenile face, which may be used by expert witnesses which goes beyond the initial screening procedures. Furthermore, the Demonstrator still needs to be tested on males and on victims of non-European origin.

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