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Study on the performance of different craniofacial superimposition approaches (II): Best practices proposal

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ABSTRACT

Craniofacial superimposition, although existing for one century, is still a controversial technique within the scientific community. Objective and unbiased validation studies over a significant number of cases are required to establish a more solid picture on the reliability. However, there is lack of protocols and standards in the application of the technique leading to contradictory information concerning reliability. Instead of following a uniform methodology, every expert tends to apply his own approach to the problem, based on the available technology and deep knowledge on human craniofacial anatomy, soft tissues, and their relationships. The aim of this study was to assess the reliability of different craniofacial superimposition methodologies and the corresponding technical approaches to this type of identification. With all the data generated, some of the most representative experts in craniofacial identification joined in a discussion intended to identify and agree on the most important issues that have to be considered to properly employ the craniofacial superimposition technique. As a consequence, the consortium has produced the current manuscript, which can be considered the first standard in the field; including good and bad practices, sources of error and uncertainties, technological requirements and desirable features, and finally a common scale for the craniofacial matching evaluation. Such a document is intended to be part of a more complete framework for craniofacial superimposition, to be developed during the FP7-founded project MEPROCS, which will favour and standardize its proper application.

INTRODUCTION

Participation in the study included representatives of presti-gious forensic laboratories and police forces, which in conjunction cover almost every approach described in the literature (and other methodologies not published). They represent the different historical schools of forensic anthropology, which over the last century have focused their studies in craniofacial morphometry and morphology. Thus, each participant carries out craniofacial superimposition following their own particular methodology and using their own technological means. The overall procedure differs slightly across the participants. The articulation of the mandible to the cranium was identified as the first main difference. Then, the process of adjusting the skull and face images varies significantly: some focusing on a specific pair of homologous landmarks, others relying more on a global adjustment of the facial and skull contours or morphological consistency. There were a few participants who solved the latter problem using a mathematical formulation that can be automati-cally produced using optimization methods. Another important difference refers to the technological approach. Craniofacial superimposition (CFS) has evolved as new technology has become available, although the foundations were laid in early anthropology [1,2]. A large number of diverse approaches can now be found in the literature [3–5]. Thus, the number of technological approaches that coexist is increasing: photo CFS, video CFS, computer-aided photo CFS, computer-aided video CFS, computer-aided 3D–2D CFS, manual, semi-automatic and automatic approaches, etc. The other main difference is related to the criteria applied to assess the anatomical consistency between the skull and the face. Besides the different population studies utilized according to the characteristics of the cases, participants employ different anatom-ical criteria: contours, lines, proportions, landmarks and soft tissue depth studies at those points, morphology, asymmetries, and positional relationships. The differences are not only in relation to the criteria, but also on the assessed weight of those criteria in the skull–face relationship. Finally, each expert has his own decision scale, with a different number of labels, different names and meanings, and movement along the scale may be according to different criteria. Thus, a multiple-lab study on craniofacial superimposition has been carried out for the first time. In particular, 26 participants from 17 different institutions in 13 countries were asked to deal with 14 identification scenarios, some of them involving the comparison of multiple candidates and unknown skulls. In total, 60 craniofacial superimposition problems, divided in two sets of females and males, were analysed. Participants followed their own methodology and employed their own particular technology [6]. The ‘New Methodologies and Protocols of Forensic Identifica-tion by Craniofacial Superimposition (MEPROCS)’ project aims to propose a common framework, avoiding particular assumptions that could bias the process, to allow the extensive application of the CFS technique in practical forensic identification scenarios. At the end of this study, the objective was to produce quantitative and qualitative information to facilitate an informed discussion on:

- Best practices
- Practices that should be avoided
- Requirements and desirable features of the technological means employed
- The definition of a standard decision scale including the requirements of each decision grade
- Identification of the main sources of error along the CFS process
- Identification of the main sources of uncertainty

This manuscript presents the results of this discussion and the corresponding agreement, which can be considered the first standard in the field; including good and bad practices, sources of error and uncertainties, technological requirements and desirable features, and finally a common scale for the craniofacial matching evaluation.

MATERIALS AND METHODS

All MEPROCS partners were provided with a detailed report summarizing the results of the study together with the individual results of each participant. In particular, the report included: (i) a summary of every methodology followed by each participant; (ii) global performance together with false/true positive/negative identification rates achieved by each participant; (iii) performance on male and female data sets separately and integrated; (iv) performance grouped by level of experience and by technological approach; and (v) all superimposition images and skull–face relationship reports grouped by case (only in those cases with a higher variability and worst performance). MEPROCS partners attended a meeting in Jerusalem (Israel) and then a second meeting in Salerno (Italy) to reach agreement on the standards. The list of participants involved in the discussion were: C. Wilkinson (University of Dundee, Scotland), T. Kahana (Israel National Police, Israel), E. Veselovskaya (Russian Academy of Sciences, Russia), R. Jankauskas (Vilnius University, Lithuania), P. T. Jayaprakash (University Sains Malaysia, Malaysia), E. Ruiz (Com-plutense University of Madrid, Spain), F. Navarro and M. Huete (University of Granada, Spain), E. Cunha (University of Coimbra, Portugal), F. Cavalli (Azienda Ospadaliera-Universitaria di Trieste, Italy), J. Clement (University of Melbourne, Australia), P. Lesto´n and F. Molinero (Spanish Civil Guard, Spain), T. Briers (South African Police Service, South Africa), F. Viegas (Policia Judiciaria, Portugal), K. Imaizumi (National Research Institute of Police Science, Japan), D. Humpire (Legal Medicine and Forensic Sciences Institute, Peru), A. Abramov (Moscow Region State Bureau of Forensic Examination, Russia), S. Damas and O. Iba´n˜ez (European Centre for Soft Computing, Spain). The following section describes all the agreed conclusions after days of discussions.

RESULTS

An in depth analysis of all the resulting superimposition images in correlation with the respective analysis of the skull–face relationship identified the main sources of errors.

3.1. Main sources of error in craniofacial superimposition

1. Skull–face overlay and, in particular, the adequate perspective of the skull. For example, most of the software programs employed for this task do not allow alteration of the projection, but ‘‘just’’ the orientation and scaling. In many cases it involves an error-prone trial and error process. Orientation + scaling + perspective.

2. The digital articulation of the mandible and cranium after scanning can introduce errors. With no access to the occlusion as it was in life, the mandible may have been placed in an incorrect position with respect to the cranium.

3. The attachment of the mandible to the cranium.

4. The replication of the AM position of the mandible.

5. The incomplete preservation and post-mortem reassembly of the skull. For example, the incorrect positioning of teeth in the sockets.

6. The inaccurate 3D skull acquisition (or segmentation in case of CT scanner), precision below <1 mm and/or specific features not properly scanned (or segmented). The latter was recorded at the nasal region, the teeth and the orbits. Presence of artefacts.

7. The aspect ratio of the photograph (the ratio between horizontal and vertical sizes of the image).

8. The unknown origin of the AM photograph, i.e., when the AM photograph is not the original one acquired by a digital camera (original digital file) or an analogic one (original revealed photography).

9. The post-mortem skull damage.

All the above issues are considered sources of errors, thus, they should be considered in order to avoid accumulating and propagating errors during the CFS process. In addition, there are several issues that can negatively affect conclusions based on CFS but, unlike sources of errors, they cannot be avoided. In contrast, they have to be considered an inherent part of the process, and thus, they have to be properly modelled and incorporated in the decision making process. Unlike complete and precise knowledge, the latter issues represent partial, incomplete, imprecise and/or vague information. We thus referred to them as sources of uncertainty.

3.2. Main sources of uncertainty in craniofacial superimposition

1. Cephalometric landmark location uncertainty: this is related to the extremely difficult task of locating the points in a completely reproducible manner. The variability may arise from reasons such as: a. variation in the distribution of shadows that are dependent on lighting condition during photography b. unsuitable camera focusing, especially when the plane of focus is too shallow and hence the critical features are not sharp c. poor image quality, i.e. low resolution d. face posture in the photograph, i.e. facial expression and angle of view of the face (lateral, frontal or oblique) e. landmark occlusion due to the presence of elements such as hair or glasses f. imprecise definition of some anthropometric landmark, could be either due to ambiguous terminology or because it is poorly defined in an anatomical sense.

2. Landmark matching uncertainty: refers to the imprecision that is involved in the matching of two sets of potentially corresponding landmarks derived from two different objects, a face and a skull. a. The correspondence between facial and cranial anthropometric landmarks is not always symmetrical and perpendicular to the skin surface and to the underlying bone. b. The facial soft tissue depth varies for each cephalometric landmark, as well as for different populations (based on age, race, and sex). c. Considerations of how the distances between potentially corresponding landmarks are affected by the posture and facial expression in the image have to be taken into account. d. There are many studies describing the uncertainty related to differing soft tissue depths for different populations but almost none of them considered the projection of those distances onto the AM photo used in the comparison.

3. Skull–face overlay uncertainty: there is no precisely quantifiable way of determining when an accurate superimposi-tion has been achieved.

4. There are many unknown (and/or uncertain) parameters involved in the replication of the original photographic conditions used to produce the image employed in the comparison.

5. Morphological criteria are subjective or difficult to quantify.

6. The amount of morphological criteria that have to be satisfied for a positive identification.

7. The effects of dental changes detected from examination of the AM photographs used for comparison with the skull, as well as their accurate interpretation.

8. Age related changes in the craniofacial morphology children need to be investigated and documented more comprehensively before comparisons between images taken at different times during childhood can be compared.

The following ‘‘best practices’’ and ‘‘practices that should be avoided’’ represent some guidelines to minimize or avoid the main sources of error, as well as, to deal with the sources of uncertainty that are concomitant to the application of CFS. These steps should be viewed as recommendations and under no circumstances should they be perceived as requirements to accomplish a ‘‘valid’’ result. The authors are fully aware that the circumstances of each case are to be taken into consideration, when evaluating the results of an identification based on craniofacial superimposition.

3.3. Best practices in craniofacial superimposition

1. Use the real skull to confirm correct fit of the mandible with the cranium.

2. Use the real cranium and mandible to articulate the dentition and establish centric occlusion.

3. Reproduce the position of the mandible as displayed in the AM photograph.

4. Locate and mark landmarks on the skull before scanning.

5. Use multiple (more than one) AM photos or frames taken from video with the candidate in different poses, as far as they provide new information, e.g. more anatomical information provided by additional viewpoints.

6. Use AM photographs of good quality. For optimal examination of full frontal images the resolution of the face image should be at least 180 pixels corresponding to the width of the head, or roughly 90 pixels between the pupils of the eyes (ISO International Standard ISO/IEC JTC 1/SC 37 N506).

7. Avoid images with obscuring objects, e.g. spectacles and beards.

8. During the growth period of children’s lives, always use the most recent AM photos. For adults, use the most informative photos.

9. Perform CFS using original AM images, avoiding as much as possible image manipulation.

10. Throughout the entire CFS process, be careful to preserve the aspect ratio of the photograph.

11. Keep all the information contained within the original image (do not use cropped images which introduces error).

12. Extract, as much as possible, information from the photograph (both digital information included in the Exif file and visual information) to infer original photographic conditions (e.g. approximate distance from the camera to the subject’s head, camera model, focal length, etc.)

13. Analyse and describe separately both the skull and the face in the photograph(s) to be compared. This will include (general morphology, specific dimensions, and any special, potentially individualizing, characteristics) prior to superimposition.

14. When multiple candidates are available, sort AM photos to be compared by reference to the existing description of the skull and prioritize them in a sequence of most to least likely to correspond.

15. Use as many criteria as possible in order to study the relationship between the face and the skull.

16. Consider the discriminative ‘‘power’’ of each anatomical criterion.

17. Give an appropriate ‘‘weight’’ to each criterion according to the degree of uncertainty related to it, which will depend also on the AM view.

3.4. Practices in craniofacial superimposition that should be avoided

1. Confirmation bias (e.g. coercive situations with investigating authorities, a misplaced enthusiasm to be a good citizen and be helpful etc.).

2. Attempt CFS on edentulous skulls (except in cases where skull morphology is highly individualizing with extreme malforma-tions).

3. Using just one single, low resolution, frontal passport-style photograph for comparison.

4. Cases where the subject is under the age of 5 years.

In close relation the technological means employed must also be considered. If these do not fulfil some basic requirements they can be part of the problem, generating errors and/or introducing more uncertainty. In contrast, they can provide an invaluable support when they incorporate, together with those requirements, some desirable features that help to reduce errors, uncertainty and the time employed. While the requirements list is intended to be a complete list of features that all the equipment have to fulfil, the desirable features should be considered an open list that can increase in line with the new research advances in the field.

Tables 1 and 2 are devoted to both the requirements and desirable features of the two main technological approaches that coexist in CFS: computer-aided and video superimposition.Finally, Table 3 collects a gradual scale for decision-making in CFS. The degree of support that a specific CFS identification case can achieve must be in line with the quality and quantity of the materials (AM photographs, mandible, and cranium). Additionally, there could be discriminatory characteristics that allow modification of the latter degree of support given an appropriate explanation. That is to say, Table 3 presents some guidelines to choose the most adequate degree of support. Considering the materials examined and the consistency of the matching between the face and the skull a final decision should be provided in terms of strong, moderate or limited support to the assertion that the skull and the facial image belong to the same person. This way, when the cranium with corresponding mandible is complete, there is sufficient dentition to evaluate occlusion and there are at least two photos in different poses of sufficient quality whatever the decision (being or not being the same person) the degree of support should be strong. When there is only one photo of sufficient quality, sufficient part of the cranium with corresponding mandible, and sufficient dentition to evaluate occlusion the degree of support should be moderate. Finally, when there is insufficient dentition to evaluate occlusion or incomplete skull and one photo of sufficient quality or complete skull and one poor quality photo, the degree of support should be limited. As explained before, there could be discriminatory characteristics that allow increasing or decreasing the degree of support given an appropriate explanation in the report (e.g. asymmetries, special facial signs, etc.)

DISCUSSION AND CONCLUSIONS

CFS is a controversial technique in forensic anthropology. The lack of standards and objective evaluation measures limits the use and consolidation of CFS. A common effort on the standardization of CFS is thus a real need. That is the main aim of the MEPROCS European project. Under the MEPROCS umbrella, it was accom-plished the first study on CFS jointly developed by a significant number of labs in 13 countries. In the study, the participants followed their own methodological approach to face a common set of CFS problems. The analysis of the results of this first study facilitated an international agreement on different aspects of CFS. This manuscript presents the results of this discussion which can be considered the first standard in the field; including good and bad practices, sources of error and uncertainties, technological requirements and

desirable features, and finally a common scale for the craniofacial matching evaluation. These critical criteria will help practitioners to make a decision on the applicability of CFS in daily forensic caseworks. This is the first step to attain similar international standards in CFS. In particular, analogous efforts should be made to analyse the reliability of the technique. Until these reliability studies are not performed, it can be argued that the utility of CFS is still marginal.

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Table 1
CFS requirements and desirable features for computer-aided equipment.

Tools for computer-aided craniofacial superimposition (3D skull model-2D face image)		
Type/name	Requirements	Desirable features
3D scanner or CT scanner	Precision <= 1 mm	Capture of texture information Multi-slice computer tomography (MSCT)
Software for landmark location	Tool to locate landmarks in a single pixel	Tool to locate landmarks in a region
Software for performing the skull–face overlay	Show landmarks Transparency mode Tools to rotate, translate and scale the 3D skull Tool to properly project 3D skull on 2D	Wipe mode Simultaneous interaction with 3D skull and the AM photograph
Software for assessing the skull–face relationship	Transparency mode	Show landmarks and contours Wipe mode Tool for measuring Euclidean and surface distances between points or perimeters Tool for marking lines or contours

Table 2
CFS requirements and desirable features for video superimposition equipment.

Tools for craniofacial video superimposition (physical skull-2D face image)		
Type/name	Requirements	Desirable features
Two high resolution CCD video cameras each with a TV Zoom lens.	Both of the same make and specification.	Minimum resolution: 600 pixels. Zoom lens: manual, 1.2/12.5-7.5 with ability to zoom in focus locked state.
Two high quality camera tripod.	Sturdy and stable while manipulating camera movement.	Facilities to fine adjust the focus maintaining stability.
A digital video vision mixer	Ability to capture analogue images in real time as captured by the CCD cameras.	Ability to mix (fade) as well as wipe the images. Mixing effect should include all types of wipe facility.
A pan and tilt device to which the universal skull clamp can be fitted.	Capable of supporting the skull and effecting the pan and tilt movements as from a device with gears.	Stepwise movement is not desirable. A remote control unit to operate the device is desirable.
A Video Cassette Recorder.	Ability to record the real time analogue images generated during the superimposition.	Enables demonstration of superimposition in analogue state.
A video capture software.	To capture the superimposed images both frame by frame or as video strip.	Enables storage and easy retrieval of images from computer.
Illumination system: vertical stands and lamps.	Stands are to be provided with soft dark blue velvet cloth to avoid shadow.	Florescent lamps are desirable since the lighting is diffuse and white.

Table 3
Decision degrees in CFS. Requirements to be fulfilled in each degree.

All these conditions hold: -Complete cranium with corresponding mandible -Sufficient dentition to evaluate occlusion -At least two photos in different poses of sufficient quality	All these conditions hold: -One photo of sufficient quality -Sufficient part of the cranium with corresponding mandible -Sufficient dentition to evaluate occlusion	Only one condition holds: - Insufficient dentition to evaluate occlusion OR -Either incomplete skull and one photo of sufficient quality OR complete skull and one poor quality photo		Only one condition holds: -Insufficient dentition to evaluate occlusion OR -Either incomplete skull and one photo of sufficient quality OR complete skull and one poor quality photo	All these conditions hold: -One photo of sufficient quality -Sufficient part of the cranium with corresponding mandible -Sufficient dentition to evaluate occlusion	All these conditions hold: -Complete cranium with corresponding mandible -Sufficient dentition to evaluate occlusion -At least two photos in different poses of sufficient quality
Increasing quality and quantity of materials				Increasing quality and quantity of materials		
Strong support	Moderate support	Limited support	Undetermined	Limited support	Moderate support	Strong support
of NOT BEING the same person				of BEING the same person		
There is incompatible inconsistency[1]				There is no incompatible inconsistency[2]		
There could be discriminatory characteristics that allow going left of right within the scale given an appropriate explanation in the report. A Strong support of not being the same person means exclusion						

[1]The skull and the face demonstrate inconsistencies that cannot be explained as effects of age, expression or image issues.
[2]The skull and the face are compatible or any inconsistencies can be explained as effects of age, expression or image issues.