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3D-3D facial superimposition between monozygotic twins: A novel morphological approach to the assessment of differences due to environmental factors

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ABSTRACT

Distinction of one twin with respect to the other, based on external appearance, is challenging; nevertheless, facial morphology may provide individualizing features that may help distinguish twin siblings. This study aims at exposing an innovative method for the facial assessment in monozygotic twins for personal identification, based on the registration and comparison of 3D models of faces.

Ten couples of monozygotic twins aged between 25 and 69 years were acquired twice by a stereophotogrammetric system (VECTRA-3D® M3: Canfield Scientific, Inc., Fairfield, NJ); the 3D reconstruction of each person was then registered and superimposed onto the model belonging to the same person (self-matches), the corresponding sibling (twin-matches) and to unrelated participants from the other couples (miss-matches); RMS (root mean square) point-to-point distances were automatically calculated for all the 220 superimpositions. One-way ANOVA was used to evaluate the differences among miss-matches, twin-matches and self-matches ($p < .05$).

RMS values for self-matches, twin-matches and miss-matches were respectively 1.0 mm (SD: 0.3 mm), 1.9 mm (0.5 mm) and 3.4 mm (0.70 mm). Statistically significant differences were found among the three groups ($p < .01$). Comparing RMS values in the three groups, mean facial variability in twin siblings was 55.9% of that assessed between unrelated persons and about twice higher than that observed between models belonging to the same individual.

The present study proposed an innovative method for the facial assessment of twin siblings, based on 3D surface analysis, which may provide additional information concerning the relation between genes and environment.

1. Introduction

Genetic and environmental interaction on craniofacial morphology has always been a topic of clinical interest in different fields of research [1–3]; however, the genetic background of craniofacial morphology has not been completely clarified yet because of its complexity, resulting in the observed variability of the population [3]. Monozygotic twins represent a useful experimental model for exploring the respective importance of genes and environment, as they share the same DNA, but not the entire set of environmental factors potentially able to influence facial morphology. Examples of environmental factors influencing facial morphology are hormones, nutrition, diseases, trauma, surgery, dento-facial orthodontics, as well as lifestyle variables (such as smoking, alcohol, physical exercise) and oral function (mastication, respiration, swallowing) [4].

On the other side, twins bring about also some issues concerning personal identification in the forensic field; an example is given by the facial recognition of persons from video-surveillance image systems [5].

With time the advancement of technologies has improved the number of 3D approaches in this field and, among the 3D acquisition systems, optical instruments have become essential tools to perform accurate morphometric analyses of the face [6–9].

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Stereophotogrammetry, in particular, is preferable since it is safe, fast and non-invasive and its accuracy and repeatability have already been positively evaluated [10,11]. Three-dimensional facial models can be registered and superimposed, with consequent calculation of point-to-point distances between two surfaces; these parameters, expressed as a mean or RMS (root mean square) value may be used as an index of similarity between the surfaces of different faces [12,13].

This type of approach may provide useful information concerning the relations between genes and environment and to quantify morphological differences between twins. This kind of superimposition has already been performed through laser scanners by Djordjevic et al. who analyzed differences in 3D models of monozygotic and dizygotic twins scaled to the average Procrustes size [1]. The study computed distances between corresponding landmarks and average distances between the points of the two models on the entire surfaces through a best-fit tool based on the iterative close point algorithm [1]. However, the use of laser scanners may show several disadvantages, among which the most important is the need to obtain several acquisitions to be merged in order to obtain the final model. For example, Djordjevic et al. performed two scans for each participant, respectively for the right and left side of the face [1]. Although the time of acquisition between the two scans may be short, the final result may be influenced by possible involuntary, limited facial movements that may play a possible role in biasing facial acquisitions through this method.

On the other side, other methods of acquisition, such as stereophotogrammetry, can provide a 3D model of the entire face in the same time, reducing the possible bias due to involuntary facial movements. To the best of our knowledge no study has so far applied stereophotogrammetric 3D-3D superimposition techniques to the analysis of facial morphology in twins.

Another limitation of existing literature about the facial assessment of twins concerns the lack of a homogeneous comparison between facial differences observed between 3D models belonging to the same individual, monozygotic twins and unrelated persons: this approach may provide additional data for describing more in detail and quantifying the respective weight of genes and environment in determining facial differences.

The aim of the current study is to provide a novel approach to estimate the influence of genetic and environmental effects on facial anatomy of monozygotic twins, based on registration and superimposition of facial 3D models belonging to the same individual, twin siblings and unrelated participants, in order to verify and quantify the relative differences in facial surfaces. This approach may represent a preliminary step for the personal identification of monozygotic twins based on facial morphology and provide also an innovative point of view for assessing the never-ending dilemma of mutual relations between genes and environment.

2. Materials and methods

2.1. Research participants

Ten couples of Caucasoid monozygotic twins, aged between 25 and 69 years (mean age: 30.2 years; SD: 13.3 years), were recruited (six male and four female couples). None of them reported a previous history of facial surgery or trauma. Zygosity was ascertained by genetic tests performed for other reasons not related to the present study.

All the individuals recruited in the study provided informed consent, according to local and international ethical rules. The entire procedure was not invasive or dangerous. The experimental study follows the Helsinki Declaration (seventh edition, 2013). The study was also approved by the University ethics committee 27 June 2014, No. 266 230 92/2014.

2.2. Image acquisition

Every participant was acquired twice through a stereophotogrammetric system (VECTRA-3D® M3: Canfield Scientific, Inc., Fairfield, NJ), an optical instrument with a geometry resolution of 1.2 mm [14]. Facial scans were performed with the participants sitting in front of the system, with closed mouth and a neutral facial expression, in order to standardize the acquisitions [15].

Before the acquisition, 50 facial landmarks were marked on the faces with a black makeup eyeliner. The marking of landmarks onto each participant's face prior to scanning offers a more reliable means of allocating landmarks than using solely the scan data [16,17]: this is because the investigator is able to directly assess bone and soft-tissue relationships. Collocation of landmarks was performed by a trained operator and followed a standardized protocol used in previous studies [18]. The set of landmarks is described in literature [19]. In all cases few seconds elapsed between the two acquisitions that were obtained with the same landmarks positions.

2.3. Facial registration and superimposition

The first step was performed on the entire facial scan and consisted of the semi-automatic selection of a facial area of interest (FAI), according to a previously detailed procedure, which was found to be well repeatable [20].

Once the facial areas of interest (FAI) were identified on the facial models of monozygotic twins, a series of superimpositions was performed. These are described as follows:

(1) The FAIs belonging to the same person, acquired on two different occasions, were superimposed for each couple of monozygotic twin participants, comprising 20 superimpositions. Such superimpositions were called self-matches. This procedure was performed to quantify the facial modifications due to any possible change in facial position involuntary facial mimicry, to be subtracted from the subsequent series of superimpositions; differences between the two models also include possible technical errors from facial registration and superimposition;
(2) Each FAI of a twin was superimposed to the FAI of the corresponding sibling, involving a total of 20 superimpositions. These superimpositions were called twin-matches. In this group, possible differences are due to the technical error, deviations from a neutral facial expression and the environmental variability, as the two participants share the same genetic material;
(3) Each FAI of a twin was superimposed with the FAIs of the other unrelated twins, comprising a total of 180 superimpositions. These superimpositions were called miss-matches. In this case, possible differences are due to the technical error, involuntary facial mimicry, genetic and environmental factors.

Superimpositions were performed following a two-step procedure: first, 9 landmarks were chosen among the 50 previously identified and were manually located on each 3D facial surface in the corresponding eyeliner marks visible on the texture (Fig. 1). This procedure was performed through Mirror® software. Repeatability of the entire procedure has been already verified in a previous publication [10]. Then a preliminary registration was performed in order to reach the least point-to-point distance between these reference points. This step is needed in order to give the first orientation of one surface according to the other one. Finally, a conclusive registration according to the least point-to-point distance on the entire facial surface was performed. Fig. 2 shows the landmarks used to superimpose the FAIs and Fig. 3 shows an example of twin-match. Conventionally, the face of the second born twin was superimposed on the face of the first.

After the superimpositions were performed, the software automatically calculated the point-to-point root mean square (RMS)