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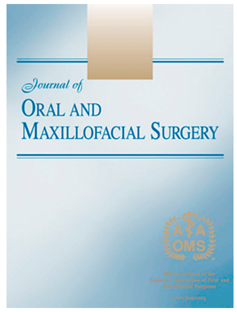

A Quantitative Assessment Of Lips Movements In Different Facial Expressions Through 3d-3d Superimposition: A Cross-Sectional Study

Daniele Gibelli, MD, PhD Researcher, Marina Codari, MSBE Resident, PhD, Valentina Pucciarelli, MBiotech Resident, Claudia Dolci, MD Researcher, Chiarella Sforza, MD Professor

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A QUANTITATIVE ASSESSMENT OF LIPS MOVEMENTS IN DIFFERENT FACIAL EXPRESSIONS THROUGH 3D-3D SUPERIMPOSITION: A CROSS-SECTIONAL STUDY

Daniele Gibelli[1], MD, PhD (Researcher), Marina Codari[2], MSBE (Resident), PhD, Valentina Pucciarelli[1], MBiotech (Resident), Claudia Dolci[1], MD (Researcher), Chiarella Sforza[1], MD (Professor)

1) LAFAS, Laboratorio di Anatomia Funzionale dell'Apparato Stomatognatico

Dipartimento di Scienze Biomediche per la Salute

Università degli Studi di Milano

2) Unit of Radiology

IRCCS Policlinico San Donato

Corresponding author: Dr. Daniele Gibelli

Dipartimento di Scienze Biomediche per la Salute

Università degli Studi di Milano

Via Mangiagalli 31, 20133, Milano, Italy

tel. +39-02-50315399

fax +39-02-50315724

daniele.gibelli@unimi.it

ORCID: 0000-0002-9591-1047

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Abstract

Purpose:

The quantitative assessment of facial modifications due to mimicry is of relevant interest for rehabilitation of patients no longer able to produce facial expressions.

This study aims at proposing a novel application of 3D-3D superimposition to facial mimicry.

Methods:

This cross-sectional study was based on ten male adults aged between 30 and 40 years, who underwent acquisitions by stereophotogrammetry with neutral, happy, sad, angry expressions. Registration of facial expressions on the neutral one was performed. RMS value (root mean square) point-to-point distance in labial area was calculated between each facial expression and the neutral one and was considered the main parameter for assessing facial modifications. In addition, effect size (Cohen's d) was calculated to assess the effects of labial movements in comparison with facial modifications.

Results:

The chosen subjects were all free from possible facial deformities, pathologies or trauma which may affect facial mimicry. RMS values of facial areas significantly differed among facial expressions (Friedman's test p: 0.0004). The widest modifications of lips were observed in happy expressions (RMS: 4.06 mm, SD 1.14 mm), with a statistically significant difference in comparison to sad (RMS: 1.42 mm, SD 1.15 mm) and angry ones (RMS: 0.76 mm, SD 0.45 mm). Effect size of labial vs. total face movements was limited for happy and sad expressions, while large for the angry one.

Conclusion:

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This study found that a happy expression provides wider modifications of lips than other facial expressions, and proposed a novel procedure for assessing regional changes due to mimicry.

Keywords: facial anatomy, lips, stereophotogrammetry, 3D-3D superimposition

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Introduction

Mimicry is a crucial function as a part of interpersonal communication, and with time has acquired a growing importance in anatomical studies. Indeed, metrical and morphological assessment of faces showing different facial expressions has a number of applications in clinical medicine: an example is given by the rehabilitation of patients affected by facial paralysis or traumatic lesions which may reduce or even cancel facial movements (1,2). In addition, the assessment of facial mimicry is of interest in cases of parotidectomy where sacrifice of the facial nerve hinders the production of facial expressions (3,4). In all these cases, the standardization of parameters describing normal movements is important in order to assess the residual function in patients affected by limitations in facial mimicry and to evaluate the outcome of rehabilitation.

Within the face, mouth movements are of special interest, not only because most of facial expressions (i.e. smiling) pass through the lips and perioral region, but also because possible alterations of this portion have aesthetic consequences with clear difficulties in inter-personal relationships. For this reason, lips movements have been analyzed by existing literature in depth: Rubin first analyzed smiling movements and classified different anatomical smiles into three categories (corner-of the-mouth smile or "Mona Lisa smile", canine smile and full-denture smile). In addition, he observed that each type of smiling occurs thanks to an orderly and coordinated contraction of muscles of lips and nasolabial folds (5).

Metrical assessment of lips movements started from linear measurement, although often differences in experimental protocols prevent from drawing a complete comparison of results; for example, some authors took measurements of facial images through rulers (6,7). This approach has the disadvantage of considering facial movements only in two dimensions, whereas facial motion is reported by literature as more extended in 3D space than in 2D. The mere analysis of two-dimensional facial movements, in fact, proved to underestimate 3D measurements by as much as 43% (8).

An improvement came from the study of Linstrom et al. who applied a computer interactive system based on the acquisition through a video camera, with the chance of measuring not only linear displacement of landmarks, but also the velocity of movement (9); however, also in this case, a full 3D visualization of facial movements could not be reached, as the system took only movements on x- and y-axis into consideration (10). Attempts at considering 3D facial movements were performed by Frey et al. who applied a digital video camera with mirrors, which reached a high accuracy in recording displacement of facial landmarks in three dimensions (11).

An important improvement to the research in this field derived from the introduction of modern 3D image acquisition systems such as stereophotogrammetry, able to acquire a 3D model of faces. Sawyer et al. analyzed smiling movements through stereophotogrammetry, focusing on displacement of landmarks in three dimensions (10). However, the potential of stereophotogrammetry in not limited to classical studies of landmarks, but allows researchers to perform more complex analyses of faces. An example is the possibility of superimposing models belonging to the same individual in order to assess variations expressed as point-to-point distances (12). This type of approach does not consider parcelled movements divided into displacement of single landmarks, but analyses the variations of the entire surface in comparison with a reference model, for example the 3D model of face in neutral position. This point of view can provide additional data to the assessment of facial movements and may be an innovative method for assessing possible amelioration of mimicry performances in cases of facial reanimation. For example, comparing the present model to a reference one dating back to the beginning of the therapy. A first attempt focusing on the entire face was performed by the authors and verified significant differences between the smiling and open-mouth surprised expressions in comparison with the sad and angry ones (12). However, a precise evaluation of labial movements in smiling expression has not yet been performed.

This article starts from the previous publication concerning superimposition of facial expressions on the entire face and aims at focusing on the labial movements in order to extract modifications of different expressions in comparison with the neutral one. The authors hypothesize that labial modifications due to facial mimicry may be different from the changes affecting the entire face. The specific aims were to apply an innovative procedure for registration and superimposition of 3D surfaces and to measure a metrical parameter (the RMS –root mean square– point-to-point distance between the 3D surfaces) as a possible marker for assessing facial movements. This may add information useful for a full comparison of this type of movement and the elaboration of methods for assessing ameliorations in patients affected by mimicry limitations.

Materials and methods

Study design/sample

To address the research purpose, the investigators designed and implemented a cross-sectional study. To be included in the study sample, patients had to be adult and having undergone facial scan through stereophotogrammetry between 2014 and 2016 Exclusion criteria were possible facial deformities, pathologies or signs of previous surgery or trauma which may affect facial mimicry. The chosen subjects represent the group already

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analyzed in a previous publication focusing on the entire face (12). This study followed the Declaration of Helsinki on medical protocol and ethics and the local ethical rules (approved by the Ethical Committee of University of Milano, no. 92/14).

In this study, the predictor variable is the facial movement in different expressions, using the rest position as the control, baseline situation.

Data collection criteria

The face from each individual underwent four acquisitions by stereophotogrammetry (VECTRA-3D®: Canfield Scientific, Inc., Fairfield, NJ) in different expressions (neutral, happy, sad, angry). In order to reach the most natural expression, each specific expression was described to the recruited subjects: in detail, upward movement of labial angles was requested for happy expression (corner-of-the-mouth smile, or Mona Lisa smile, 5); on the other side, downward movement of the corner of the mouth was suggested in sad expression, and corrugated eyebrows in angry expression.

The 3D models of happy, sad and angry facial expressions were automatically registered on the neutral one by the 3D image elaboration software included in the stereophotogrammetric device (VAM® software[1]) (Fig. 1).

The superimposition was performed in order to reach the least point-to-point distance between the two models. Finally, the metrical information concerning differences in the labial area were selected: labial region was defined as the model area included between the right and left cheilion, right and left crista philtri and labrale inferius. The definition of the labial region according to the chosen landmarks was performed automatically by the software. A chromatic sheet of the labial area was then obtained, according to the

1 http://canfieldupgrade.com/assets/media/VECTRA-M3-User-Guide.pdf

movement of labial surface in the model with each facial expression in comparison with the neutral one (Fig. 2).

The mean distance and RMS point-to-point value (root mean square) were then automatically calculated between the happy, sad and angry 3D models, and the neutral one. In addition, data concerning minimum and maximum distances were provided (13). Negative values indicate areas where a reduction in facial expressions in comparison with the neutral one is recorded, vice versa for positive values. RMS distance was used as primary outcome variable in order to assess facial movements in different expressions.

Data analysis

To assess the repeatability of the protocol, 3D model registration and calculation procedures were repeated by the same operator; possible statistically significant differences were assessed by Wilcoxon test. In addition, the relevant technical error of measurement (TEM) was also calculated (14).

Friedman's test was first applied to results ($p<0.05$): in case of statistically significant differences among the three expressions, Mann-Whitney test was applied to verify if the observed differences between RMS and mean values by happy, sad and angry expressions in comparison with the neutral one could be statistically significant.

Mean labial movements in the three expressions were compared to existing literature about mean total facial motion in the same experimental conditions (12) by using Wilcoxon tests.

For all comparisons, a p value of 5% or less was considered as significant ($p<0.05$). For post hoc tests, p values were corrected according to Bonferroni (0.05/3).

In addition, Cohen's d effect size was calculated between facial and labial movements for each facial expression (15).

Results

The study included ten male adults, aged between 30 and 40 years, who met the inclusion criteria. The sample size was set in ten individuals, as they were the same subjects recruited for the previously published study concerning the entire face (12). The measurements performed by the same operator did not show statistically significant differences ($p>0.05$). Relative TEM value was 5.2%.

Metrical modifications of labial area in the different expressions are shown in Table 1. The smiling expression showed the highest differences in comparison with the neutral standard, whereas the angry expression showed the least variations. Friedman's test found statistically significant results among the three groups (csq_r: 15.8; df: 2; p: 0.0004); post-hoc tests showed statistically significant differences between happy expressions and the sad and angry ones (respectively U=5 and p=0.0008, and U=0 and p=0.0002), whereas sad and angry expressions were not significantly different (U=28, p=0.1031).

Values of RMS point-to-point distances shown by the labial area were compared to the same parameters of the entire face, already published (12). On average, modifications of labial region in happy and angry expressions were lower than on the entire facial surface. On the other hand, in sad expression labial modifications were more pronounced than total face ones (Fig. 3). In no case observed differences were statistically significant; statistical parameters for the happy, sad and angry expressions were respectively, W=7 (p=0.74141), W=1 (p=0.9761) and W=-45 (p=0.0232). Calculation of effect size between facial and labial movements found no effect for happy expression (0.05), small effect for sad expression (-0.14) and a large effect for the angry expression (0.98).

Discussion

The present study aimed at assessing lips modifications in different types of expressions. The authors hypothesized that labial movements may be different from the same modifications recorded on the entire face. In detail, as primary outcome variable RMS point-to-point distance between the 3D surfaces was taken into consideration.

Results obtained by the present study revealed that smiling expression showed statistically significant differences for what concerns RMS point-to-point distances from the neutral expression, in comparison with the sad and angry ones. This confirms that smile provides the most relevant modifications of faces.

The present results were compared with similar data reported in our previous publication concerning the entire face (12), in order to assess the importance of the labial region in the general asset of facial expressions. Results show that in the sad expression the RMS point-to-point distance of the labial region is higher than the same parameter recorded on the entire facial surface. This indicates that most of modifications come from downward movement of lips, whereas changes in the rest of the face are limited. In angry expression, the importance of labial movement is lower in comparison with the rest of the face (i.e. wrinkled eyebrows) where most of modifications occur. In the case of smiling models, RMS value is slightly lower than those reported in the rest of face. These data indicate that in smiling and angry expressions a relevant contribution of facial modification come also from other facial regions (for example, cheek protrusion in smiling and eyebrows movements in sad expression), as facial modifications of the entire face and lips does not show statistically significant differences in none of the three expressions. This result suggests to analyze the regional alteration suffered by faces in different typologies of mimicry more in depth.

The existing literature usually takes displacement of facial landmarks rather than the modification of surfaces into consideration. However, the present data are partially confirmed even by existing literature based on the analysis of single landmark displacement. Sidequersky et al. in 2014 verified that in brow-lift expression the displacement of supraciliare landmark was observed in all the recruited subjects, independently from the 3D image acquisition device (optoelectronic 3D motion analyzer or surface laser scanner, 16). On the other hand, in smiling expressions the cheilion position changed in all the subjects and was considered the tracing landmark in this type of mimicry, underlining the importance of lips movements (16). In general, the present data confirmed that in smile expression the largest modifications were recorded in the mouth and chin areas, as also reported by literature (17-19).

Literature provided other examples of analysis of facial mimicry performed through laser scanner and video-analysis; for example, Verzè et al. applied laser scanning to the face of adults and children in order to assess facial landmarks movements (20). On the other hand, Okada took changes in facial contour units into consideration (21). In both cases results are not directly comparable with the present ones. For what concerns video-analysis, a specific study based on labial analysis was performed by Mishima et al. (22); however, they used verbal expressions as the main stimulus to evoke labial movements and did not consider not verbal expressions.

The present study has the relevant advantage of applying a 3D image elaboration procedure, whereas most of literature are still limited to the assessment of distance between landmarks. The practical applications may be found in the clinical assessment of facial mimicry in pre- and post-operative phases of patients affected by mimicry

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impairments. In addition, in the future the same method may provide a quantitative parameter for evaluating the normal facial movements, useful to verify the success of surgical procedures and rehabilitative protocols. Possible fields of applications include orthognathic, facial aesthetic and maxillofacial surgery.

Possible limits can be found in the small sample which needs to be increased in future studies. In addition, all the recruited personnel were males, whereas literature based on linear measurements suggests that facial landmark movement is higher in males than in females by an average of 5-15% (10). Further studies are needed in order to verify if the present results can also be observed in females. Other variables which may have a role in determining facial mimicry, such as skin type, medical history, age, exposure to drugs or smoke, etc., were not taken into consideration. Future studies should explore the importance of all these conditions.

Another limit of the present study includes possible intra-subject variability of expressions. However, this issue is partially solved in the present study, at least for what concerns the comparison between facial and labial movements in different expressions; in detail, the selection of labial surface occurred on the same scans previously analyzed for the facial expression. From this point of view, possible discordances between facial and labial movements due to intra-individual variability were prevented by their assessment within the same 3D models. In addition, we assessed expressions which were reproduced according to specific descriptions. This choice is due to the difficulties in recreating spontaneous reactions in the recruited subjects (especially for what concerns the sad and angry expressions). The next studies will attempt at applying the same procedure to spontaneous mimicry.

Finally, the proposed protocol represents a rigid registration of faces, which does not provide an exact point-to-point correspondence, but minimize differences between the two sets of point at the least. However, the objective of the present article was not to expose a mathematically adherent method for the description of facial mimicry, but to propose a highly repeatable protocol which may be used for comparing the facial movements in follow-up of patients affected by possible mimicry impairments.

In conclusion, the present study proposes a novel method for assessing regional facial movements in different expressions: this may provide a useful tool for the pre-operative and post-operative analyses of labial changes according to mimicry in aesthetic and reconstructive surgery.

Conflict of interest

None.

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Legends to figures

Fig. 1: example of registration of a smiling 3D model with a neutral one: a) neutral model; b) smiling model; c) superimposition: the neutral model is colored in light blue

Fig. 2: example of point-to-point distance assessment between different facial expression and the neutral one, with construction of a chromatic sheet reporting distances between the two models: a) smiling expression; b) sad expression; c) angry expression

Fig. 3: comparison between the RMS point-to-point distances shown by each expression in the labial region and the entire face

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Expression		Min	Max	RMS	Mean
Happy	**Mean**	-7.93	0.35	4.06	-3.68
	SD	2.04	1.16	1.14	1.18
Sad	**Mean**	-0.96	2.80	1.42	0.99
	SD	1.31	1.65	1.15	1.31
Angry	**Mean**	-1.44	1.83	0.76	-0.03
	SD	0.48	1.28	0.45	0.28

Table 1: mean values and standard deviation of RMS (Root Mean Square), maximum, minimum and mean point-to-point distances between the models superimposed in 10 subjects, divided in the three expressions: all the values are expressed in mm.

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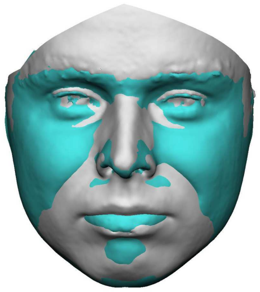

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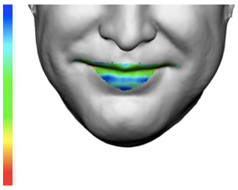

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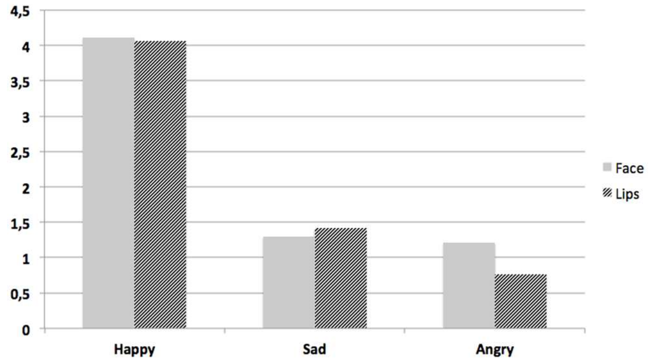

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