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Comparison of three dimensional and two dimensional analyses of facial motion

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ABSTRACT

The purpose of this study was to compare the amplitude of facial motion obtained using three-dimensional (3-D) and two-dimensional (2-D) methods. The amplitude of motion of fifteen facial landmarks during five maximal animations (smile, lip-purse, grimace, eye closure, and cheek-puff) was quantified in 3-D and 2-D using a video-based system. Results showed that the 3-D amplitudes were significantly larger than the 2-D amplitudes, especially for landmarks on the lower face during the smile animation. In the latter instance, the 2-D amplitudes underestimated the 3-D amplitudes by as much as 43%. The difference between 3-D and 2-D amplitudes was greater for 2-D amplitudes obtained from one camera rather than from multiple cameras. The results suggest that a 2-D analysis may not be adequate to assess facial motion during maximal animations and that a 3-D analysis may be more appropriate for detecting clinical differences in facial function.

Keywords— *2 Dimensional, 3 Dimensional*

1. INTRODUCTION

Three-dimensional methods have been used to study asymmetry of the soft tissues of the face but very few studies have quantified the 3-D motion of the face. The 3-D methods that have been used to study facial asymmetry include stereo photogrammetry, [5,6] video,[7] and laser scanning.[8] Caruso et al.[9] demonstrated the feasibility of obtaining 3-D trajectories of lip and jaw landmarks during chewing movements using a video-based system and a single subject.

Table 1: Definition of anatomical landmarks

Point	Definition
RSO, ISO	Right and left supra-orbital points (in line with the pupils).
RC, LC	Right and left medial canthal points.
RIO, LIO	Right and left infraorbital margin points (in line with the pupils).
RA, LA	Right and left lateral-most alar rim points.
NT	Nasal tip point (the centre of the tip of the nose).
COL	Columella base point.
RCB, LCB	Right and left cupid's bow points.
RCO, LCO	Right and left commissure points.
CH	Chin point (a point on chin 2 cm below lower lip vermilion in the midline)

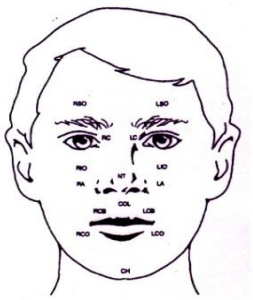

Fig. 1: Schematic diagram showing the locations the anatomical land

Using a similar method, Frey et al.[10] documented facial motion during 10 different facial animations in normal subjects. They demonstrated that some facial landmarks were more sensitive than others in detecting motion of the different regions of the face during the facial animations. They reported the displacement of each moving landmark relative to a stable reference marker rather than the 3-D amplitudes of the actual landmark motions. Thus, very little is known about the 3-D motion of the face during animations, and whether or not 3-D descriptions of facial motion are different than 2-D descriptions. The purpose of this study was to compare the amplitudes of landmark motions obtained using both 3-D and 2-D methods to determine whether a 3-D analysis provides a better assessment of facial motion than does a 2-D analysis.

2. MATERIALS AND METHODS

Four subjects participated in the study, two control subjects (mean age 23.0 years) and two patients with repaired unilateral cleft lip and palate (mean age 12.6 years). Each subject was seated comfortably in a dental chair with the headrest adjusted to ensure a steady, upright head posture. Small reflective markers (either 2 mm or 5 mm in diameter; the 5 mm markers had a 2 mm hole in the center for accurate placement) were placed on each subject's face over a set of 15 well-defined anatomical landmarks (Table 1, Figure 1). To collect the motion_data. Three 60-Hz video cameras were placed near each subject's face (0.5-0.75 m), with one camera in front and the other two cameras on either side.

Subjects were instructed to perform a set of five maximal facial animations from rest: lip purse, cheek puff, grimace, smile, and eye closure. Subjects performed these animations in sequential order. Before each trial, a cue card with drawing of the particular animation to be made was shown to the subject. The subject then began the animation after a verbal signal from the experimenter ("go"). Data were collected for three-seconds following the "go" signal. Three trials of each set of facial animations were collected during each of two test sessions; data from the first test session only were analyzed in this study. Reliability of the method is reported in our companion paper (Trotman et al.[11]).

Video images from each camera were automatically digitized, and coordinates for each marker were obtained using Expert Vision Flextrak software (Motion Analysis Corporation, Santa Rosa, Calif). Both three-dimensional (3-D) and two-dimensional (2-D) coordinates were calculated for each marker. The 3-D coordinates were obtained using data from simultaneous views of each marker from at least two of the three cameras. The 2-D data were calculated in two different ways: (1) the "multi-camera 2-D" coordinates for each marker were obtained using the x- and y-coordinates but not the z-coordinates from the 3-D dataset, and (2) the "single-camera 2-D" coordinates for each marker were obtained using the x and y data from the frontal-view camera only. The measurement space was calibrated using eight markers mounted on a 410 x 210 x 210 mm rigid frame; measurement error was less than 1 mm. The amplitude of marker motion for each landmark during each animation was calculated in both two and three dimensions. First, the location of each landmark was expressed relative to a stable reference marker, either the right or left: LC) markers, or the Nasal Tip (NT) marker (Frey et al., 10 Trotman et al."). The motion amplitude than was calculated as either the 3-D or 2-D vector difference between the location of each marker at rest and at maximum facial animation. The 3-D motion amplitudes were calculated using the 3-D coordinates of the marker positions, and the 2-D motion amplitudes were calculated using the 2-D marker coordinates. The effects of animation, landmark, and measurement method on motion amplitudes were tested using paired t-tests.

2.1 Facial motion analyses

Table 2: Three-dimensional (3-D) and two-dimensional (2-D) motion amplitudes for each animation.

Animation	3-D amplitude (mm)	Single-camera 2-D amplitude (mm)	Multi-camera 2-D amplitude (mm)	Difference between 3-D and single-camera 2-D (mm)	Difference between 3-D and multi-camera 2-D (mm)	Single-camera 2-D amplitude relative to 3-D (%)	Multi-camera 2-D amplitude relative to 3-D (%)
Smile	8.0±5.6	5.1 ±3.0'	6.6±5.2'	2.9±3.3	1 .4*2.0'	70.0±17.5	83.3±16.6
Cheek puff	6.8±3.6	5.6±3.1'	55.9±3.2'	1.3±1.2	0.9±1.2'	80.9±12.1	88.0±11.4
Eye closure	7.5±3.6	5.2±2.9'	6.7±3.6'	2.2±3.2	0.8±1.0'	72.6±22.0	89.2±13.9
Grimace	4.9±2.2	4.0±2.0'	4.3±2.1'	1.0±0.9	0.7±0.9'	80.4±15.5	87.1±16.2
Lip purse	2.9±2.2	2.2±1.9'	2.4±1.8'	0.6±0.6	0.5±0.7'	74.6±17.5	84.2±16.7

* Significantly less than 3-D amplitude (P<0.001)

Table 3: Three-dimensional (3-D) and two-dimensional (2-D) motion amplitudes for each landmark.

Landmark	3-D amplitude (mm)	Single-camera 2-D amplitude (mm)	Multi-camera 2-D amplitude (mm)	Difference between 3-D and single-camera 2-D (mm)	Difference between 3-D and multi-camera 2-D (mm)	Single-camera 2-D amplitude relative to 3-D (%)	Multi-camera 2-D amplitude relative to 3-D (%)
Commissure	8.5±5.8	5.6±3.5'	6.7*5.3'	2.9±3.0	1.8±2.2'	79.9±17.6	70.3±15.2
Cupid's Bow	6.1 ±3.5	3.5±1.2'	5.1±3.6'	2.6±3.7	2.6±3.7	82.5±18.5	67.8±24.4
Alar rim	5.7±4.0	4.1±2.3'	5.0±3.8'	1.6±2.6	0.7±0.5"	85.9±10.9	73.7±15.2
Supraorbital	5.2*3.5	4.3*3.3'	4.7±3.3'	0.9±0.6	0.5±0.5'	90.8±6.8	79.6±11.7
Infraorbital	5.7±2.7	5.0±2.5'	5.2±2.5'	0.6±0.4	0.5±*0.8'	92.3±9.4	87.6±8.9
Chin	6.5±3.7	5.4*3.7'	6.3±3.7'	1.1 ±0.9	0.2±0.3	95.8±5.7	79.3±17.5
Columella base point	3.3±1.0	1 .2±0.3	1.8*1,0	2.0±1.0	0.2±0.2	57.8±37.1	39.5±11.6

" Significantly less than 3-D amplitude (P<0.01)

3. RESULTS

3.1 Difference between single-camera 2-D and multi-camera 2-D amplitudes.

The single-camera 2-D amplitudes were significantly smaller than the multi-camera 2-D amplitudes for each animation except lip purse (table 2). The difference was greatest for the smile and eye closure animations. Although the single-camera 2-D amplitudes were greater than the multi-camera 2-D amplitudes, the difference was Gross; Trotman; Moffatt significant only for the commissure (RCO/ LCO - 1.112.3, P<0.02), supraorbital (RSO, LSO -0.5±0.5, P<0.001)/ and chin point (CH -0.1±1.0/P<0.014) markers. Difference between 3-D and 2-D amplitudes.

Table 4: Component motion amplitudes for landmarks during the smile animation.

Landmark	Superior inferior (mm)	Medial-lateral (mm)	Anterior-posterior (mm)
Commissure	4.3±4.5*	10.5±7.6	8.2±4.8
Cupid's bow	2.3±1.3	3.3±2.8	4.2±2.6
Alar rim	5.3±2.2	5.6±6.1	3.4±2.0
Supraorbital	2.4±1.5	1.9±1.5	1.8*1.1
Infraorbital	5.3±2.0	1.7±1.3	2.8±1.0
Chin	4.7±5.8	3.6±3.6	0.6±0.4

* Calculated as the difference position between maximum animation and rest

Although the 3-D and 2-D motion amplitudes were highly correlated for all animations and landmarks (r=0.83, P<0.001 for the single-camera 2-D data; r=0.95, P<0.001 for the multi-camera 2-D data), the 2-D amplitudes were significantly less than the 3-D amplitudes across all animations and landmarks (P<0.001) (Tables 2 and 3). The difference between 3-D and 2-D amplitudes was greater for the single-camera 2-D method than for the multicamera 2-D method (Tables 2 and 3). The magnitude of the difference between 2-D and 3-D amplitudes increased as the 3-D amplitudes increased (Figure 2). Thus, the difference between the 3-D and 2-D amplitudes was greatest when the facial motion was the largest.

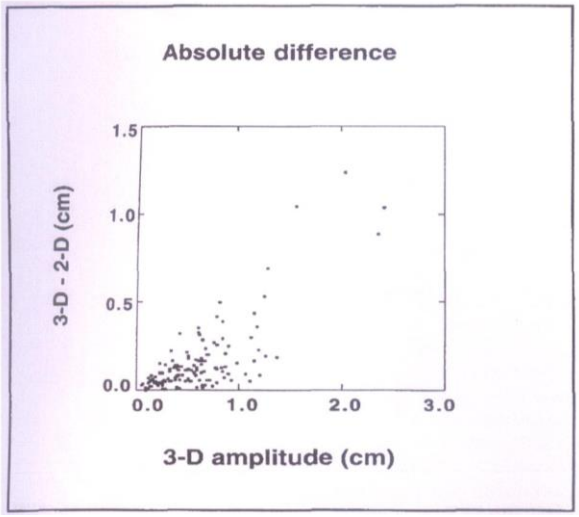

Fig. 2: Difference between 3-D and 2-D amplitudes as a function of the 3-D amplitude of motion. The difference between 3-D and single-camera 2-D amplitudes is plotted against the corresponding 3-D amplitude of motion. The data include all animations and all landmarks.

The difference between the 3-D and 2-D motion amplitudes depended on the animation and landmark. Although the 2-D amplitudes were less than the 3-D amplitudes for every animation (P<0.001), the magnitude of the difference varied among animations, ranging from 0.6 mm for the lip purse animation to 2.9 mm for the smile animation (Table 2). The difference between the 3-D and 2-D amplitudes also depended on the landmark, ranging from 0.6 mm for the infraorbital landmark to 2.9 mm for the commissure landmark. The 2-D amplitudes significantly underestimated (P<0.01) the 3-D amplitudes for every landmark except columella base point (COL, Table 3). Although the 3-D amplitudes were greater than the single-camera 2-D amplitudes for columella base point, only three observations were available for the analysis, so the difference failed to reach significance.

The difference between the 3-D and 2-D motion amplitudes is related to the magnitude of the anteroposterior component of the displacement vectors. The mean values of each of the three components of the 3-D displacement vector are given in Table 4 for landmarks during the smile animation. Consistent with the differences between 3-D and 2-D motion amplitudes discussed above, the magnitude of the anteroposterior component of the displacement vectors is greatest for the landmarks that move the most during the animation (e.g., commissure) and is least for the landmarks that move the least during the animation (e.g., chin).

3.2 Magnitude of the 2-D amplitudes relative to the 3-D amplitudes

Although the difference between the 2-D and 3-D amplitudes was small when expressed in absolute terms (i.e., in millimetres), the difference between the 3-D and 2-D amplitudes was much larger when the 2-D amplitudes were expressed as a percent of the 3-D amplitudes (Figure 3). The 2-D amplitudes relative to the 3-D amplitudes depended on the magnitude of the 3-D motion so that the relative magnitude of the 2-D amplitude decreased as the amplitude of the 3-D motion increased (figure 3).

The 2-D amplitudes relative to the 3-D amplitudes were greater for the multi-camera 2-D method than for the single-camera 2-D method (Tables 2 and 3). Thus, the single-camera 2-D method underestimated the 3-D amplitudes more than the multicamera 2-D method.

The magnitude of the 2-D amplitudes relative to the corresponding 3-D amplitudes depended on the animation and landmark. The relative magnitudes of the 2-D amplitudes ranged from 70% for the smile animation to 81% of the 3-D values for lip purse and grimace animations (Table 2), and from 68% for Cupid's bow landmark to 88% for the infraorbital landmark (Table 3). The 2-D amplitudes relative to the 3-D amplitudes were smallest for the combinations of animations and landmarks that produced the greatest facial motion. The 2-D amplitudes were most like the 3-D amplitudes for the combinations of animations and markers that produced the least facial motion, for example, the infraorbital and supraorbital markers during the grimace animation. In the best case, that is, the in-fraorbital and supraorbital markers during the grimace animation, the 2-D amplitude was 86.7+10.5% of the corresponding 3-D amplitude. In the worst case, that is, the commissure and columella base point markers during a smile animation, the relative 2-D amplitude decreased to only 57.1±14.1% of the corresponding 3-D amplitude.

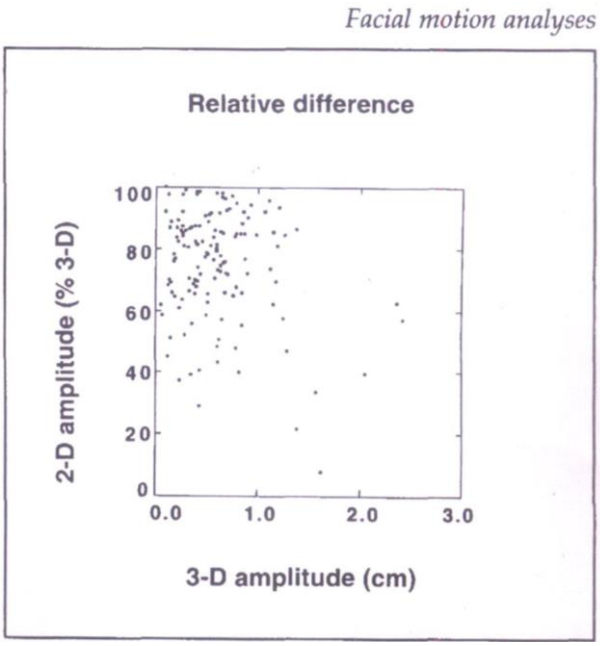

Fig. 3: Magnitude of 2-D amplitude relative to 3-D amplitude as a function of the 3-D amplitude of motion. The relative magnitude of the single-camera 2-D amplitudes as a per cent of the corresponding 3-D amplitudes Is plotted against the 3-D amplitude. The data include all animations and all landmarks.

4. DISCUSSION

The motion of facial landmarks during maximal amplitude animations was quantified using both 2-D and 3-D analyses of video-based data. Although the 2-D amplitudes significantly underestimated the 3-D amplitudes for all animations and landmarks, the differences were small, averaging less than 3.0 mm. When the 2-D amplitudes were expressed as a per cent of the 3-D amplitudes, however, the differences were as large as 43%, especially for the lower face during smiling. Because the 2-D amplitudes underestimated the magnitude of the 3-D amplitudes, it is possible that clinically relevant differences in facial motion would go undetected using 2-D analysis. Thus, we suggest that a 2-D analysis may not be adequate to assess facial motion during maximum animations and that a 3-D analysis is more appropriate for detecting differences in facial function due to disfigurement or surgical interventions. Few studies in the past have quantified the 3-D motion of the face. Three-dimensional distances. Figure 3 has been measured in calliper-based studies of facial motion.[10,12] Although the amplitude data in these studies are three-dimensional and relatively easy to obtain, the measurements are dependent on the choice of a reference marker and thus are not equivalent to the 3-D displacement vector of a landmark during an animation. They do not include information on the direction or velocity of motion, which may be clinical relevant. The amplitudes reported in this study are representative of the displacement vector of landmarks during animations, calculated in both 2-D and 3-D. Recently, Frey et al.[10] used a method based on video technology to report landmark motion as a per cent of reference distances on the face. Since their motion amplitudes depended on which landmark was used as a reference marker, it is not possible to directly compare there amplitudes with those obtained in this study.

If landmarks move at all in the anteroposterior direction during maximal facial animations, the 3-D amplitudes must be larger than the 2-D amplitudes. Theoretically, the difference between the 3-D and 2-D amplitudes is due to projection error, since the 2-D amplitude represents a projection of the 3-D trajectory onto the frontal plane. The difference between the 3-D and multicamera 2-D amplitudes in this study represents this type of projection error. The magnitude of the projection error varied from 4.7% to 16.6% of the 3-D amplitudes. As expected, the difference between the 3-D and multicamera 2-D amplitudes was greatest when the magnitude of

This projection error was the greatest (e.g., when landmarks moved substantially in the anteroposterior direction during an animation, such as the commissure landmarks during the smile animation).

A more clinically relevant comparison, however, is between the 3-D and single-camera 2-D amplitudes. The difference between these amplitudes was not only due to projection error but also system error. The projection error arose from the inability of the 2-

D method to detect any anterior-posterior motion of the landmarks, as well as from misalignment between the frontal plane of the face and the image plane of the camera sensors (i.e., the planes were not parallel). The system error arose from inherent differences in the 3-D and 2-D analysis software used to locate the landmarks. We found that these errors compound, so that the difference between the 3-D and single-camera 2-D amplitudes was significantly greater than the difference between the 3-D and multicamera 2-D amplitudes.

Central to all of these analyses, however, is the question of whether or not a 2-D analysis of 3-D facial motion is sufficiently accurate for clinical studies of facial motion. We have shown that the 3-D amplitudes can be substantially greater than the col-responding 2-D amplitudes, especially for the lower face during some animations, arid when the 2-D data are obtained from a single camera. Future work is needed to determine whether or not these differences are clinically relevant.

5. ACKNOWLEDGEMENTS

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