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THREE-DIMENSIONAL QUANTIFICATION OF "STILL" POINTS DURING NORMAL FACIAL MOVEMENT

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This study investigated the 3-dimensional displacement of points on the face that were thought to be still during facial movement. These points are currently used to measure displacement of moving facial regions during assessment of normal facial movement and treatment interventions following facial nerve paralysis. It is, however, unknown if these places are "still" points. The Expert Vision Motion Analysis System was used to collect and analyze data on 42 normal subjects during facial movement. No point on the face was found to be still during facial expression. However, several points were present with very small movements for each individual expression. These were termed "reference" points. These small movements may be the result of system noise, physiological tremor, skin movement, or head-holder movement during facial expressions. Future studies of the displacement of the markers during facial movement in both normal subjects and patients with facial nerve paralysis may take into account the contribution of the "reference" point displacements to the overall facial movement.

KEY WORDS — facial expression, facial nerve, facial paralysis, movement, reference values.

INTRODUCTION

To understand more about dysfunctional facial movement such as that following facial nerve paralysis, we must better understand the parameters of normal facial movement. To date, some studies of facial movement have assumed that parts of the face do not move during facial expression.[1,2] Certain facial points such as the tragus, the nasal apex, and a midpoint on the nose have also been proposed to move very little, and have been nominated as "facial reference points."[1-4] However, no evidence was provided that these points did not move, or had relatively small movement during facial expression. As these points have been used to measure the excursion of moving facial marker points, the validity of movement data collected on this basis is questionable.

One pilot study of 3 men and 3 women has used an objective, 3-dimensional (3-D) computerized method to investigate the 3-D displacement of facial reference points for a protocol of 6 facial expressions.[5] It was found that there was no completely still point on the face during facial expression; however, there were reference points with very small movements for each individual expression. As the pilot study used low subject numbers, it may not be statistically relevant in a larger population. Therefore, this current study aimed to investigate increased subject numbers to determine facial reference points during normal facial movement.

METHOD

Forty-two subjects, 21 men and 21 women, with no past history of facial nerve paralysis formed the study group. The age range was 19 to 44 years, with the mean age being 32.33 years. The subjects were volunteers, and the study was approved by The University of Sydney Ethics Committee. All testing was performed by the first author at the Biomechanics Laboratory, School of Exercise and Sports Science, The University of Sydney.

Seven specific facial points that were previously thought not to move during facial expression were chosen following a review of the literature.[1,2,6-9] These points included 1) midpoint at the uppermost part of the forehead, 7 cm vertically above the soft tissue nasion (7 cm mid-forehead point); 2) soft tissue nasion; 3) midnasal point, 1.5 cm vertically below the soft tissue nasion; 4) subnasale; 5) left mid-tragus; 6) right mid-tragus; and 7) 3 cm vertically below the mid–lower vermilion border. The subjects had 7 spherical retroreflective markers, approximately 7 mm in size, attached on the proposed facial reference points with Scotch Double Stick Tape (3M). The subjects then performed a series of facial movements. The protocol of facial expressions (at rest, forehead raise, eye closure, nose wrinkle, maximum smile, pout, lips pulled down) was thought to reflect

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TABLE 1. MEAN DISPLACEMENT AND STANDARD DEVIATION OF REFERENCE POINTS FOR FACIAL MOVEMENTS

Movement	*Facial Reference Point*	*Horizontal Axis (mm)*	*Vertical Axis (mm)*	*Anterior-Posterior Axis (mm)*	*3-D Combined (mm)*
Forehead raise	3InfML lip	0.61 ± 0.44	0.26 ± 1.28	0.73 ± 0.49	0.99
Eyes closed	3InfML lip	1.00 ± 0.77	2.11 ± 2.09	1.09 ± 0.93	2.58
Nose wrinkle	Left tragus	1.07 ± 0.62	1.43 ± 0.95	1.66 ± 0.94	2.44
Maximum smile	Nasion	1.46 ± 0.93	1.34 ± 0.97	1.83 ± 1.74	2.27
Pout	Nasion	1.44 ± 1.04	1.58 ± 1.56	2.06 ± 2.27	2.60
Lips pulled down	Nasion	1.53 ± 0.78	1.71 ± 1.00	1.79 ± 1.55	2.48
Mean		1.19	1.41	1.53	2.40

3InfML lip — 3 cm inferior to mid–lower lip; nasion — soft tissue nasion.

movement in the branches of the facial nerve and had been used in previous studies.[5,10] The subjects were asked to perform each movement maximally 3 times in succession over an 8-second period, relaxing after each attempt.

Four NEC TI23A video cameras with an electronic shutter speed of 0.001 s and a filming frequency of 60 Hz were used to record the marker positions. Cameras were placed in the recommended "umbrella configuration,"[11] with 2 cameras at 30° and 2 at 70° on either side of the subject's face, at a distance of 1.2 m. Four 75-W spotlights were mounted on the camera tripods in line with the optical axis of the cameras. The Expert Vision Motion Analysis System (Motion Analysis Corporation, Santa Rosa, Calif) was integrated with the video cameras to collect data and allow computerized analysis of the 3-D coordinates of the centroids of the retroreflective markers.

A calibration frame of known proportions was used to define the 3-D area in which data were collected. There were 16 spheres hung in 4 strings in a cubic arrangement, and a minimum of 6 markers on the frame must be viewed by at least 2 cameras to allow direct linear transformation of the coordinate points using an 11-parameter calculation.[12] The horizontal (x) axis, the vertical (y) axis, and the anterior-posterior (z) axis were defined, with the vertical axis being true vertical. The expected accuracy of the data collected in the area defined by the calibration frame would be approximately 1 part in 1,500, or >0.07%.[13]

A head-holder was used to comfortably restrain the subject's head so that any displacement of reference marker positions was not thought to be due to head movement. The head-holder consisted of a metal jig to which a disposable wooden bite bar was attached. Subjects were asked to gently bite on the bite bar to stabilize the head. Subjects were allowed adequate rest between trials and were allowed practice trials to ensure familiarity with the movements.

Following data collection, each frame of data was viewed to label the marker positions and ensure continuity of the marker trajectories. The data were then smoothed at 5 Hz, which was the frequency determined by the residual analysis and curve fitting techniques described by Winter.[14]

The reference points were determined for each axis and each movement by examining the mean displacement of the proposed reference points at rest and then during movement. In order to determine the range of motion of the reference marker for each expression, the minimum displacement was subtracted from the maximum displacement to give a total displacement in each of the 3 axes of movement. Points were defined as still, if during facial expression the range of movement of those points was not more than 2 standard deviations from the resting mean. By this calculation, no points on the face were found to be "still" in all 3 dimensions during the test protocol of facial expressions. So, the points that moved the least in the x, y, and z axes were investigated. Of the points that moved the least, the reference points chosen for each facial movement had the lowest mean 3-D displacement, and had the most frequently occurring lowest displacement in each axis. When 2 points equally satisfied these criteria, then the point with the lowest standard deviation for the mean 3-D displacement was chosen as the reference point.

RESULTS

Facial reference points were derived mathematically from the trials that were performed in a head-holder. No points were found to be still during facial expression. The displacements for the chosen reference points are listed in Table 1. The point 3 cm inferior to the mid–lower lip was chosen for forehead raise and tight eye closure, the left tragus was chosen for nose wrinkle, and the soft tissue nasion was chosen for maximum smile, pout, and lips pulled

TABLE 2. MEAN DISPLACEMENTS OF INDIVIDUAL AXES AND 3-D COMBINED DISPLACEMENTS OF FACIAL REFERENCE POINTS FOR AVERAGE OF REST TRIALS 1 AND 2

	Horizontal Axis (mm)	*Vertical Axis (mm)*	*Anterior-Posterior Axis (mm)*	*3-D Combined (mm)*
Nasion	0.24	0.17	0.23	0.37
Left tragus	0.32	0.27	0.38	0.57
3InfML lip	0.22	0.21	0.27	0.41

down.

On Table 1, during facial movements, the mean 3-D displacements of the chosen points range from 0.99 mm for the 3-cm-inferior mid–lower lip marker during forehead raise and 2.60 mm for the soft tissue nasion marker during pout. The lowest mean individual axis displacement (0.26 ± 1.28 mm) was recorded for the vertical axis of the 3-cm-inferior mid–lower lip marker during forehead raise. The highest displacement (2.11 ± 2.09 mm) was for the 3-cm-inferior mid–lower lip marker during tight eye closure.

The largest amount of overall mean reference marker movement occurred in the anterior-posterior axis (mean 1.53 mm) for the majority of movements, except for tight eye closure, which has a higher individual axis mean vertical displacement. The vertical axis had the second highest overall reference marker displacement, and the horizontal axis the lowest overall mean displacement.

The movement of the reference markers was examined at rest to determine the amount of system noise and physiological tremor present. There were 2 rest trials, rest 1 and rest 2, performed at the beginning and the end of the head-holder movement sequence. The mean individual axis displacements and 3-D combined displacements of the reference markers at rest for these 2 trials are presented in Table 2.

During rest trials, the mean displacement of the individual axes of the facial reference points chosen for this study, as shown in Table 2, ranged from 0.17 mm, for the vertical axis of the soft tissue nasion, to 0.38 mm, for the left tragus in the anterior-posterior axis. The combined 3-D displacement ranged from 0.37 mm, for the soft tissue nasion, to 0.57 mm for the left tragus.

DISCUSSION

The establishment of facial reference points from which facial movement may be tracked is fundamental to the accuracy of future displacement data. This study examined facial reference points and found that there was no place on the face that was completely still during facial expression. However, places of minimal movement on the face were determined for each individual expression. This movement was investigated by examining the displacement of the facial reference markers with the face at rest and during facial movement. Reasons for finding no completely still points may be motion analysis system error, physiological tremor, a small amount of skin movement, or some combination of these. Slight head-holder movement during facial expressions also may have occurred if the subject bit down hard on the bite bar. System error and physiological tremor were measured by the combined 3-D displacement of the facial reference points at rest, ranging from 0.37 mm, for the soft tissue nasion, to 0.57 mm, for the left tragus (Table 2). Although the reference markers only moved a relatively small amount, the overall displacement of the markers during facial movement is also relatively small.[15] Reference marker movement must be taken into account when examining future displacement data.

CONCLUSIONS

The displacement of facial reference points was examined during facial expressions, and it was found that

1. There were no completely still points on the face.

2. Reference points were determined with very small movements for each individual expression.

3. Small reference point movements were thought to be the result of system noise, physiological tremor, skin movement, or slight head-holder movement during facial expressions.

Future studies of the displacement of the markers during facial movement in both normal subjects and patients with facial nerve paralysis may use these reference points, taking into account the contribution of the reference point displacements to the overall facial movement.

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