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Kinematic analysis of a Duchenne smile

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ABSTRACT

Objective: Facial expressions are communicative motor outputs, whose kinematics likely are due to musculoskeletal anatomy, neuromotor activity and the well-being and internal states of the individual. However, little has been published on the kinematics of facial expression. This study quantified lip, eye and cheek movements during the production of a Duchenne smile involving movement of lips and tissues surrounding the eyes.

Design: The three-dimensional positions of 20 markers placed around the eyes, cheeks, lips and chins of 24 young adult female subjects were digitized while they performed smiles after practicing to feedback from an investigator trained in the facial action coding system (FACS). Displacement, velocity and acceleration variables were extracted and analyzed from the markers.

Results: Results demonstrated several consistencies across subjects including: (1) relatively high peak velocities, accelerations and displacements for lip and cheek markers in the vertical and anteroposterior dimensions, (2) relatively large movements of the lower lateral eye region compared with other eye regions.

Conclusion: The results indicate that there is significant movement in the anteroposterior dimension that is not observable in frontal views of the face alone.

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1. Introduction

Motor behavior is produced by neuromuscular systems acting on hard and soft tissues such as bones and skin. Significant insights into biomechanics (Pileicikiene & Surna, 2004), function (Wainwright, Mehta, & Higham, 2008; Ross & Iriarte-Diaz, 2014), neuromotor control (Sessle, 2011), development (Barlow, 2009) and evolutionary issues (Sherwood et al., 2005) have resulted from studies of respiration, locomotion, licking, swallowing and chewing (Taylor, Leite, McKenzie, & Wang, 2010; More et al., 2010; Inokuchi et al., 2014; Travers, Dinardo, & Karimnamazi, 1997; Quintero et al., 2013a; Quintero, Ichesco, Myers, Schutt, & Gerstner, 2013b). Also, numerous recent advances in quantitative and descriptive methods promise improved ways of rendering and analyzing human and animal movement (Gerstner, Madhavan, & Crane, 2015; Crane, Childers, Gerstner, & Rothman, 2015; Crane, Cassidy, Rothman, & Gerstner, 2010; Ramsay, Hooker, & Graves, 2009; Brainerd et al., 2010; Gallo, 2005).

With respect to chewing, jaw kinematics are relatively easily studied, given that the dentition can be used to represent mandibular movements. Furthermore given its semi-rigid properties, the mandible's movements can be documented with reference to relatively few markers. By contrast, movements of soft tissues, such as the tongue (Palmer, Hiiemae, & Liu, 1997; Hiiemae, Hayenga, & Reese, 1995; Hiiemae & Palmer, 2003; Hiiemae et al., 2002), lips (Sekita, Minakuchi, Hirano, Kobayashi, & Nagao, 2000) and face (Trotman & Faraway, 2004; Trotman, Faraway, & Phillips, 2005; Trotman, Stohler, & Johnston, 1998; Weeden, Trotman, & Faraway, 2001), are more difficult to document. This is because soft tissues possess unique biomechanical properties including elasticity and hysteresis (Bush, Ferguson, Mason, & McGrouther, 2007) and typically have a relatively large number of degrees of freedom. To document variation in soft-tissue movements requires addressing several challenges.

Three initial challenges include determining what behavior to track, what landmarks to track, and how to manage the resultant large data sets. Toward addressing these initial challenges, this study characterizes the kinematics of soft facial tissues during production of the Duchenne smile as defined by Ekman, et al. (Ekman, Davidson, & Friesen, 1990) and by us in previous work on smile esthetics (Lin, Braun, McNamara, & Gerstner, 2013). The

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study elected to track twenty markers, whose placement was informed by several sources including the Facial Action Coding System (FACS) (Ekman & Friesen, 1978), computer animation of the human face (Arya & Dipaola, 2007; Gavrila, 1999), and previous studies of facial kinematics (Trotman & Faraway, 2004; Weeden et al., 2001; Mendez, 1999). The purpose of the study was to quantify the kinematics of this relatively complex facial motor behavior and identify significant sources of variation within a sample population.

2. Materials and methods

2.1. Study population

Twenty-four healthy young–adult females (mean age ± SD = 24.3 ± 1.5) participated in the study. None had known functional insufficiencies, and all were drawn from the 2nd and 3rd year dental classes at the University of Michigan School of Dentistry. Inclusion criteria were: (1) willingness to participate, (2) female gender, (3) full complement of adult teeth (excluding 3rd molars), (4) no congenital orofacial abnormalities, (5) ability to follow study instructions, (6) no known facial impairment or orofacial pain that might interfere with facial expression or facial/masticatory motor behavior, and (7) no allergies to adhesives used to place the markers. Exclusion criteria were: (1) decayed or missing teeth, sans 3rd molars, (2) congenital orofacial defects or abnormalities, (3) reported neuromotor or musculoskeletal impairments that would interfere with smile production, e.g., (Bologna et al., 2013; Marsili et al., 2014) and (4) reported use of medications with known motor side-effects, e.g., abnormal involuntary movements, extrapyramidal symptoms. The study was approved by the University of Michigan Medical Institutional Review Board.

2.2. Experimental set-up

Twenty retroreflective spherical markers, each 4 mm in diameter, were used to acquire smile-motion data. These 20

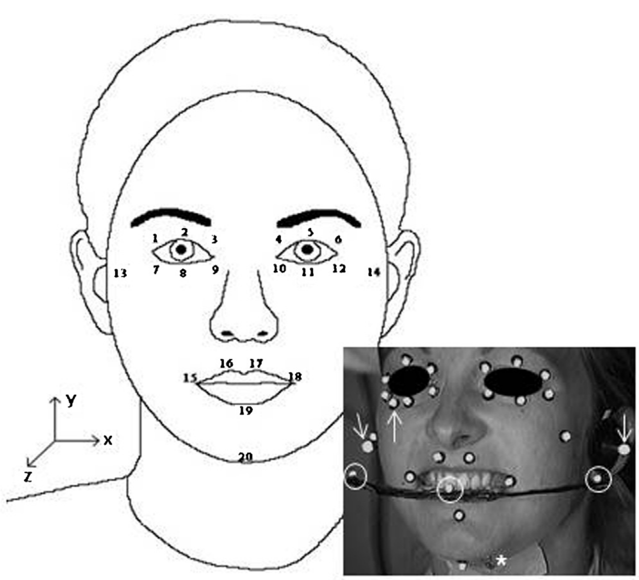

Fig. 1. Diagram showing location of the 20 numbered markers and orientation of axes. Markers represent right and left superior lateral canthus (1, 6), inferior lateral canthus (7, 12), superior center eye (2, 5), inferior center eye (8, 11), superior medial canthus (3, 4), inferior medial canthus (9, 10), zygoma (13, 14), lip commissure (15, 18), philtrum (16, 17), lower lip (19), and chin (20). Photo shows a subject performing a smile with 20 smile markers in place. Also shown are facebow markers (circled), Frankfort horizontal markers (arrows), and LED (asterisk).

markers were attached to the numbered facial sites illustrated in Fig. 1 and represent sites used in previous studies, with some modification (Trotman & Faraway, 2004; Weeden et al., 2001; Mendez, 1999). Briefly, markers were placed immediately superior and inferior to the left and right lateral and medial canthi (markers 1, 3, 4, 6, 7, 9, 10, 12), half way between the medial and lateral canthi (markers 2, 5, 8, 11), in-line with the posterior border of the zygomatic process of the frontal bone and immediately superior to the inferior border of the zygomatic bone, i.e., insertion of the zygomaticus major muscle (markers 13, 14), adjacent to the left and right lip commissures (markers 15, 18), on the left and right grooves of the philtrum and superior to the vermillion border of the upper lip (markers 16, 17), adjacent to the vermillion border of the lower lip and in the midsagittal plane (marker 19), and on the soft tissue gnathion (marker 20).

Markers were secured to the subject's skin using spirit gum adhesive, which allowed for free, unrestricted movement of the facial soft tissue. White face powder was applied to the remaining facial surfaces to minimize reflections that might have interfered with automated detection of the retro-reflective markers during data acquisition.

An orthodontic facebow appliance was affixed to the maxillary dentition using medium bodied polyvinylsiloxane (PVS) impression material in a manner based on a previous study (Trotman et al., 1998). The facebow was covered with flat-black masking tape to reduce light reflecting off the bow during motion capture. Three retro-reflective reference markers were affixed to the facebow, one at its midline, and one at each end of the two outer arms (Fig. 1, circled).

Each subject was asked to bite into maximum intercuspation, allowing for an examiner to position the facebow buccal to the posterior dentition. PVS impression material was flowed into the vestibule, securing the facebow in place to the maxillary teeth. Once the impression was set, the subject was checked to ensure that neither the facebow nor the PVS impression material interfered with the soft tissue positions at rest or in motions associated with smile production.

Subjects' heads were allowed to move freely during videotaping sessions. The head movements were subtracted from the data by custom algorithms designed to fix the position of the three facebow markers, so that the subject's Frankfort horizontal was parallel to room horizontal. This provided a way to standardize head positions between subjects. Frankfort horizontal was identified using three additional retroreflective markers that were placed on the ear canals bilaterally and right orbitale (Fig. 1, arrows). The position of these three Frankfort horizontal markers with respect to the three facebow markers was acquired with the motion capture system while the subjects maintained a relaxed position. Because the Frankfort horizontal markers were placed on soft tissue that would move during smile production, the facebow markers had to be used as the fixed reference plane during smile production. Subsequent data processing involved mathematically adjusting the plane of the facebow markers, frame-by-frame, so that the position of the Frankfort horizontal at rest was parallel to horizontal (Fig. 1).

2.3. Videotaping and digitization

Subjects were videotaped with two gen-locked video cameras (Panasonic 5100HS camera, Panasonic AG 7400 SVHS recorder, Panasonic AG 455 camcorder) in a similar manner to that described in previous experiments (Gerstner & Kinra, 1999; Gerstner, Marchi, & Haerian, 1999; Gerstner & Parekh, 1997; Gerstner, Lafia, & Lin, 2005). A time code generator identified each video field on the tapes so that time-based errors associated with digitization would

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