

# A computer analysis of reflex eyelid motion in normal subjects and in facial neuropathy

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## Abstract

**Objective.** To demonstrate how computerized eyelid motion analysis can quantify the human reflex blink.

**Design.** Seventeen normal subjects and 10 patients with unilateral facial nerve paralysis were analyzed.

**Background.** Eyelid closure is currently evaluated by systems primarily designed to assess lower/midfacial movements. The methods are subjective, difficult to reproduce, and measure only volitional closure. Reflex closure is responsible for eye hydration, and its evaluation demands dynamic analysis.

**Methods.** A 60Hz video camera incorporated into a helmet was used to analyze blinking. Reflective markers on the forehead and eyelids allowed for the dynamic measurement of the reflex blink. Eyelid displacement, velocity and acceleration were calculated. The degree of synchrony between bilateral blinks was also determined.

**Results.** This study demonstrates that video motion analysis can describe normal and altered eyelid motions in a quantifiable manner.

**Conclusions.** To our knowledge, this is the first study to measure dynamic reflex blinks. Eyelid closure may now be evaluated in kinematic terms. This technique could increase understanding of eyelid motion and permit more accurate evaluation of eyelid function. Dynamic eyelid evaluation has immediate applications in the treatment of facial palsy affecting the reflex blink.

## Relevance

No method has been developed that objectively quantifies dynamic eyelid closure. Methods currently in use evaluate only volitional eyelid closure, and are based on direct and indirect observer assessments. These methods are subjective and are incapable of analyzing dynamic eyelid movements, which are critical to maintenance of corneal hydration and comfort. A system that quantifies eyelid kinematics can provide a functional analysis of blink disorders and an objective evaluation of their treatment(s). © 2000 Elsevier Science Ltd. All rights reserved.

**Keywords:** Eyelid motion analysis; Blink; Objective measurement

## 1. Introduction

Diseases and injuries of the facial nerve compromise reflex and volitional eyelid closure. Current techniques used to evaluate eyelid movement measure only volitional closure (i.e. displacement) (see below). These

methods rely on subjective grading of movement. They are incapable of analyzing the rapid and variable reflex blink of the eyelid, upon which ocular health depends. A method that provides objective, quantitative data regarding the dynamic parameters of eyelid motion (i.e. displacement, velocity and acceleration) would allow more accurate diagnosis and treatment of patients with disorders of eyelid blink.

Existing methods of eyelid closure measurement produce static representations, which serve as a “snap

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shot” of one instant during eyelid closure. The House and Brackmann [1] system was introduced in 1983, and grades facial motion using a six point scale assigned by an examiner. The Burres and Fisch [2] system quantifies the distance between standard reference points on the face at rest and at maximal expression. While more objective than the House–Brackmann system, it is time consuming and subject to inter-observer variation. The numerical data used to describe facial function obtained by this system do not accurately measure eyelid motion [3].

Computer analysis of a combination of video and still photography of facial movements offers a more quantitative analysis [4–6]. In 1992, Johnson introduced the Maximal Static Response Assay (MRSA), a method to assesses facial function by measuring displacement of standard reference points of the face [7]. The MRSA records the amplitude of standard facial movements by comparing facial photographs taken at rest and at maximal contraction. MRSA, like other systems, provides only a static assessment and measures only the displacement of eyelid blink. It is also subject to inter-observer error.

Frey et al. [8] used a three-dimensional video system to analyze motion of the face. This system accurately measures the kinematics of lower facial motion but does not analyze eyelid motion. It requires four cameras for data acquisition, making it time consuming and difficult to reproduce.

Therefore, the purpose of this study was to demonstrate how computerized eyelid motion analysis (CEMA) can quantify the kinematics of the human reflex blink in normal and unilateral facial nerve paralyzed individuals.

## 2. Methods

In the present study, a single 60Hz camera (Qualysis, Glastonbury, CT, USA), incorporated into a lightweight helmet developed to create animated facial movements from human expressions in real time (FaceTrax, Associated Optical Associates, Cambridge, MA, USA), was used to record eyelid motion (Fig. 1). Since the single camera contained a fixed-focal length lens and aperture, adjustments were not required before data collection. The fixed relationship of the subject’s face and the camera minimized errors in the computation of marker trajectories induced by head movements, eliminating the need for three dimensional methodology to account for head movement.

The camera system was controlled by Mac Reflex software (Qualysis), which reliably determines marker locations to within  $\pm 0.1$  mm (Mac Reflex user manual, pp. 3–6). The video camera and this analytic software were used to quantify the displacement, velocity and

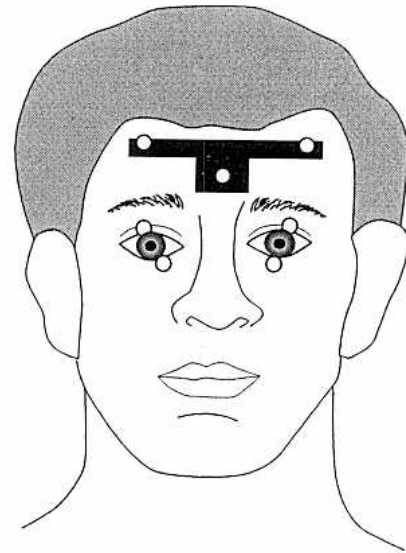


Fig. 1. Subjects wear a lightweight helmet with an attached 60 Hz motion analysis camera.

acceleration of eyelid motion, and the degree of synchronicity between the eyelid motion of each hemiface. The validity and reliability of the system in measuring eyelid motion has been demonstrated [9–11]. Manually measured displacement within and between days were not significantly different from CEMA measured eyelid displacements (Day 1 manual = 10.00 mm (SD, 2.53), Day 1 CEMA = 9.80 mm (SD, 2.40). Day 2 manual = 10.10 (SD, 2.19), Day 2 CEMA = 10.30 (SD, 2.78)). The averaged CEMA measured maximum blink velocity for day 1 and 2 were 163.60 mm/s (SD, 57.40) and 158.60 mm/s (SD, 59.70), respectively. The averaged CEMA measured maximum blink acceleration for day 1 and 2 were 4210.40 mm/s<sup>2</sup> (SD, 1980.80) and 4068.00 mm/s<sup>2</sup> (SD, 1876.80), respectively. The coefficient of multiple determination (CMD) was used to compare bilateral eyelid synchronicity and day 1 versus day 2 values were not significantly different. Days 1 and 2 average bilateral displacement CMD values were 0.90 (SD, 0.04) and 0.91 (SD, 0.03), respectively. Days 1 and 2 average bilateral velocity CMD values were 0.96 (SD, 0.01) and 0.92 (SD, 0.05), respectively while the days 1 and 2 average bilateral acceleration CMD values were 0.94 (SD, 0.01) and 0.90 (SD, 0.06), respectively.

### 2.1. Subjects

Seventeen normal volunteers (age range 23–74 years) with no previous history of neurological disorder, eyelid surgery or facial anomaly, and 10 patients with unilateral facial nerve paralysis (age range 32–66 years) were studied. In the latter group, patients were not stratified according to the etiology or duration of the paralysis since the objective of this study was limited to evaluating

the ability of CEMA to measure eyelid kinematics in differing populations. The measuring procedure was explained to each individual and those who agreed to participate signed an informed consent form approved by the Institutional Review Board at Frazier Rehab Center, Louisville, KY, USA.

## 2.2. Marker placement

Reflective markers 2.5 mm in diameter of negligible weight ( $<0.05$  g) were affixed to each eyelid with an adhesive at predetermined points (Figs. 2 and 3). No visible change in resting eyelid position occurred after marker placement, and there was no subjective sensation of altered blink noted by the study participants. A “T” shaped reference bar with three markers was affixed to the forehead between the nasion and eyelids, creating a local coordinate system (Fig. 2). The system was positioned so that the lower marker on the reference bar was

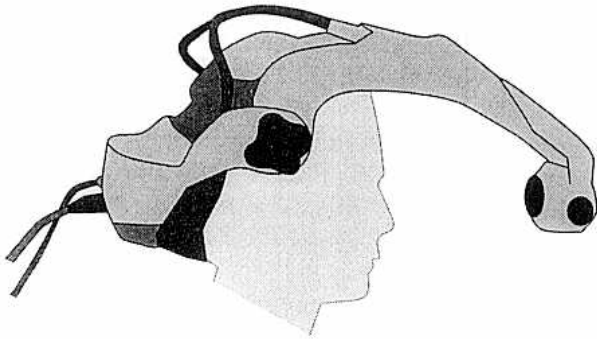


Fig. 2. Predefined marker locations. The ‘T’ shaped reference bar bearing three markers is affixed to the forehead, establishing a local coordinate system. The upper eyelid marker was placed on the axis of the pupil and the lower eyelid marker on the axis of the lateral corneal limbus.

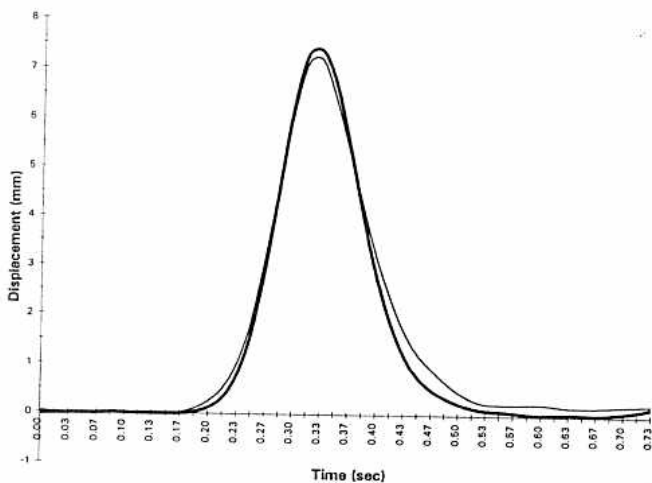


Fig. 3. Curves depicting displacement of both eyelid pairs during a blink in a randomly selected normal subject. The thick line indicates the right eyelid pair and the thin line the left pair.

5.0 cm above the nasion and the upper markers were superolateral and equidistant from the nasion. The upper eyelid markers were placed just above the eyelashes on the axis of the pupil. The lower eyelid markers were placed below the eyelashes on the axis of the lateral corneal limbus. This offset was used so that the upper and lower lid markers would not merge together, thus being recognized as discrete points by the computer at complete eyelid closure. Markers were placed by the same investigator in all subjects to minimize placement variation (NS).

## 2.3. Data collection

With the helmet/camera in place and the subject maintaining straight-ahead gaze, 20 reflex eyelid closures were recorded. The real time two-dimensional motion of the markers was taken directly from the camera/video processor, and stored on a computer.

After the measurements were completed, tracking and data analysis were performed offline. The coordinates generated by the markers on the computer screen were identified and then used to construct a two-dimensional “stick diagram”. Visual inspection of all markers ensured that adjacent markers were not erroneously joined.

After the marker trajectories were tracked, the paths were interpolated with a cubic spline if data were missing, and the coordinates were then smoothed to eliminate high frequency noise caused by random digitizing error. This also reduced amplification of artifacts when taking the first and second derivatives (velocity and acceleration, respectively). A 4th order Butterworth filter with an effective cutoff of 10Hz was utilized on all coordinate data. The upper two reference markers on the ‘T’ bar served as the ‘X’-axis. The midpoint of the ‘X’-axis and the lower reference marker on the ‘T’ bar served as the ‘Y’-axis. All data were then rotated and translated into this local coordinate system before computing the eyelid motion kinematics. Velocity and acceleration were calculated by the forward difference technique.

Of the 20 blinks collected from each of the two hemifaces, 10 were randomly chosen and the kinematics of each eyelid were calculated using the standard forward difference technique. The motion of each unilateral eyelid pair (upper and lower) was analyzed separately in terms of lid displacement, velocity and acceleration and then compared with identical parameters of the contralateral eyelids. The kinematic values obtained from the 10 blinks were averaged to establish a subject average. The averaged subject data were then averaged for an overall group average. Graphing and report generation of the sequence of eyelid motion was performed with Microsoft Excel.

### 3. Statistical analysis

Since kinematic data displayed over time typically result in a waveform, simple statistical analysis is not applicable [12,13]. To compare the waveforms generated by eyelid motion, the adjusted coefficient of multiple correlation ( $R_a$ ) was used to evaluate the similarity of eyelid waveforms and thus the degree of synchrony in the motions of the respective eyelid pairs.  $R_a$  ranges from 0 to 1. When waveforms are identical and blinks are synchronous,  $R_a$  equals 1. If the waveforms are dissimilar,  $R_a$  approaches 0. Thus,  $R_a$  is an indicator of the degree of synchronous, normal eyelid closure when the bilateral eyelid motion is compared.

The CMD is obtained when  $R_a$  is squared. Expressed as a percentage, the CMD indicates the amount of variance between the waveforms, which can be taken as a measure of blink normalcy (assuming the blink of one of the two eyelid pairs is considered normal). A CMD was computed for displacement, velocity and acceleration for all blinks. The average CMD values were determined for each parameter within a subject and then averaged between subjects.

### 4. Results

The mean kinematic parameters of bilateral eyelid motion in the normal subjects ( $n = 17$ ) are summarized in Table 1. Figs. 4–6 exhibit the waveforms of these parameters for both eyelids in a randomly selected normal subject. In all figures, the waveforms are very similar, suggesting bilaterally synchronous eyelid motion during closure.

The CMD values for the displacement, velocity and acceleration of the normal subject group ( $n = 17$ ) are summarized in Table 2. Having all three kinematic parameters averaged CMD values above 0.92 reflects synchronous eyelid motion (0.96, 0.96, 0.93 for displacement, velocity and acceleration, respectively). This can be thought of as indicating that overall, the kinematic plot of one eyelid in a pair explains 96%, 96% and 93% of the variance found in the plot of the contralateral eyelid for displacement, velocity and acceleration, respectively.

Table 1  
Mean and SD ( ) of the maximum kinematic parameters of eyelid motion in the normal subject group ( $n = 17$ )<sup>a</sup>

Parameter	Right eyelid	Left eyelid
Displacement (mm)	8.59 (1.20)	8.44 (1.38)
Velocity (mm/s)	206.53 (17.35)	205.54 (22.84)
Acceleration (mm/s <sup>2</sup> )	5879.41 (978.32)	5921.60 (920.44)

<sup>a</sup> Within subjects maximums averaged 1st, then between subject maximums averaged.

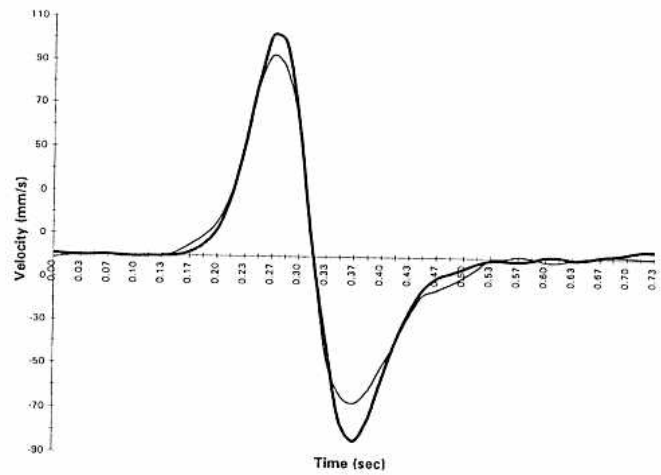


Fig. 4. Curves depicting the velocity of the right (thick line) and left (thin line) eyelid pairs of a normal subject.

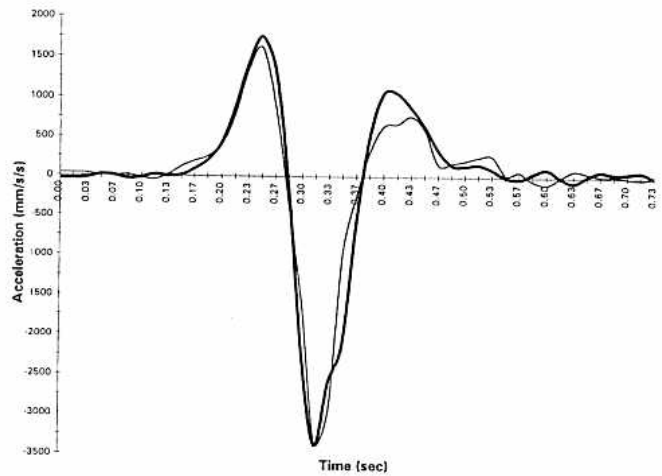


Fig. 5. Curves depicting the acceleration of the right (thick line) and left (thin line) eyelids during blink.

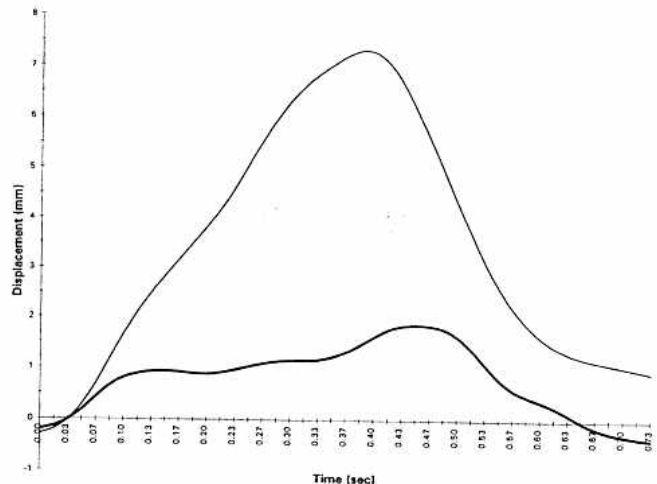


Fig. 6. Curves depicting displacement of a paretic eyelid (thick line) and its normal fellow eyelid pair (thin line).

Table 2

Mean and SD ( ) of the coefficient of multiple determination (CMD) of the kinematic parameters of eyelid motion in the normal subject group ( $n = 17$ ) indicating synchronous motion

Parameter	CMD
Displacement	0.96 (0.01)
Velocity	0.96 (0.01)
Acceleration	0.93 (0.01)

#### 4.1. Eyelid motion in facial paralysis

The mean kinematic parameters of eyelid motion for unilateral facial nerve paralysis group ( $n = 10$ ) are summarized in Table 3. The waveforms of the eyelid motion parameters of a pair of eyelids, in a randomly chosen subject, are presented in Figs. 6–8. When compared to plots of normal eyelid motion Figs. 4–6, these dissimilar waveforms suggest asynchronous, abnormal eyelid motion. Table 4 summarizes the mean CMD value for displacement, velocity and acceleration in the facial paralysis group ( $n = 10$ ). The average CMD is consistently low as anticipated (0.29, 0.31 and 0.25 for displacement, velocity and acceleration, respectively).

Table 3

Mean and SD ( ) of the maximum kinematic parameters of the paralyzed and normal eyelids in the facial paralysis group ( $n = 10$ )<sup>a</sup>

Parameter	Paralyzed eyelid	Normal Eyelid
Displacement (mm)	2.41 (0.59)	8.06 (0.17)
Velocity (mm/s)	41.15 (8.67)	172.05 (41.16)
Acceleration (mm/s <sup>2</sup> )	1167.02 (332.61)	5386.93 (845.80)

<sup>a</sup> Within subjects maximums averaged 1st, then between subject maximums averaged.

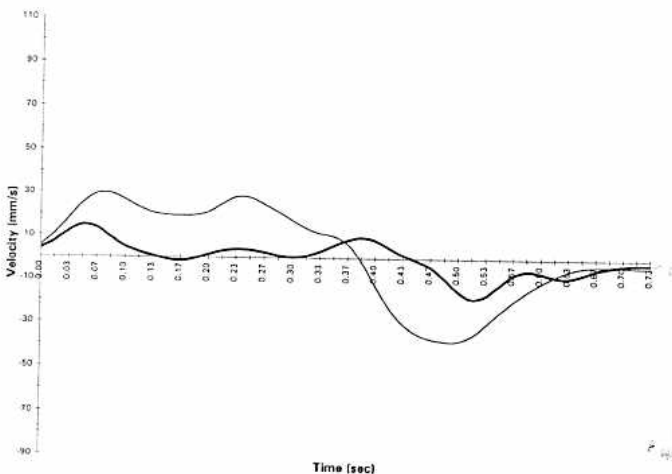


Fig. 7. Curves depicting the velocity of a parietal eyelid (thick line) and its normal fellow eyelid pair (thin line).

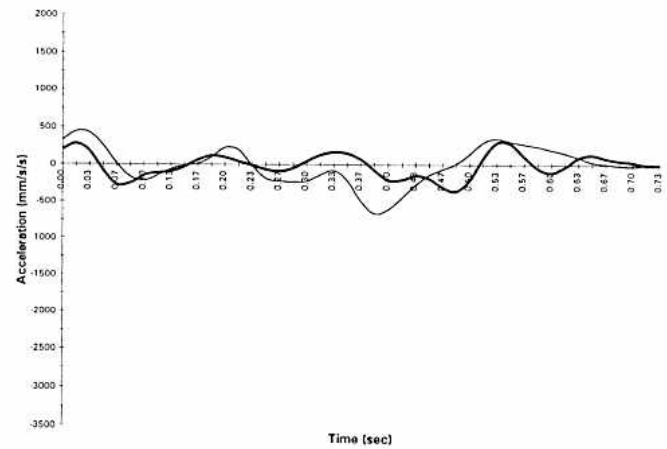


Fig. 8. Curves depicting the acceleration of a parietal eyelid (thick line) and its normal fellow eyelid pair (thin line).

Table 4

Mean and SD ( ) of the CMD of the kinematic parameters of eyelid motion in the unilateral facial paralysis group ( $n = 10$ ), indicating asynchronous motion

Parameter	CMD
Displacement	0.29 (0.14)
Velocity	0.31 (0.25)
Acceleration	0.25 (0.11)

## 5. Discussion

Although some of the most profound consequences of facial paralysis occur due to loss of the protective reflex eyelid blink, no method in current use allows accurate dynamic analysis of eyelid motion. Visual estimation, the current measurement practice, is subjective and evaluates only maximum volitional displacement of the two eyelids. It is incapable of providing dynamic analysis of the blink reflex, which is a critical component of eyelid closure. Diagnostic accuracy and evaluation of therapeutic measures would be improved by an objective, eyelid closure analysis system, capable of providing data about functional performance.

This paper describes a simple, objective method to analyze eyelid motion using a computerized, single-camera video analysis system. It continuously tracks the position of a point (or points) in space (i.e. a marker affixed to the eyelid) over time in relation to a fixed, local coordinate system. Using this method, we quantified the major components of eyelid motion in subjects with normal reflex blink and in those with unilateral lower motor neuron facial paralysis.

The data derived from this work provide a first preliminary, objective analysis of eyelid movement. The results may serve as an adjunct to or substitute for subjective scales in current use and provide normative reference data for the profile of a normal eyelid blink.

A number of potential applications for this system of measurement exists. If, for example, one uses the CMD value, CEMA could confirm a suspected disorder of eyelid closure in patients with otherwise unexplained corneal desiccation. A study is planned to determine if CEMA-guided selection improves the clinical outcome of procedures that implant a weight in the paretic eyelid to improve its closure. CEMA may have value in predicting or documenting functional recovery following facial nerve injury, allowing more rational therapeutic planning.

## 6. Conclusion

The evaluation and graphical description of eyelid motion has been limited by the absence of an objective, safe and non-invasive measurement technique. A new method to measure the kinematic parameters of normal and altered eyelid motion and quantify the degree of synchronicity is presented. This objective technique may aid in planning and monitoring treatment and be used in research. By study of larger numbers of patients, it may be possible to identify changes in eyelid displacement, acceleration and velocity that are prognostic indicators of facial nerve injury and recovery.

## Acknowledgements

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