

# Measurement and analysis of associated mimic muscle movements

Guodong Feng, Yuan Zhuang, Zhiqiang Gao\*

Department of Otolaryngology, Peking Union Medical College Hospital, China Medical Science Academy, 100730, Beijing, China

Received 6 February 2015; revised 7 February 2015; accepted 19 February 2015

## Abstract

**Objective:** To measure movements of markers over the primary site and associated mimic muscles in certain facial expressions, for evaluating facial paresis and synkinesis. **Methods:** Participants included 22 normal subjects aged 45–66 years. Maximum shift ( $S_{max}$ ) and velocity ( $V_{max}$ ) were measured using a custom-designed 3-D dynamic quantitative analysis system of facial motion (3-D ASFM) based on motion capture technology. Measures were taken from peri-oral muscles during forceful brow raising and tight eye closure, and from muscles around the eye during grinning, right/left/bilateral mouth corner raising and smiling. **Results:** 1) During forceful brow raising,  $S_{max}$  was 3.65–4.46 mm for markers over perioral muscles, with the marker over the nasolabial fold showing a  $V_{max}$  greater than others (60.60 mm/s on left and 62.70 mm/s on right). 2) In tight eye closure,  $S_{max}$  of perioral muscle markers was 1.58–1.92 mm, with  $V_{max}$  being 11.40–14.76 mm/s. 3) In grinning, the largest eye muscle marker  $S_{max}$  was seen at the lower lid (3.93 mm on left and 4.15 mm on right) and the smallest at the inner canthus (1.59 mm on left and 1.53 mm on right), with the largest  $V_{max}$  seen at the upper lid and smallest also at the inner canthus (11.71 mm/s on left and 11.09 mm/s on right). 4) In smiling, the largest non-oral  $S_{max}$  and  $V_{max}$  were seen at the upper lid (3.05 mm and 36.14 mm/s on left and 2.53 mm and 28.90 mm/s on right) and the smallest also at the inner canthus (0.69 mm and 7.22 mm/s on left and 0.77 mm and 7.80 mm/s on right). 5) In right mouth corner raising,  $S_{max}$  and  $V_{max}$  at lateral and medial canthus and at lower lid were greater on right than left, while those at upper lid and brow were slightly greater on left than right. 6) In left mouth corner raising,  $S_{max}$  and  $V_{max}$  at lateral canthus and upper and lower lids were greater on left than right. **Conclusions:** There are no absolute immobile points on the face when making facial expressions. In addition to the primary movement site, there are associated movements at other points on the face with consistent  $S_{max}$  and  $V_{max}$ . In assessing facial paresis and synkinesis, physiological associated facial movements should be taken into consideration.

Copyright © 2015, PLA General Hospital Department of Otolaryngology Head and Neck Surgery. Production and hosting by Elsevier (Singapore) Pte Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

**Keywords:** Facial expression; Associated movement; 3-Dimensional measurement; Healthy volunteers; Facial nerve

## 1. Introduction

Facial expression is one of the basic modes of conveying emotional messages in human and forms the foundation of human social functionality. Facial paralysis is a common

condition (Adour et al., 1978; Devriese et al., 1990) and results from facial nerve dysfunction, which leads to loss of facial muscle motor functions and synchronized facial movements. This is not only a loss of physiological function, but also affects the patient's psychological wellbeing and social activities. Treatments aim at restoring precise control of target facial muscles by the facial nerve, but about 12–29% of patients are left with some defects even after “effective” treatment, including synkinesis (Sullivan et al., 2007; Engstrom et al., 2008; Lockhart et al., 2010; Teixeira et al., 2010; Valenca et al., 2001).

\* Corresponding author.

E-mail address: [tallee@sina.com](mailto:tallee@sina.com) (Z. Gao).

Peer review under responsibility of PLA General Hospital Department of Otolaryngology Head and Neck Surgery.

Synkinesis refers to abnormally associated movements, generally considered to be related to misalignment in facial nerve fiber regeneration or re-organization/excitability changes in facial nuclei or supra-nucleus centers. It is represented by involuntary movements triggered by voluntary contraction of the intended muscle, including upward mouth corner movement when closing eyes or eye closure when opening mouth. Synkinesis can significantly impact a patient's quality of life. However, even in healthy people, associated movements in various facial areas are frequently seen in facial expressions. Existing studies on facial movements mostly focus on planar measurements in areas around the primary movement, such as movements around the eye during eye-related facial expressions (Doughty, 2014; Frigerio et al., 2014; Nemoto et al., 1994; Jiang et al., 2013; Cook et al., 2003). The lack of three-dimensional measurement of associated movements in different facial areas hinders a comprehensive assessment of facial movement association. The current study aims to measure associated displacement of markers in areas different from the primary facial movement using a proprietary three-dimensional analysis system of facial motion (3-D ASFM) based on capturing facial movements (Feng et al., 2014), and to analyze relevant factors.

## 2. Materials and methods

### 2.1. Subjects

Twenty two healthy volunteers aged 46–60 years (mean = 54.4 years) participated in the study. They were all right-handed and presented no history of conditions that might affect mimic muscles functions. Consents were obtained before participating in the study.

### 2.2. Measurement of facial movements

The 3-D ASFM sampled at 60 frames/s. As reported previously, a total of 16 markers were placed symmetrically at the brow, upper and lower lids, medial and lateral canthus, nasolabial fold, middle point of lip and mouth corners (Fig. 1) (Feng et al., 2014). For forceful brow raising and tight eye closure that involved primarily muscles around the eye, the brow and upper lid markers were used as the reference points while the perioral markers were measured. Similarly, for facial movements involving mainly perioral muscles (grinning, forceful right or left mouth corner raising and smiling), the left and right mouth corners and upper and lower lip mid points were used as reference points while markers over muscles around the eye were measured.

The maximum shift ( $S_{\max}$ ) and maximum velocity ( $V_{\max}$ ) were used as the indices in measurement and analysis.  $S_{\max}$  and  $V_{\max}$  of various markers were recorded and plotted. The SAS 9.1.3 software was used for statistical analysis. Temporal synchronization among markers was assessed using repeat Chi square test (Chen, 2003) and  $P < 0.05$  was considered to be statistically significant.

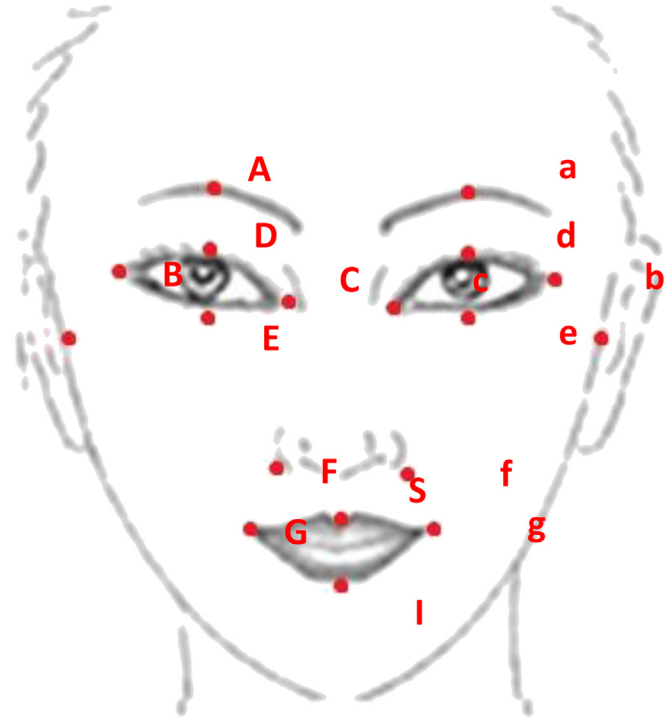


Fig. 1. Locations of the markers. A/a-eyebrow; B/b-lateral canthus; C/c-medial canthus; D/d-palpebra superior; E/e-palpebra inferior; F/f-nasolabial groove; G/g-modiolus; S-middle of the upperlip; I-middle of the underlip (With capitals showing the markers on the right side of the face and lowercases showing the markers on the left side.).

## 3. Results

### 3.1. Temporal synchronization

Tables 1 and 2 show the Chi square test results on temporal synchronization based on  $S_{\max}$  and  $V_{\max}$  of measured markers relative to reference markers during facial movements.

### 3.2. Forceful brow raising

$S_{\max}$  and  $V_{\max}$  of the brow marker were 9.75 mm and 24.11 mm/s on left and 10.14 mm and 25.87 mm/s on right. For perioral markers,  $S_{\max}$  ranged from 3.65 mm at the nasolabial fold to 4.46 mm at the lower lip.  $V_{\max}$  of the nasolabial marker (60.60 mm/s on left and 62.70 mm/s on right) was greater than those of the other markers (ranging

Table 1

Temporal synchronization of  $S_{\max}$  and  $V_{\max}$  of measured markers relative to reference markers in forceful brow raising and tight eye closure (F value from Chi square test with P value in parenthesis,  $\alpha = 0.05$ ).

Facial action	Forceful brow raising		Tight eye closure	
	$S_{\max}$	$V_{\max}$	$S_{\max}$	$V_{\max}$
Left brow	4.04(0.0527)	0.11(0.7433)		
Right brow	4.00(0.0538)	0.06(0.8006)		
Left upper lid			2.50(0.1232)	2.92(0.0969)
Right upper lid			2.44(0.1280)	2.92(0.0971)

Table 2

Temporal synchronization of  $S_{max}$  and  $V_{max}$  of measured markers relative to reference markers in grinning, right/left mouth corner raising and smiling (F value from Chi square test with P value in parenthesis,  $\alpha = 0.05$ ).

Action	Grinning		R mouth corner raising		L mouth corner raising		Smiling	
	$S_{max}$	$V_{max}$	$S_{max}$	$V_{max}$	$S_{max}$	$V_{max}$	$S_{max}$	$V_{max}$
L mouth corner	2.17(0.15)	1.67(0.21)			1.63(0.21)	1.19(0.28)		
R mouth corner	2.19(0.15)	1.66(0.21)	1.66(0.21)	0.96(0.33)				
Center of upper lip							1.44(0.24)	1.42(0.24)
Center of lower lip							1.38(0.25)	1.35(0.25)

$S_{max}$  and  $V_{max}$  distribution (Figs. 2–5).

from 11 mm/s at the mouth corner to 25.73 mm/s at the center of lower lip).

3.3. Tight eye closure

$S_{max}$  and  $V_{max}$  of the medial canthus marker were the smallest (1.33 mm and 13.29 mm/s on left and 1.46 mm and 14.64 mm/s on right) while those of the upper lid marker were the greatest (10.56 mm and 87.68 mm/s on left and 10.54 mm and 81.83 mm/s on right).  $S_{max}$  of other markers around the eye ranged from 5.73 to 8.36 mm, and  $V_{max}$  from 53.31 mm/s to 63.03 mm/s.  $S_{max}$  of perioral markers ranged from 1.58 mm (nasolabial fold) to 1.92 mm (mouth corner), and  $V_{max}$  from 11.40 mm/s (upper lip) to 14.76 mm/s (mouth corner), showing no significant differences.  $S_{max}$  and  $V_{max}$  of perioral markers were greater in brow raising than in eye closure.

3.4. Grinning

$S_{max}$  of lower lids (3.93 mm on left and 4.15 mm on right) was the greatest and >lateral canthus > upper lids > eye brow > medial canthus (1.59 mm on left and 1.53 mm on right).  $V_{max}$  of left upper lid was the greatest (42.64 mm/s) and >other lid markers 记点 > lateral canthus > eye brow > medial canthus (11.71 mm/s on left and 11.09 mm/s on right).

3.5. Smiling

$S_{max}$  and  $V_{max}$  of the upper lid markers were the greatest (3.05 mm and 36.14 mm/s on left and 2.53 mm and 28.90 mm/s on right) and >lower lids > lateral canthus > eye brow > medial canthus (0.69 mm and 7.22 mm/s on left and 0.77 mm and 7.80 mm/s on right).

3.6. Raising right mouth corner

$S_{max}$  and  $V_{max}$  of lateral canthus and lower lid markers on right were greater than those on left, and showed no significant right-left differences among other markers.

3.7. Raising left mouth corner

$S_{max}$  and  $V_{max}$  of lateral canthus and upper/lower lid markers on left were significantly greater than those on right, while  $S_{max}$  and  $V_{max}$  of other markers were slightly greater on right than left.  $S_{max}$  and  $V_{max}$  of markers around the eye were the greatest in grinning and smallest in smiling.

4. Discussion

Objective quantification of facial movements is at the core of assessment of facial paresis and treatment outcomes. At this

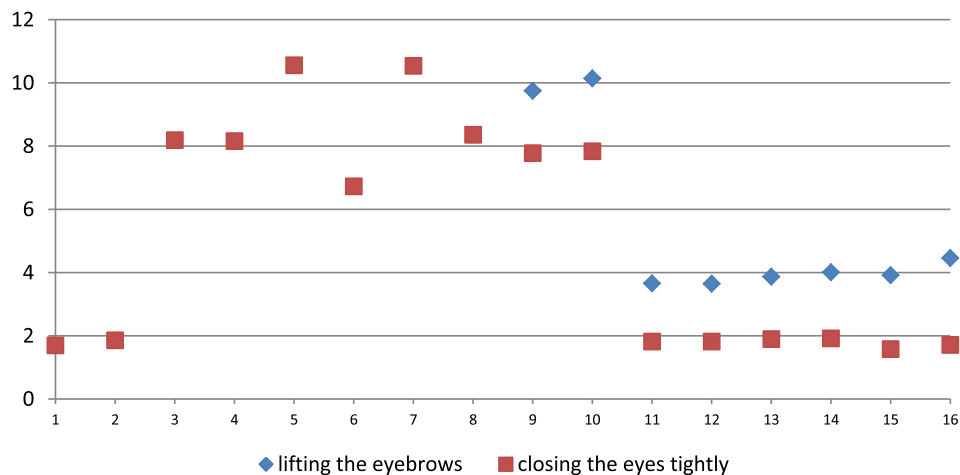


Fig. 2. Maximum shift of markers in forceful brow raising and tight eye closure (in mm). 1-left medial canthus; 2-right medial canthus; 3-left lateral canthus; 4-right lateral canthus; 5-left palpebra superior; 6-left palpebra inferior; 7-right palpebra superior; 8-right palpebra inferior; 9-left eyebrow; 10-right eyebrow; 11-left nasolabial groove; 12-right nasolabial groove; 13-left modiolus; 14-right modiolus; 15-middle of the upper lip; 16-middle of the under lip.

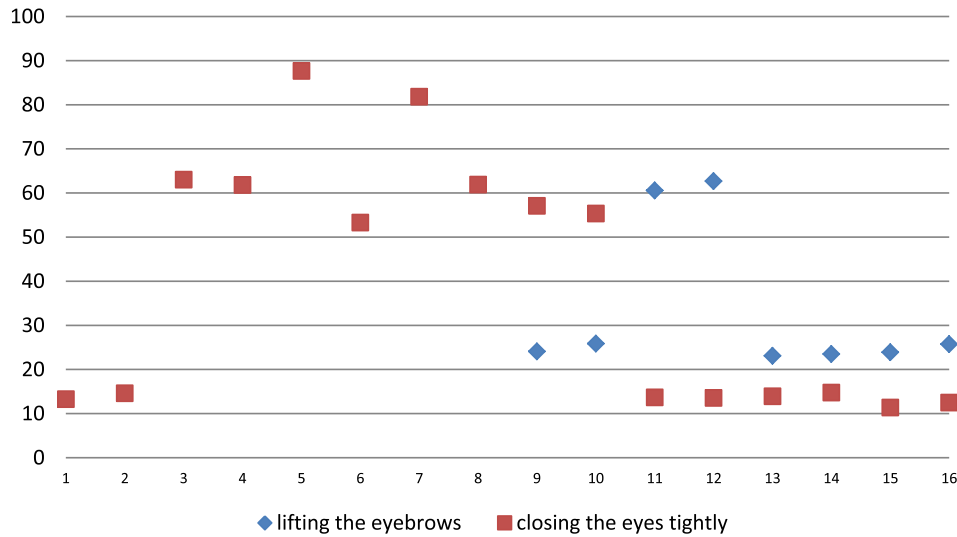


Fig. 3. Maximum velocity of markers in forceful brow raising and tight eye closure (in mm/s). 1-left medial canthus; 2-right medial canthus; 3-left lateral canthus; 4-right lateral canthus; 5-left palpebra superior; 6-left palpebra inferior; 7-right palpebra superior; 8-right palpebra inferior; 9-left eyebrow; 10-right eyebrow; 11-left nasolabial groove; 12-right nasolabial groove; 13-left modiolus; 14-right modiolus; 15-middle of the upper lip; 16-middle of the under lip.

time, objective evaluation of facial nerve function is based either on electroneuronography and electromyography (Wilkinson and Kaufmann, 2005; Li, 2006) or on assessment of facial muscle movements and change of facial appearance (Tomat and Manktelow, 2005; Cecini et al., 2013; Paletz et al., 1994; Linstrom, 2002; Holman et al., 1996; Hadlock and Urban, 2012; Meier-Gallati et al., 1998; Jorge et al., 2012; Frey et al., 1999, 2011; Tzou et al., 2012). There are 15 pairs of mimic muscles (Marur et al., 2014) supplied by various branches of the facial nerve. Their locations are superficial and their contraction causes local facial skin displacement via their connection to the skin (Frigerio et al., 2014) and subsequently

visible facial appearance changes. As such, it is possible to assess mimic muscles contraction (and facial nerve function) by observing facial appearance changes. This study attempts to record and analyze movements of facial markers at various locations on the face and their association using a 3-D ASFM system that captures displacement parameters of the markers.

The key in assessing movement association among markers is the temporal synchronization of marker parameters. The camera in the system used in this study is capable of capturing images at 60 frames/s with an inter-image interval of 0.017 s, which can be used to calculate primary movement parameters including time, displacement distance and velocity. The Chi

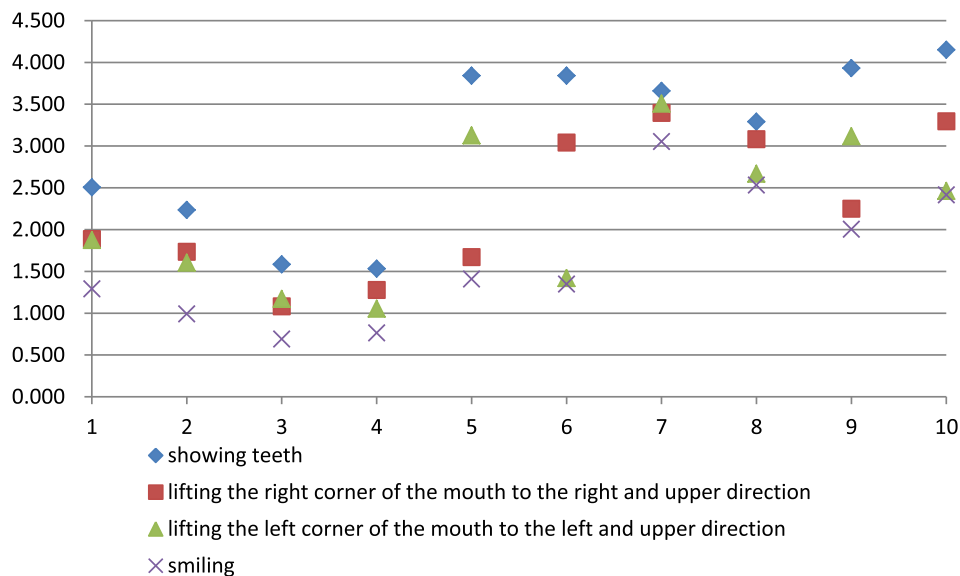


Fig. 4. Maximum shift of markers around the eye during mouth movements (in mm). 1-left medial canthus; 2-right medial canthus; 3-left lateral canthus; 4-right lateral canthus; 5-left palpebra superior; 6-left palpebra inferior; 7-right palpebra superior; 8-right palpebra inferior; 9-left eyebrow; 10-right eyebrow.

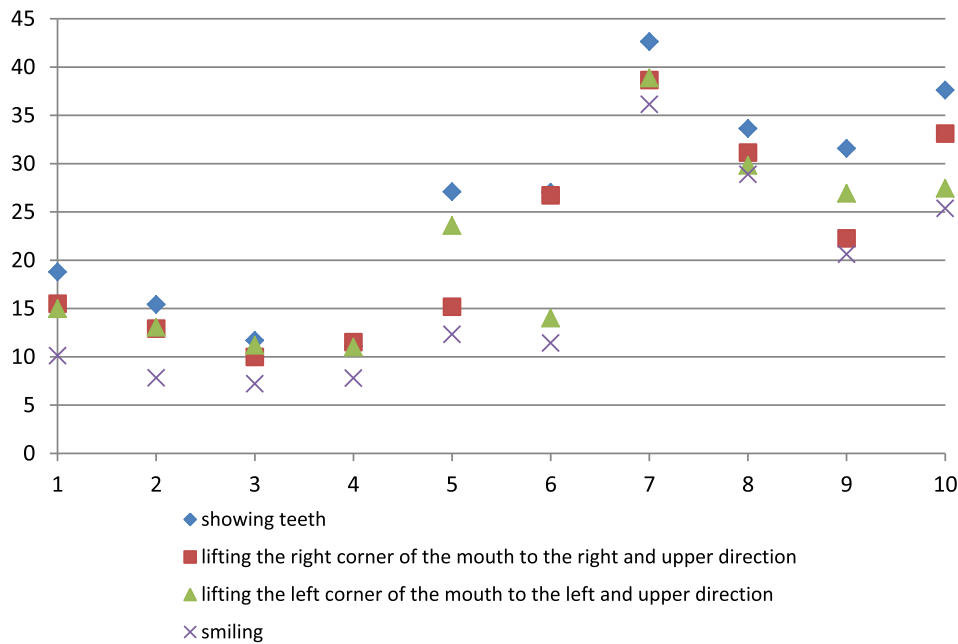


Fig. 5. Maximum velocity of markers around the eye during mouth movements (in mm). 1-left medial canthus; 2-right medial canthus; 3-left lateral canthus; 4-right lateral canthus; 5-left palpebra superior; 6-left palpebra inferior; 7-right palpebra superior; 8-right palpebra inferior; 9-left eyebrow; 10-right eyebrow.

square test can be used to evaluate temporal synchronization regarding maximum shift and maximum velocity, with  $P > 0.05$  indicating synchronization. Therefore,  $S_{\max}$  and  $V_{\max}$  can be used as the parameter reflecting associated facial movements.

There are many types of associated facial movements, but mouth–eye association is the most common and has the greatest impact on a patient's quality of life. From our results, it is easy to see that our healthy volunteers demonstrated associated movements in areas separate from the primary voluntary facial movements, indicating that physiological movement association should be taken into account when assessing pathological synkinesis. Only  $S_{\max}$  and  $V_{\max}$  beyond normal ranges or unexpected movement association should be considered diagnostic of synkinesis.

Facial appearance is affected by both soft tissue and bone structures, the former being composed of skin, fatty tissue, muscles, fascia and nerves (Kahn DM, Shaw, 2010; Fitzgerald et al., 2010). Distribution of mimic muscles is rather complex, although traditionally muscles are grouped in the upper, middle and lower divisions separated by the upper zygomatic rim-lateral canthus line and lower tragus border-mouth line. Fibers of mimic muscles overlap with closely related attachments in some. Their contraction generate complex and delicate interactions and collaboration, resulting in natural looking facial expressions. This is especially true with muscles around the eye and mouth. In forceful brow raising, the main actuator is the frontalis muscle which is located under the skin over the brow and inserts into the orbicularis oculi and corrugator muscles. It is supplied by the frontal branch of facial nerve and its contraction can affect positions of orbicularis oculi and corrugator muscles (Fujimura and Hotta, 2013; Ezure and Amano, 2010). Tight eye closure relies mainly on the

orbicularis oculi muscle. Frontalis, corrugator, zygomaticus major/minor, levator labii superioris, nasalis and procerus muscles, supplied by the zygomatic, frontal and buccal branches of facial nerve, can also be involved due to overlap and cross-link of their fibers with orbicularis oculi. The mouth movements tested in this study are effected by contraction of the orbicularis oris, buccinator, zygomaticus major/minor, levator labii superioris, nasalis, levator anguli oris and risorius muscles. Their effects on upper face start from cheeks and nasal ridge and spread to the lower lid and lateral canthus, while having little influence on the upper lid and eye brow. Our results confirm these observations, showing  $S_{\max}$  and  $V_{\max}$  greater at primary motion sites than other facial areas and greater on the ipsilateral side than contralateral side when single side motion was intended. Smiling is a natural expression involving no forceful actions and therefore is associated with only small marker displacement with relatively low  $S_{\max}$  and  $V_{\max}$ .

Facial muscles are innervated by the facial nerve in various patterns, including one-to-one, many-to-one and one-to-many, which also contribute to variable forms of associated facial movements. Abnormal association from mis-aligned facial nerve fiber regeneration, nucleus excitability changes/reorganization or abnormal synaptic transmission can lead to abnormal association of facial movements, measured as abnormal increase in  $S_{\max}$  and  $V_{\max}$  or change of motion direction. Understanding these may bring novel approaches in evaluation of facial paresis and its sequelae.

As markers were placed on the surface, the elasticity and wrinkles of the skin may affect the accuracy of measurement and lead to overestimated marker  $S_{\max}$  and  $V_{\max}$  near the site of primary movement as compared to other locations. During mouth movements,  $S_{\max}$  and  $V_{\max}$  of markers at medial



canthus may be smaller than those of more distant sites, probably because of lack of subcutaneous tissue and skin elasticity and relatively small extent of muscle contraction over the nasal ridge. However, the motion parameters should be synchronized to those of primary mouth movement, although probably more uniformed than when caused by other neuromuscular factors. Additionally, the skin in older patients tends to be relaxed with increased wrinkles and decreased elasticity and maybe reduced muscle control as part of the physiological changes (Ebner and Johnson, 2010; Ebner et al., 2010), which can contribute to age-related differences when facial markers are measured and should be considered when assessing facial paresis and synkinesis.

Most existing reports on measuring facial expressions focus on the primary movement sites and there are limited reports on quantifying association of movements in separate areas. Three dimensional studies in this field are rare. Clinically, objective and reliable diagnosis of facial paresis or synkinesis requires finding facial marker movements beyond normal range or showing abnormal association inconsistent with physiological synchronization. In designing and improving facial prosthesis, assessment of effects of various stimulation electrodes based on analysis of facial marker movements is needed to achieve vivid and physiological facial expressions. In the field of gaming and animation production, there is also a desire for increasingly synchronized and vivid facial expression representation. The measurement in the current study employed a three-dimensional, dynamic and quantitative approach. Our data support the hypothesis that there is no immobile standing point in facial expressions and allow assessment of influences on the muscle, nerve, subcutaneous tissue and skin by facial movements under physiological and pathological conditions. This methodology may continue to produce abundant and accurate data and provide theoretical basis for development in the above mentioned clinical and industrial fields, and is of value of broad applications.

## References

- Adour, K.K., Byl, F.M., Hilsinger, R.J., Kahn, Z.M., Sheldon, M.I., 1978. The true nature of Bell's palsy: analysis of 1,000 consecutive patients. *Laryngoscope* 88 (5), 787–801.
- Cecini, M., Pavese, C., Comelli, M., Carlisi, E., Sala, V., Bejor, M., et al., 2013. Quantitative measurement of evolution of postparetic ocular synkinesis treated with botulinum toxin type A. *Plast. Reconstr. Surg.* 132 (5), 1255–1264.
- Chen, P., 2003. Chi square analysis in repeat measurement of quantitative data. *Chin. J. Trauma Orthoped.* (01)
- Cook, T., Goldberg, R.A., Douglas, R., Eshaghian, B., Shorr, N., Fagien, S., 2003. The horizontal dynamic of the medial and lateral canthus. *Ophthalm. Plast. Reconstr. Surg.* 19 (4), 297–304.
- Devriese, P.P., Schumacher, T., Scheide, A., de Jongh, R.H., Houtkooper, J.M., 1990. Incidence, prognosis and recovery of Bell's palsy. A survey of about 1000 patients (1974–1983). *Clin. Otolaryngol. Allied Sci.* 15 (1), 15–27.
- Doughty, M.J., 2014. Spontaneous eyeblink activity under different conditions of gaze (eye position) and visual glare. *Graefes Arch. Clin. Exp. Ophthalmol.* 252 (7), 1147–1153.
- Ebner, N.C., Johnson, M.K., 2010. Age-group differences in interference from young and older emotional faces. *Cogn. Emot.* 24 (7), 1095–1116.
- Ebner, N.C., Riediger, M., Lindenberger, U., 2010. FACES—a database of facial expressions in young, middle-aged, and older women and men: development and validation. *Behav. Res. Methods* 42 (1), 351–362.
- Engstrom, M., Berg, T., Stjernquist-Desatnik, A., Axelsson, S., Pitkaranta, A., Hultcrantz, M., et al., 2008. Prednisolone and valaciclovir in Bell's palsy: a randomised, double-blind, placebo-controlled, multicentre trial. *Lancet Neurol.* 7 (11), 993–1000.
- Ezure, T., Amano, S., 2010. The severity of wrinkling at the forehead is related to the degree of ptosis of the upper eyelid. *Skin. Res. Technol.* 16 (2), 202–209.
- Feng, G., Zhao, Y., Tian, X., Gao, Z., 2014. A new 3-dimensional dynamic quantitative analysis system of facial motion: an establishment and reliability test. *PLoS One* 9 (11), e113115.
- Fitzgerald, R., Graivier, M.H., Kane, M., Lorenc, Z.P., Vleggaar, D., Werschler, W.P., et al., 2010. Update on facial aging. *Aesthet. Surg. J.* (30 Suppl.) 11S-24S.
- Frey, M., Giovanoli, P., Gerber, H., et al., 1999. Three-dimensional video analysis of facial movements: a new method to assess the quantity and quality of the smile. *Plastic Reconstr. Surg.* 104 (7), 2032–2039.
- Frey, M., Tzou, C.H., Michaelidou, M., Pona, I., Hold, A., Placheta, E., et al., 2011. 3D video analysis of facial movements. *Facial Plast. Surg. Clin. North Am.* 19 (4), 639–646.
- Frigerio, A., Cavallari, P., Frigeni, M., Pedrocchi, A., Sarasola, A., Ferrante, S., 2014. Surface electromyographic mapping of the orbicularis oculi muscle for real-time blink detection. *JAMA Facial Plast. Surg.* 16 (5), 335–342.
- Fujimura, T., Hotta, M., 2013. A novel method to investigate the relationship between facial movements and wrinkle formation using particle image velocimetry. *Skin. Res. Technol.* 19 (1), e54–e59.
- Hadlock, T.A., Urban, L.S., 2012. Toward a universal, automated facial measurement tool in facial reanimation. *Arch. Facial Plast. Surg.* 14 (4), 277–282.
- Holman, M.L., Neely, J.G., Joaquin, A.H., 1996. Computer-assisted clinic-metric tool for the study of facial expression: a pilot validity study. *Laryngoscope* 106 (2 Pt 1), 135–138.
- Jiang, X., Tien, G., Huang, D., Zheng, B., Atkins, M.S., 2013. Capturing and evaluating blinks from video-based eyetrackers. *Behav. Res. Methods* 45 (3), 656–663.
- Jorge, J.J., Palarissi, P.R., Borges, G.C., Squella, S.A., de Gouveia, M.F., Saragiotto, J.J., et al., 2012. Objective computerized evaluation of normal patterns of facial muscles contraction. *Braz. J. Otorhinolaryngol.* 78 (2), 41–51.
- Kahn DM, Shaw, R.B., 2010. Overview of current thoughts on facial volume and aging. *Facial Plast. Surg.* 26 (5), 350–355.
- Li, J., 2006. Electromyography study of post-facial paresis mouth-eye synkinesis and its clinical significances. *Chin. J. Otolaryngol. Head Neck Surg.* (11), 774–776.
- Linstrom, C.J., 2002. Objective facial motion analysis in patients with facial nerve dysfunction. *Laryngoscope* 112 (7 Pt 1), 1129–1147.
- Lockhart, P., Daly, F., Pitkethly, M., et al., 2010. Antiviral treatment for Bell's palsy (idiopathic facial paralysis). In: *The Cochrane Library*, Issue 2. John Wiley & Sons, Ltd, Chichester, UK. Search date 2008.
- Marur, T., Tuna, Y., Demirci, S., 2014. Facial anatomy. *Clin. Dermatol.* 32 (1), 14–23.
- Meier-Gallati, V., Scriba, H., Fisch, U., 1998. Objective scaling of facial nerve function based on area analysis (OSCAR). *Otolaryngol. Head Neck Surg. Off. J. Am. Acad. Otolaryngol. Head Neck Surg.* 118 (4), 545–550.
- Nemoto, Y., Sakaue, T., Kubota, N., 1994. Observation of the eyelid structure with opening and closing of the eye in magnetic resonance imaging. *Nihon Ganka Gakkai Zasshi* 98 (9), 846–851.
- Paletz, J.L., Manktelow, R.T., Chaban, R., 1994. The shape of a normal smile: implications for facial paralysis reconstruction. *Plast. Reconstr. Surg.* 93 (4), 784–789 discussion 790–781.
- Sullivan, F.M., Swan, I.R., Donnan, P.T., Morrison, J.M., Smith, B.H., McKinstry, B., et al., 2007. Early treatment with prednisolone or acyclovir in Bell's palsy. *N. Engl. J. Med.* 357 (16), 1598–1607.
- Teixeira, L.J., Soares, B.G., Vieira, V.P., et al., 2010. Physical therapy for Bell's palsy (idiopathic facial paralysis). In: *The Cochrane Library*, Issue 2. John Wiley & Sons, Ltd, Chichester, UK. Search date 2008.

- Tomat, L.R., Manktelow, R.T., 2005. Evaluation of a new measurement tool for facial paralysis reconstruction. *Plast. Reconstr. Surg.* 115 (3), 696–704.
- Tzou, C.H., Pona, I., Placheta, E., et al., 2012. Evolution of the 3-dimensional video system for facial motion analysis: ten years' experiences and recent developments. *Ann. Plast. Surg.* 69 (2), 173–185.
- Valenca, M.M., Valenca, L.P., Lima, M.C., 2001. Idiopathic facial paralysis (Bell's palsy): a study of 180 patients. *Arq. Neuropsiquiatr.* 59 (3-B), 733–739.
- Wilkinson, M.F., Kaufmann, A.M., 2005. Monitoring of facial muscle motor evoked potentials during microvascular decompression for hemifacial spasm: evidence of changes in motor neuron excitability. *J. Neurosurg.* 103 (1), 64–69.