Otology & Neurotology
35:e97–e103 © 2014, Otology & Neurotology, Inc.

Importance of the Brow in Facial Expressiveness During Human Communication

*John Gail Neely, †Paul Lisker, and †Jesse Drapekin

**Department of Otolaryngology–Head and Neck Surgery, and †Students and Teachers as Research Scientists (STARS) program, Washington University School of Medicine, St. Louis, Missouri, U.S.A.*

Objective: The objective of this study was to evaluate laterality and upper/lower face dominance of expressiveness during prescribed speech using a unique validated image subtraction system capable of sensitive and reliable measurement of facial surface deformation.
Rationale: Observations and experiments of central control of facial expressions during speech and social utterances in humans and animals suggest that the right mouth moves more than the left during nonemotional speech. However, proficient lip readers seem to attend to the whole face to interpret meaning from expressed facial cues, also implicating a horizontal (upper face–lower face) axis.
Study Design: Prospective experimental design. Experimental maneuver: recited speech. Outcome measure: image-subtraction strength-duration curve amplitude.
Methods: Thirty normal human adults were evaluated during memorized nonemotional recitation of 2 short sentences. Facial movements were assessed using a video-image subtractions system capable of simultaneously measuring upper and lower specific areas of each hemiface.
Results: The results demonstrate both axes influence facial expressiveness in human communication; however, the horizontal axis (upper versus lower face) would appear dominant, especially during what would appear to be spontaneous breakthrough unplanned expressiveness.
Conclusion: These data are congruent with the concept that the left cerebral hemisphere has control over nonemotionally stimulated speech; however, the multisynaptic brainstem extrapyramidal pathways may override hemiface laterality and preferentially take control of the upper face. Additionally, these data demonstrate the importance of the often-ignored brow in facial expressiveness.
Level of Evidence: Experimental study. EBM levels not applicable. **Key Words:** Facial expression—Facial nerve—Facial paralysis—Lip reading.
Otol Neurotol **35:**e97–e103, 2014.

During facial paralysis recovery and reanimation interventions, brow movement is often generally ignored compared with concern for eye closure, mouth sphincter function, and smiling. This tendency easily translates to questioning the value of brow movement all together.

It is only when considering more complex central neural control mechanisms and facial expressions in human communication that the brow emerges as important. The study of lip reading (face reading) suggests that the whole face, not just the lips, is important in conveying nonverbal cues, such emphasis or nuance. Lip reading represents the interaction of two complex sensory-motor systems, one from the sender and the other from the receiver, each with unique central control centers and differing peripherals. The sending expressive face is the motor end-organ peripheral of numerous cortical and subcortical control mechanisms functioning in crossed and uncrossed pathways. The receiving visual/auditory peripherals input to complex subcortical and cortical transmitter-receiver coders and decoders (1–3).

A considerable body of literature has addressed laterality in facial movement along a vertical axis (right versus left). Observations showing that the left hemiface is more mobile

Address correspondence and reprint requests to J. Gail Neely, M.D., F.A.C.S., Otology/Neurotology/Base of Skull Surgery, Department of Otolaryngology–Head and Neck Surgery, Washington University School of Medicine, 660 South Euclid Avenue, Box 8115, St. Louis, MO 63110; E-mail: jgneely@aol.com; neelyg@ent.wustl.edu

All financial and material support for this research and work: STARS program, supported by Pfizer Inc., LMI Aerospace/D3 Technologies, Saint Louis Symphony Orchestra, Solae, Washington University, and University of Missouri-St. Louis. Any financial interests the authors may have in companies or other entities that have an interest in the information in the The Facial Analysis Computerized Evaluation (FACE) system is a research program developed by Neely and Cheung and is not commercially available. Neither Neely or Cheung derive financial support for the system.

All authors fulfilled the following criteria by the following: 1) participating in the conception and design of project and analysis of the manuscript data, 2) drafting and critically revising the content of the manuscript submitted for publication, and 3) giving final approval of the version to be published.

The authors disclose no conflicts of interest.

and expressive during emotional states, especially in right-handed individuals and in women, implicate the right hemisphere as being influential in conveying facial emotion (4–6). Conversely, during speech, babbling, or social utterances, the right mouth has been shown to move more than the left in adults, infants, and marmosets (5,7–10). However, not all investigators have found hemi-facial differences (11).

Alternatively, studies suggest the horizontal axis (upper face versus lower face) may also participate in facial expressions. Prodan et al. (12) and Ross et al. (13) hypothesized that primary emotions (anger, fear, etc.) are processed by the right hemisphere and are unmasked and expressed in the upper face, whereas social emotions (guilt, jealousy, etc.) are processed by the left hemisphere and expressed, or masked, in the lower face. Accordingly, receptive visual peripherals of the receiving individual, under phylogenetic adaptive central control, preferentially attend to the upper face of the sender, especially around the eyes, during vocalization in monkeys (14).

More recently, experimental neuroanatomic data opened new insights into the neuroscience of facial expressions. In contrast to voluntary and more thoughtful facial expressions, mediated by motor cortices on the lateral cerebral surface, involuntary and emotional facial expressions are controlled by a complex multisynaptic mechanism involving the thalamus, basal ganglia, limbic system, including the amygdala, and motor cortices on the medial side of the cerebrum, especially the anterior and posterior cingulate gyri (M3 and M4). Amygdala-generated emotional responses are ultimately sent to the rostral cingulate motor cortex (M3), which projects bilaterally to the facial subnuclei controlling the frontalis and orbicularis oculi (upper face), and to the posterior cingulate gyrus (M4), which projects contralaterally to the lower face (15–20).

The objective of this study was to evaluate laterality and upper/lower face dominance of expressiveness during prescribed speech using an unique validated image subtraction system capable of sensitive and reliable measurement of facial surface deformation (21–23). Hypotheses were as follows: 1) the right mouth will generate greater amplitude of movement than the left mouth during recitation speech, 2) the right mouth dominance during speech may be influenced by degrees of expressiveness, and 3) the upper face will show a greater increase/change in activity as expressiveness increases than will the lower face. To our knowledge, this is the first use of such an image subtraction system to analyze laterality and axis dominance in facial expressions during speech.

METHODS

Subjects

These experiments were conducted using a protocol approved by the Human Research Protection Office, institutional review board (IRB) of Washington University. Thirty normal young and middle aged adult volunteers with no current or antecedent neurologic disease, facial trauma, facial surgery, or paralysis were consented and enrolled. They were seated comfortably in headrest chair with their face 5 feet from a stable tripod mounted digital video camera that generated a miniDV tape. Subjects were instructed to look directly into the lens. Real-time monitoring of facial expressions were made to ensure stable full-face orientation video recordings. Video-image data sets were taken using uniform diffused soft lighting across the entire face to avoid shadows or uneven illumination.

Each subject was asked to repeat each of the 2 short sentences 3 times in a conversational voice. Subjects were given no special instructions of how to recite the sentences; they were specifically not instructed to be expressive or ''dead pan.'' The sentences were as follows: A) ''I like melon'' and B) ''Call the police.'' After this first recording session (1), the subject was allowed to stand and then return to sitting for a second recording session (2). These sentences were constructed to be very brief to facilitate easy memorization, to minimize facial movement, and to differ in meaning, which might influence expressiveness. The sentences were constructed to be of equal lengths in terms of syllables, had similar phonetic composition (1 plosive, 2 liquids, and 1 palatal) and were ''direct speech'' (3).

Image Processing

The miniDV tapes containing the initial image sets of the subjects' faces during speaking were inserted into a JVC Super VHS ET Professional MiniDV and VHS videocassette recorder SR-VS10 (JVC USA, Wayne, NJ, USA) connected to a dedicated computer. The MiniDV data were captured into a stand-alone hard drive tower (Intel Corel Quad CPU, 2.33 GHz 3.25 GB of RAM with Microsoft Windows XP operating system) using Adobe Premiere Pro CS4 (Adobe Systems Inc., San Jose, CA, USA). These initial image sets were maintained for further review.

The initial image sets in .avi files were compressed using Microsoft Run Length Encoding (Microsoft Corporation, Redmond, WA, USA) to generate the specific .avi file type required by the FACE system. (The Facial Analysis Computerized Evaluation (FACE) system is a research program developed by Neely and Cheung and is not commercially available. Neither Neely or Cheung derive financial support for the system.) The image sets for each subject were imported into the FACE system. The operator, while viewing the full-screen facial image, manually set 4 anchors on a vertical line demarcating the center of the face. The first anchor was a horizontal line through the outer orbital canthi; the next was a horizontal tangent to the superior most arch of the eyebrows. The third was a horizontal at the base of the nasal columella, and the fourth was a horizontal through midline where the lips met. Twelve areas of interest were automatically demarcated by boxes pivoting on midline and inscribing areas of the brow, eye, and mouth on each hemiface with large boxes of 120 pixels wide and 120 pixels high and small boxes of 120 pixels wide and 60 pixels high. The large boxes demarcated the major facial regions that move on request; these overlap slightly. The small boxes isolate brow, eye, and mouth areas that do not overlap. Only large boxes were used in this study to capture the complete movement of the brow, eye, and mouth of the right and left hemiface simultaneously during the subject's recitation.

In the computerized image subtraction program, FACE system, all of the pixels of the facial image at rest were subtracted from the pixels in each sequential image frame in motion. The FACE system digitizes each pixel of each frame in the original facial video and gives each pixel a value between 0 (black) and 255 (dense white). Then, it uses the face at rest as a reference and subtracts all the pixels in it from all the pixels in each subsequent frame of the moving face video. The result is a new gray scale image for each frame in motion composed of the subtracted pairs (motion minus rest). This gives a time-intensity curve for facial motion with no movement being black and increasing degrees of movement intensity congruent with increasing degrees of whiteness. The configuration of movement intensity can then be seen and measured.

This process results in a new gray scale image set composed of only changed pixel values over the time of facial movement. If an area of the face does not move, the subtracted pixel value in that area is zero or black; when an area moves, the subtracted absolute pixel value is greater than zero and turns varying degrees of gray or white along 255 gray-scale range. The intensity of facial movement is congruent with the intensity of whiteness seen on the subtracted image (22,24–26). The changed pixel values within the boxes were summed. The summed changed pixel values, in thousands, within a box of interest, over the time of the facial expression generated a strength-duration curve. Facial movements during the recitation of the 2 brief sentences were quite variable in amplitude for the duration of the recitation. The FACE motion value was recorded as the maximum amplitude for each facial area (brow, eye, and mouth) for each hemiface during recitation (Fig. 1).

Identification of Degrees of Expressiveness

Two naive observers were asked to review the computer stored initial image sets, silently with no auditory tract and not yet in the FACE system. They reviewed the image sets together and made a unified determination of expressiveness. This combined determination was used in the study. Image sets reviewed were from Sessions 1 and 2 and reciting sentences A and B. To not bias the observers as to the hypotheses or any preconceived notion of ''expressiveness,'' the observers were given no instructions except to identify subjects whose facial expressions seemed to be varying degrees of expressiveness within a specific session or sentence. ''Expressiveness'' was not defined for them. Because each sentence was repeated 3 times, if any of the 3 repetitions seemed expressive, that subject on that session and that sentence was judged expressive. If the subject's recitation seemed without expressiveness (''dead pan''), the subject was given a rating of ''0''; if the observes felt the subject was slightly more expressive, the subject was given a rating of ''1''; if the observers felt the subject was very expressive, the subject was given a rating of ''2.'' Once a subject, per session per sentence was given an expressiveness rating, this rating was never changed. When asked, following these determinations, the observers defined expressiveness as greater movement of the face, especially the upper face (brow and eye).

FACE System Analysis and Recording

The FACE motion values for the 3 repetitions were averaged and recorded as the maximum amplitude, in thousand changed pixel values, for each facial area (brow, eye, and mouth) for each hemiface during recitation, by expressiveness rating. An example of this arrangement is seen in Table 1.

Data Management and Analysis

Six variables per subject (LR1–LR30), as illustrated in Table 1, include human observer determined expressiveness rating (0, 1,

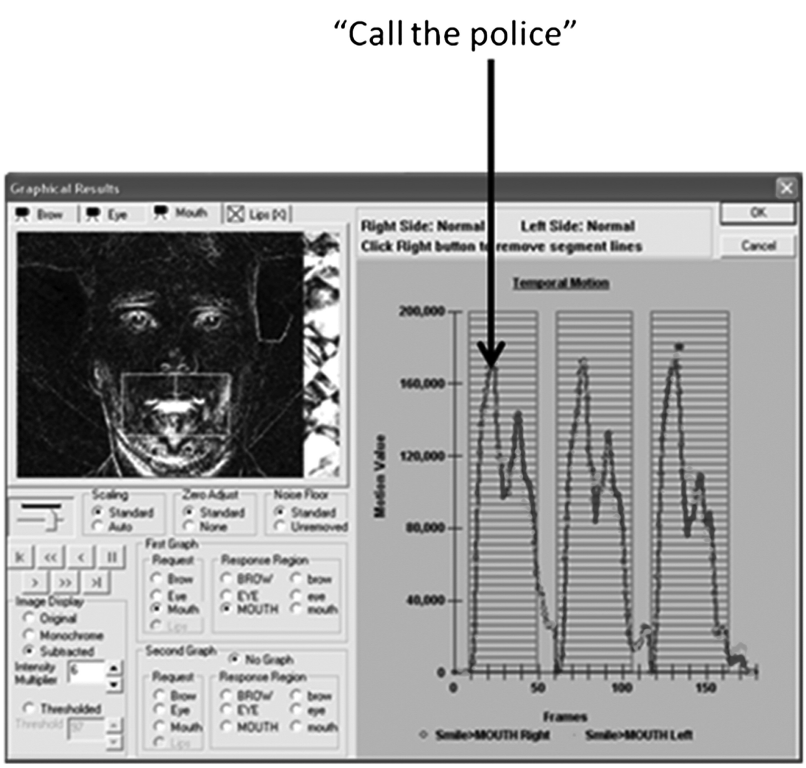

FIG. 1. Print-screen illustration of the FACE system (image subtraction system) of strength-duration output of bilateral curser box inscribed mouth facial movement during "dead-pan" (Grade 0 expressiveness) recitation of "Call the police." There is some movement about the eyes and brow.

TABLE 1. *Repetitions averaged face system values per facial area, recording session (1 and 2), and sentence (A and B) and expressiveness rating in 2 subjects (LR1 AND LR2)*

		LR1		LR2	
Left (in thousands)		Rating	Motion value	Rating	Motion value
1A	Brow	0	41	0	70
	Eye		37		63
	Mouth		195		120
2A	Brow	1	100	0	80
	Eye		92		87
	Mouth		175		120
1B	Brow	1	110	0	72
	Eye		120		60
	Mouth		237		105
2B	Brow	2	207	0	67
	Eye		212		45
	Mouth		188		127
Right (in thousands)					
		LR1		LR2	
		Rating	Motion value	Rating	Motion value
1A	Brow	0	46	0	65
	Eye		45		63
	Mouth		168		103
2A	Brow	1	110	0	80
	Eye		103		82
	Mouth		210		120
1B	Brow	1	106	0	69
	Eye		120		63
	Mouth		210		114
2B	Brow	2	207	0	64
	Eye		215		56
	Mouth		172		106

and 2), facial area (brow, eye, and mouth), hemiface (left and right), recording session (1 and 2), sentence recited (A and B), and maximum amplitude FACE motion value in thousands. The outcome, dependent, variable was the FACE motion value. The other 5 variables were considered independent.

The effect of the independent variables on the dependent variable was assessed using paired *t* test where appropriate, especially during comparisons between hemifaces. When comparisons between 3 rating effects on outcome were necessary, ANOVA or equivalent was used. The significance level was set at $p < 0.05$.

TABLE 2. *Left-right hemiface differences by expressiveness rating (paired t test)*

			95% CI of difference		
Label	Mean (face values in thousands)	Difference	Low	High	*p*
Brow 0 left	61.9630				
Brow 0 right	62.9815	−1.01852	−3.14502	1.10798	0.341
Brow 1 left	94.9412				
Brow 1 right	94.2941	0.64706	−4.48468	5.77880	0.801
Brow 2 left	130.5714				
Brow 2 right	134.2857	−3.71429	−11.58688	4.15830	0.327
Eye 0 left	63.8519				
Eye 0 right	64.6852	−0.83333	−2.89421	1.22755	0.421
Eye 1 left	103.0196				
Eye 1 right	102.8824	0.13725	−11.06191	11.33642	0.980
Eye 2 left	148.4667				
Eye 2 right	136.1333	12.33333	−12.60060	37.26727	0.307
Mouth 0 left	154.5185				
Mouth 0 right	158.7963	−4.27778	−12.37044	3.81488	0.294
Mouth 1 left	178.0196				
Mouth 1 right	185.0196	−7.00000	−17.74746	3.74746	0.197
Mouth 2 left	221.5333				
Mouth 2 right	236.0000	−14.46667	−27.22232	−1.71102	0.029

0, 1, 2 = expressiveness rating.

The SPSS (IBM SPSS statistics, version 20.0.0; Armonk, NY, USA) statistical program was used for data analysis.

RESULTS

Session and Sentence Effects on FACE System Motion Outcomes

FACE motion values for both left and right hemifaces were combined in single columns by session and sentence. Motion values were compared by session (first versus second) and by sentence (A versus B) by paired *t* test. The brow and eye facial areas were significantly affected by session. The second session generated greater movement in the upper face (brow and eye) than the first session. Sentence content had a statistically significant effect on the brow but only in the second session. ''Call the police'' resulted in more brow movement than ''I like melon.'' The mouth area was not affected by session or by sentence.

Left Versus Right by Facial Region by Expressiveness

The averaged 3 repetitions FACE motion values by expressive grades (0–2) were compared between hemiface sides by paired *t* test. There was a significant difference between sides in the mouth only during grade 2 expressiveness. In that condition, the overall motion in the right mouth was greater than the left. No other comparisons were significantly different (Table 2).

Upper Face Versus Lower Facial Regions

The averaged 3 repetitions FACE motion values by expressive grades (0–2) were arranged so that each column contained both the values for the left and right hemifaces. The values of each facial area increased with the increasing degrees of expressiveness (Fig. 2). Values of the upper face (brow and eye) were compared with each other and with the lower face (mouth) using 1-way ANOVA or the Kruskal-Wallis 1-way ANOVA on ranks. There were consistently significant differences of FACE motion values in all expressive grades between the brow and the eye compared with the mouth but not with each other. The mouth moved consistently more than the brow or eye. Because the primary behavior under study was speech, it was expected that the mouth motion would be significantly greater than the upper face movements.

To assess the degree to which each facial area increased above baseline as expressiveness varied from ''0'' to ''1'' to ''2,'' all motion values of combined right and left hemifaces were averaged within expressiveness ratings. The changes in averaged motion values between

TABLE 3. *Averages of facial motion values by facial area per expressiveness and proportional change of facial motion by degrees of expressiveness*

	Expressiveness		
	0	1	2
Brow			
Average pixel values (in thousands)	62	95	132
Change from 0	0	32	70
% increase from 0	0	52	112
Eye			
Average pixel values (in thousands)	64	103	142
Change from 0	0	39	78
% increase from 0	0	60	121
Mouth			
Average pixel values (in thousands)	157	182	229
Change from 0	0	25	72
% increase from 0	0	16	46

Average pixel values = average of all three repetitions on right and left sides combined for facial area.

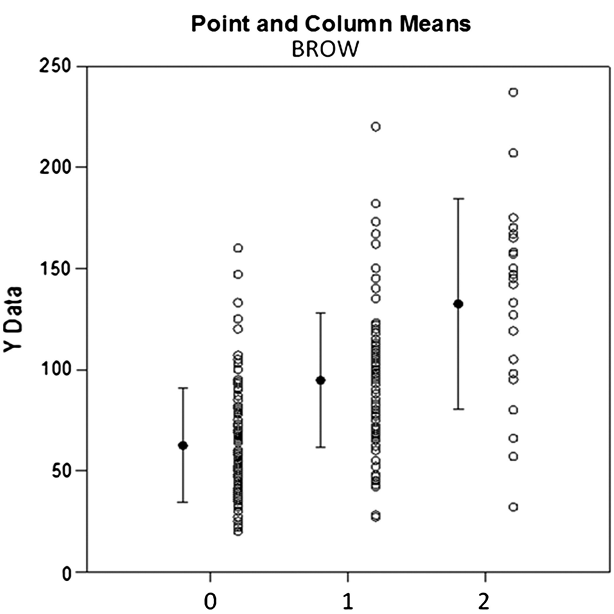

FIG. 2. SPSS graphic output showing ''point and column means'' of FACE data of brow. The *x* axis is the expressiveness grade (0, 1, and 2) *Circles* represent individual subject data in columns, and the column group means are represented by *black dots* with the standard deviations bars. The *y* axis is the summed changed from rest pixel values, within the inscribed curser box.

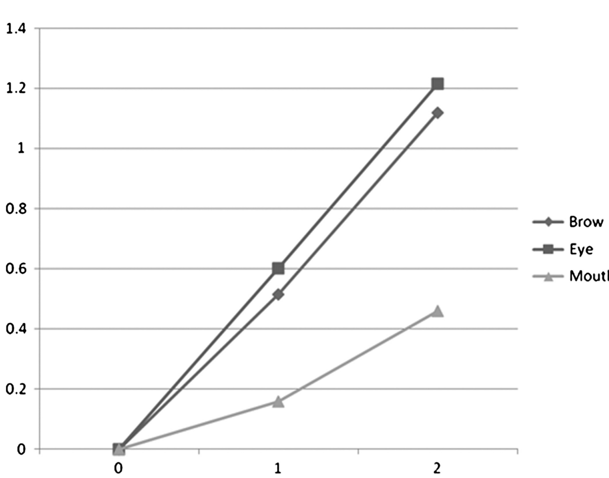

FIG. 3. Plot of the proportional change from ''dead-pan'' (expressive Grade 0) as the expressiveness changes from 0 to 1 to 2. Note the brow and eye change considerably more than does the mouth.

TABLE 4. *Summary*

Qualitative human observations	Spontaneously occurring expressiveness during recitation speech seemed predominantly localized in the upper face (brow and eye)
Quantitative Evaluations during recitation speech	Results
Session effect	Second session generated greater movement than the first in the upper face (brow and eye). Mouth not affected.
Sentence content effect	''Call the police'' resulted in greater movement than ''I like melon'' only in brow and only in second session. Mouth not affected.
Left versus right hemiface	Right mouth moved more than the left, but only in Grade 2 expressiveness
Upper face versus lower face	Upper face (brow and eye) moved proportionally greater than the lower face at all increasing levels of expressiveness regardless of session or sentence content

expressiveness ratings were calculated. The proportion (%) of the change in motion values from ''0'' was then calculated (Table 3; Fig. 3). As illustrated, the proportional increase in facial motion, compared with the expressionless face, markedly increase in the upper face (brow and eye) as compared with the modest increase of movement in the lower face.

DISCUSSION

These data confirm right mouth dominance during speech but only in a more expressive condition. It is likely that previously reported adult spontaneous social speech, infant babbling, and marmoset social utterances may be more expressive than ''dead pan'' recitation; this may account for the right mouth dominance in those reported experiments.

These data also confirm a large horizontal axis effect. The upper face (brow and eye) robustly moves more than the lower face (mouth) as expressiveness increases. Human observations and the computed image subtraction technique demonstrate the upper face seems more involved with expressiveness, even during speech recitation, than the lower face.

Subhypotheses that ''Call the police,'' a potentially more urgent utterance, would result in more animation than ''I like melon'' and the second, more familiar and relaxed, session would also generate more expressiveness were accepted. These data supported session order, and sentence content did seem to have an effect on expressiveness, predominantly in the upper face.

CONCLUSION

It would seem that both axes influence facial expressiveness in human communication; however, the horizontal axis (upper face versus lower face) would appear dominant, especially during what would seem to be spontaneous breakthrough of unplanned expressiveness (Table 4).

These data seem congruent with the concept that the left cerebral hemisphere has control over nonemotionally stimulated speech; however, the multisynaptic brainstem extrapyramidal pathways may override hemiface laterality and preferentially take control of the upper face. Additionally, these data demonstrate the importance of the often-ignored brow in facial expressiveness.

Acknowledgment: The authors thank Nancy Tye-Murray, Ph.D., for the critical reading of this article.

REFERENCES

1. De Filippo CL, Lansing CR. Eye fixation of deaf and hearing observers in simultaneous communication perception. *Ear Hear* 2006; 27:331–52.
2. Lansing CR, McConkie GW. Attention to facial regions in segmental and prosodic visual speech perception tasks. *J Speech Lang Hear Res* 1999;42:526–39.
3. Yao B, Belin P, Scheepers C. Silent reading of direct versus indirect speech activates voice-selective areas in the auditory cortex. *J Cogn Neurosci* 2011;23:3146–52.
4. Borod JC, Haywood CS, Koff E. Neuropsychological aspects of facial asymmetry during emotional expression: a review of normal adult literature. *Neuropsychol Rev* 1997;7:41–60.
5. Koff E, Borod JC, White B. Asymmetries of hemiface size and mobility. *Neuropsychologia* 1981;19:825–30.
6. Moscovitch M, Olds J. Asymmetries in spontaneous facial expressions and their possible relation to hemispheric specialization. *Neuropsychologia* 1982;20:71–81.
7. Holowka S, Petitto LA. Left hemisphere cerebral specialization for babies while babbling. *Science* 2002;297:1515.
8. Hook-Costigan MA, Rogers LJ. Lateralized use of the mouth in production of vocalizations by marmosets. *Neuropsychologia* 1998; 36:1265–73.
9. Nicholls ME, Searle DA, Bradshaw JL. Read my lips: asymmetries in the visual expression and perception of speech revealed through the McGurk effect. *Psychol Sci* 2004;15.
10. Wolf MF, Goodale MA. Oral asymmetries during verbal and non-verbal movement of the mouth. *Neuropsychologia* 1987;25: 375–96.
11. Kowner R. Laterality in facial expressions and its effect on attributions of emotion and personality: a reconsideration. *Neuropsychologia* 1995; 33:539–59.
12. Prodan CI, Orbelo DM, Testa JA, et al. Hemispheric differences in recognizing upper and lower facial displays of emotion. *Neuropsychiatry Neuropsychol Behav Neurol* 2001;14:206–12.
13. Ross ED, Prodan CI, Monnot M. Human facial expressions are organized functionally across the upper-lower facial axis. *Neuroscientist* 2007;13:433–46.
14. Ghazanfar AA, Nielsen K, Logothetis NK. Eye movements of monkey observers viewing vocalizing conspecifics. *Cognition* 2006;101:515–29.
15. Ghashghaei H, Barbas H. Pathways for emotion: interactions of prefrontal and anterior temporal pathways in the amygdala of the rhesus monkey. *Neuroscience* 2002;115:1261–79.
16. Morecraft RJ, McNeal DW, Stilwell-Morecraft KS, et al. Amygdala interconnections with the cingulate motor cortex in the rhesus monkey. *J Comp Neurol* 2007;500:134–65.
17. Morecraft RJ, Louie JL, Herrick JL, et al. Cortical innervation of the facial nucleus in the non-human primate. A new interpretation

of the effects of stroke and related subtotal brain trauma on the muscles of facial expression. *Brain* 2001;124:176–208.
18. Morecraft RJ, Stilwell-Morecraft KS, Rossing WR. The motor cortex and facial expression: New insights from neuroscience. *The Neurologist* 2004;10:235–49.
19. Yuasa S. Somatotopy in the emotional exression by the amygdala [in Japanese]. *Brain Nerve* 2009;61:1395–404.
20. Holstege G. Emotional innervation of facial musculature. *Mov Disord* 2002;17:S12–6.
21. Neely JG, Cheung JY, Wood MW, et al. Computerized quantitative dynamic analysis of facial motion in the paralyzed and synkinetic face. *Am J Otol* 1992;13:97–107.
22. Neely JG, Jekel JF, Cheung JY. Variations in maximum amplitude of facial expressions between and within normal subjects. *Otolaryngol Head Neck Surg* 1994;110:60–3.
23. Neely JG, Wang KX, Shapland CA, et al. Computerized objective measurement of facial motion: normal variation and test-retest reliability. *Otol Neurotol* 2010;31:1488–92.
24. Helling TD, Neely JG. Validation of objective measures for facial paralysis. *Laryngoscope* 1997;107:1345–9.
25. Holman ML, Neely JG, Joaquin AH. Computer-assisted clinimetric tool for the study of facial expression: a pilot validity study. *Laryngoscope* 1996;106:135–8.
26. Neely JG, Joaquin AH, Kohn LA, et al. Quantitative assessment of the variation within grades of facial paralysis. *Laryngoscope* 1996;106:438–42.