Specific Forms of Facial EMG Response Index Emotions During an Interview: From Darwin to the Continuous Flow Hypothesis of Affect-Laden Information Processing

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Previous research has demonstrated that mild negative emotional imagery and unpleasant sensory stimuli lead to greater electromyographic activity over the brow muscle region than mild positive imagery and stimuli, even in the absence of significant changes in visceral and general facial EMG activity. Previous research has not addressed whether electromyographic responses over the brow region are a sensitive and specific index of emotions, however, since a multiplicity of events lead to changes in brow activity. In this research, facial electromyographic and audiovisual recordings were obtained while individuals were interviewed about themselves. Afterwards, individuals were asked to describe what they had been thinking of during specific segments of the interview marked by distinctive electromyographic responses over the brow region in the context of ongoing but stable levels of activity elsewhere in the face. The results are interpreted in terms of a continuous flow hypothesis of affect-laden information processing.

> Certain complex actions are of direct or indirect service under certain states of the mind, in order to relieve or gratify certain sensations, desires, etc.; and *whenever the same state of mind is induced, however feebly, there is a tendency through the force of habit and association for the same movements to be performed,* though they may not be of the least use (Darwin, 1872/1965, p. 28, italics added).

Research on the language of emotions has shown that intense reportable states such as sadness, fear, joy, and disgust are organized in terms of intensity, valence, and spontaneity or controllability, and that these states are influenced by biological, physiological, cognitive, social, and cultural factors (e.g., Mandler, 1984; McHugo, Smith, & Lanzetta, 1982; Russell, 1983; Schachter & Singer, 1962; Smith & Ellsworth, 1987). Charles Darwin (1872/1965), whose writings provided early impetus for much of this research, further observed that actions of the muscles of mimicry, such as those he termed the "grief-muscles" (e.g., the corrugator supercilii muscle, whose actions pull the brows down and together), were brought into momentary action by even subtle emotions, and that patterns of these actions could be observed during interpersonal interactions.

The origin of the actions of the corrugator supercilii muscle during threat and negative emotions, like that of the muscles of mimicry generally, was thought by Darwin to stem primarily from the adaptive significance of the actions for the organism (e.g., enhanced acuity and ocular protection, communication of intention to conspecifics), secondarily through what Darwin termed *serviceable associated habit* (see quotation), and through antithesis. The study of emotions was advanced yet further when, building on the pioneering observations of Darwin, it was found that (a) individuals perform at better-than-chance levels when categorizing facial expressions of happiness, sadness, surprise, anger, disgust, and fear; (b) the inductions of what individuals report as being positive and negative emotional states are associated with distinctive facial actions; (c) cultural influences can, but do not necessarily, alter these outcomes significantly; (d) these outcomes can be found in neonates and the blind as well as sighted adults; (e) emotion-specific activity in the autonomic nervous system is observed when generated by constructing facial prototypes of emotion muscle by muscle and by reliving past emotional experiences; and (f) the variability in emotional expressions observed across individuals and cultures is attributable to factors such as differences in which emotion, sequence of emotions, or blend of emotions were evoked and to cultural prescriptions regarding the display of emotions (e.g., see Ekman, 1973a, 1973b, 1973c, 1982; Ekman & Friesen, 1978; Ekman, Levenson, & Friesen, 1983; Izard, 1971, 1977; Tomkins, 1962).

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Subtle and Fleeting Emotional Events

Many subtle emotional processes or events are not accompanied by significant visceral changes or by visually perceptible expressive facial actions, however, and these facts have hindered the objective study of emotion as well as theory and research on the contribution of emotions to social processes and behavior (e.g., Graham, 1980; Rajecki, 1983; cf. Cacioppo, Losch, Tassinary, & Petty, 1986; Zajonc, 1980). Darwin (1872/1965) recognized this limitation, stating that "The study of expression is difficult, owing to the movements being often extremely slight, and of a fleeting nature" (p. 12). Closer analyses of the construction of facial expressions reveal that they are the result of movements of facial skin and connective tissue caused by the contraction of facial muscles. These movements create folds, lines, and wrinkles in the skin and the movement of facial landmarks, such as the brows and corners of the mouth (e.g., Ekman & Friesen, 1978; Izard, 1971; Rinn, 1984). Although muscle activation must occur if these facial feature distortions are to be achieved (see Figure 1), it is possible for muscle activation to occur in the absence of any overt facial action if the activation is weak or transient or if the overt response is aborted.

Briefly, the neural activation of the striated muscles results in the release of acetylcholine at motor end plates, which in turn leads to muscle action potentials (MAPs) that are propagated bidirectionally across muscle fibers and activate the physiochemical mechanism responsible for muscle contraction. The activating neurotransmitter acetylcholine is quickly eradicated by the enzyme cholinesterase, so that continued efferent discharges are required for continued propagation of MAPs and fiber contraction. Add to this the physiological finding that low amplitude neural volleys along motor nerves activate small motoneurons, which innervate relatively few and small muscle fibers (a relationship attributable to the size principle; Henneman, 1980), and one can begin to comprehend the extent to which there is a temporally as well as spatially ordered flow of low-level efferent activity in all but completely relaxed striated muscles (cf. Cacioppo, Marshall-Goodell, & Dorfman, 1983). Finally, fast or low-level changes in these efferent discharges can occur without leading to any visible feature distortions on the surface of the face. This is because of the structure and elasticity of the facial skin, facial sheath, adipose tissue, and facial muscles. The muscles of expression are attached to other muscles, bones, or a facial sheath below the surface of the facial skin and adipose tissue; not unlike a loose chain, the facial muscles can be pulled a small distance (i.e., contracted slightly) before exerting a significant force on the object to which they are anchored (cf. Tassinary, Cacioppo, & Geen, in press). In addition, the elasticity of the facial sheath, facial skin, and adipose tissue acts like a low-pass mechanical filter, attenuating the visible effects of very rapid contractions (Fridlund, 1987; cf. Fridlund & Cacioppo, 1986).

These advances in our understanding of the somatic nervous system and effectors, coupled with several technological developments over the past century, have made it possible to extend Darwin's line of reasoning to suggest that emotions too subtle or fleeting to effect a change in visceral response or to register an overt facial action may nevertheless result in transient, small amplitude changes in facial MAPs. For instance, even the low amplitude MAPs generated by the depolarization of small motoneurons can be detected using electromyography (EMG), and evidence from several laboratories now exists showing that MAP activity in the face can be monitored by using the surface EMG whether or not there are socially perceptible muscle contractions or movements of facial landmarks (e.g., Cacioppo & Petty, 1981; Cacioppo, Petty, Losch, & Kim, 1986; Cacioppo, Petty, & Marshall-Goodell, 1984; Ekman, Schwartz, & Friesen, 1982, cited in Ekman, 1982; Schwartz, Fair, Salt, Mandel, and Klerman, 1976). In addition, advances in laboratory computing and descriptive statistics have provided a means for recording and quantifying transient features of rapid and complex responses such as the surface EMG (e.g., Cacioppo & Dorfman, 1987; Cacioppo, Petty, & Morris, 1985; Fridlund & Cacioppo, 1986; Loeb & Gans, 1986). Consistent with expectations, negative (in contrast to positive) emotional imagery, sensory stimuli, and social events have been found to evoke increased EMG activity over the corrugator supercilii muscle region and decreased EMG activity over the zygomaticus major muscle region (e.g., Brown & Schwartz, 1980; Cacioppo & Petty, 1979; Cacioppo et al., 1984; Cacioppo, Petty, et al., 1986; Dimberg, 1986; Fridlund, Schwartz, & Fowler, 1984; McCanne & Anderson, 1987; McHugo, Lanzetta, Sullivan, Masters, & Englis, 1985; Schwartz et al., 1976).

Inferences About Emotion From Facial EMG Responses

The study of small amplitude, visually imperceptible changes in MAPs has particular potential for advancing our understanding of the contribution of emotion to social behavior if these changes provide an accurate episodic marker of emotion.[1] Although the presentation of mildly negative stimuli has consistently resulted in a small increase in EMG activity recorded over the corrugator supercilii muscle region, inferences regarding a change in emotion based on the appearance of a specific and phasic change in EMG activity recorded over the corrugator supercilii muscle region are often dubious given existing research. This is because previous research has not addressed the extent to which such changes covary primarily or only with changes in emotion. Increased EMG activity over the corrugator supercilii muscle region might result from the arousal of negative affect, blinking, paralinguistic signaling through movements of the brow, and so on (Ekman, 1979). Hence, even though there is considerable evidence that variations in emotion lead to changes in EMG activity over the corrugator supercilii muscle region, to infer changes in emotion occurred (or failed to occur) on the basis of EMG activity over the corrugator supercilii muscle region would be to commit the logical error of affirmation of the consequent.[2]

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[1] A marker is defined as a response that, within a given assessment context, is present during a psychological process or event of interest (e.g., emotional arousal) or that is related to the psychological episode of interest by some well-defined temporal function such that the measure can be used to delineate the onset and offset of the episode of interest. Markers can be distinguished from invariants in that the latter hold across situations (see Cacioppo & Tassinary, in press).

[2] Although a statement and its contrapositive are logically equivalent, a statement and its converse are not logically equivalent. Thus, knowledge that a statement is true (i.e., A implies B) implies the contrapositive is true (i.e., Not-B implies Not-A) but does not imply that the converse is true (i.e., B implies A). While knowledge that A implies B can be sufficient when contrasting two or more theoretical predictions (i.e., hy-

The aims of this research, therefore, were twofold. First, we sought to address the usefulness of momentary and specific changes in EMG activity over the corrugator supercilii muscle region as a basis for inference about emotions by using EMG activity as a blocking variable and ratings of emotional experience as the dependent variable. This tactic is in sharp contrast to the usual strategy of measuring EMG activity as a function of emotional experience. Second, we sought to determine whether biologically motivated hypotheses regarding the form of the EMG responses over the corrugator supercilii muscle region could enhance the extent to which such responses are predictive of emotion. There are many reasons mean level of EMG activity over the corrugator supercilii muscle region might change, and the existence of nonemotional determinants of increased mean EMG activity weakens the grounds for inference about emotion based on these EMG responses. The rationale for the specific EMG forms used as blocking variables in this research follows.

EMG Response Forms

Previous research has examined the spatial pattern of facial EMG activity evoked by variations in emotion, but this approach can be insensitive when individuals are speaking (e.g., because of the EMG cross-talk recorded over the zygomaticus major muscle region, which is attributable to overt articulatory movements and to false smiles) or when very mild emotions are involved (e.g., see Cacioppo, Petty, et al., 1986; Tassinary, Cacioppo, & Geen, in press). A potentially important and complementary approach involves specifying with greater precision the form of EMG response over the corrugator supercilii muscle region that is predictive of variations in emotion (cf. Cacioppo et al., 1983). Such an approach widens (or, in the worst case, leaves unchanged) the range of validity of somatic markers of emotion. Because the goal in this research was to predict mild variations in people's emotional experience as they were speaking during an interview, attention was given to the manner in which the EMG response over the corrugator supercilii muscle region unfolded over time (i.e., its form) while matching for the gross level of EMG activity observed over the zygomaticus major and medial frontalis muscle regions.

Four forms of phasic EMG activity over the corrugator supercilii muscle region were identified during pilot testing and are illustrated in Figure 2. The first form represents basal levels of EMG activity over the corrugator supercilii muscle region and was included to establish baselines for reports of emotional experience (EMG controls or pseudotrials; cf. Johnson & Lubin, 1972). The second represents an acicular burst of EMG activity over the corrugator supercilii muscle region (EMG spike). Acicular EMG responses could be expected to occur for a variety of reasons. Increases in muscle tonus, as might result from sustained attention to a task, result in changes in spontaneous EMG response, which can manifest as very brief semistochastic unimodal EMG pulses or spikes (i.e., less than a couple seconds in duration). Such activity is said to be spontaneous, or nonspecific, because the spikes occur in the absence of any known precipitating or associated thought, emotion, or intention (e.g., see Sternbach, 1966, p. 68). Eyeblinks can also manifest in this form. A fleeting emotion could also lead to this form of EMG response, but the transient nature of the emotion, coupled with the various nonemotional determinants of EMG spikes, should weaken the prediction of an individual's emotional experience on the basis of the appearance of an EMG spike during an interview.

The final two forms of EMG response were defined as (a) a relatively smooth response less than 5 s in duration marked by a gradual onset and offset (EMG mound) and (b) a ballistic EMG response also less than 5 s in duration that manifests more like a cluster of two or more partially overlapping EMG spikes than an EMG mound (EMG cluster; see Figure 2). Facial actions include those that serve primarily an interpersonal communicative function (e.g., raising one of the brows while speaking to emphasize nonverbally a point made verbally), as well as those, to paraphrase Darwin, that are of direct or indirect service of personal sensations and desires (e.g., see Darwin, 1872/1965, p. 28). Interpersonal communication, verbal and nonverbal, is facilitated by the transmission of high-fidelity signals. In producing clear, unambiguous signals, the train of MAPs that are recruited with interpersonal communicative intent (or of a similar but more feeble state of intention) may be characterized by a relatively smooth sequence of activation (e.g., EMG mounds in contrast to EMG clusters). Of course, there need not be a contradiction between the facial actions that serve interpersonal communication and those that originate from personal sensations or desires; moreover, emotions can rise and fall gradually and, accordingly, may also be associated with relatively smooth increments and decrements of EMG activation. The important point here, however, is that phasic EMG clusters over the corrugator supercilii muscle region are less likely than EMG spikes or mounds to be the consequence of nonemotional events (e.g., spontaneous activation, paralinguistic signalling) and, hence, may be especially likely to mark variations in emotions during an interview.

To summarize, four specific forms of phasic EMG activity over the corrugator supercilii muscle region were investigated as blocking variables in this research: basal levels of activity, spikes, mounds, and clusters. Because relatively few nonemotional antecedents were thought to exist for EMG clusters over the corrugator supercilii muscle region during an interview, the emotional experiences marked by EMG clusters were predicted to differ from those marked by basal levels; and the emotional experiences marked by EMG spikes and mounds were predicted to fall between these extremes.

Videotape reconstructions and ratings by the subjects were used in an effort to access and quantify in as nonreactive a fashion as possible the emotions felt by subjects at specific points in time during the interview. Similar efforts to access and quantify the deep, in contrast to surface, structure of communications have been used with success in previous research. For instance, Gottman and Levenson (1986) reported that the autonomic responses exhibited by subjects viewing a videotape of themselves during a social interaction mirrored those exhibited during the interaction. They referred to this phenomenon as *physiological*

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pothetico-deductive research), the logic of using the consequent, B, as an index of the antecedent, A, requires a conditional probability approach (i.e., P(A/B)), such as that used here. Interested readers may wish to consult Cacioppo and Tassinary (in press) for a detailed discussion of these distinctions and their theoretical implications.

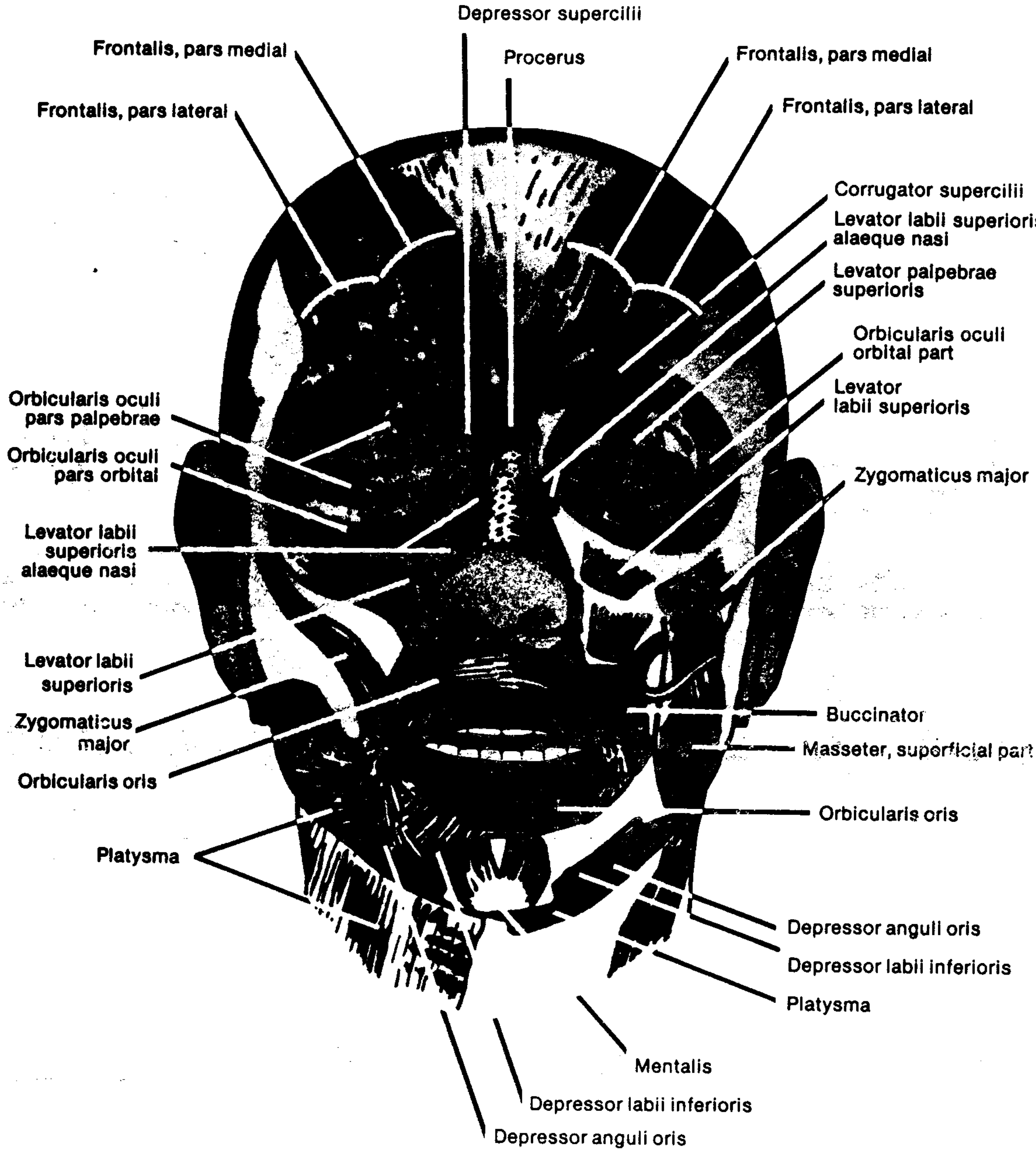

Figure 1. Schematic representation of selected facial muscles. (Overt facial expressions of emotion are based on contractions of the underlying musculature that are sufficiently intense to result in visibly perceptible dislocations of the skin and landmarks. The more common visible effects of strong contractions of the depicted facial muscles include the following. *Muscles of the lower face:* Depressor anguli oris—pulls the lip corners downward; Depressor labii inferioris—depresses the lower lip; Orbicularis oris—tightens, compresses, protrudes, or inverts the lips; Mentalis—raises the chin and protrudes the lower lip; Platysma—wrinkles the skin of the neck and may draw down both the lower lip and the lip corners. *Muscles of the mid-face:* Buccinator—compresses and tightens the cheek, forming a dimple; Levator labii superioris alaeque nasi—raises the center of the upper lip and flares the nostrils; Levator labii superioris—raises the upper lip and flares the nostrils, exposing the canine teeth; Masseter—adducts the lower jaw; Zygomaticus major—pulls the lip corners up and back. *Muscles of the upper face:* Corrugator supercilii—draws the brows together and downward, producing vertical furrows between the brows; Depressor supercilii/procerus—pulls the medial part of the brows downward and may wrinkle the skin over the bridge of the nose; Frontalis, pars lateral—raises the outer brows, producing horizontal furrows in the lateral regions of the forehead; Frontalis, pars medial—raises the inner brows, producing horizontal furrows in the medial region of the forehead; Levator palpebrae superioris—raises the upper eyelid; Orbicularis oculi, pars orbital—tightens the skin surrounding the eye causing crows-feet wrinkles; Orbicularis oculi, pars palpebrae—tightens the skin surrounding the eye causing the lower eyelid to raise. Descriptions are consistent with those in articles by Daniels & Worthingham, 1986; Ekman & Friesen, 1978; Kendall & McCreary, 1980; Izard, 1980; and Weaver, 1977.)

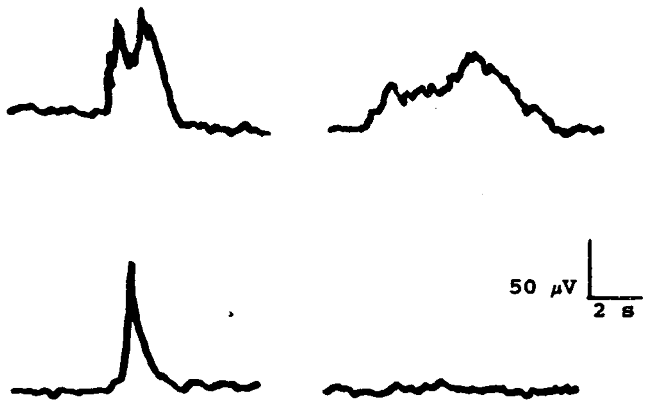

Figure 2. Exemplars of the four forms of electromyographic response over the corrugator supercilii muscle region used to help define 10-s segments of the interview about which subjects would be asked to rate their feelings and emotions: cluster (upper left), mound (upper right), spike (lower left), and control (lower right). (The EMG signals were rectified and smoothed using contour-following integrators with time constants of 0.02 s.)

reliving and took this as evidence for the validity of videotape reconstruction in the assessment of emotion (see also Ickes, Robertson, Tooke, & Teng, 1987; Martzke, Andersen, & Cacioppo, 1987).

Method

Subjects and Equipment

Fifteen undergraduate women participated in a study involving what was described as an interview about themselves. Following a recruitment meeting, at which time the nature of psychophysiological recording was explained, subjects were interviewed individually while unobtrusive videorecording and surface EMG recordings over the corrugator supercilii (CS), zygomaticus major (ZM), and medial frontalis (MF) muscle regions on the left side of the face (see Figure 1) were secured following the guidelines outlined by Fridlund and Cacioppo (1986). Subjects were unaware that somatic responses over which they had control were being recorded (cf. Cacioppo et al., 1984). The EMG signals were relayed through shielded cable to wideband AC preamplifiers, where they were rectified and smoothed by using contour-following integrators with time constants of 0.02 s. The preamplifiers/integrators were calibrated using a 200-μV, 500-Hz square-wave signal to yield a full-scale deflection, and the rectified and smoothed EMG recordings from each muscle region were displayed continuously on the polygraph. A chronographic record was superimposed on the video image and used to relate the subject's verbal responses and the video image to EMG responses.

Procedure

Following a 10-min adaptation period, subjects were asked to continue to relax with their eyes closed (to minimize artifacts and EMG responses over the CS region attributable to blinking) and to begin talking about themselves, being as frank, honest, and self-disclosing as possible. The interviewer, an advanced graduate student in clinical psychology, was located in a separate room and was blind to the experimental condition. The interviewer used an intercom to communicate with the subject and sought descriptions ranging from the superficial (e.g., demographics, physical attributes) to the intimate (e.g., perceived strengths and weaknesses, traumatic experiences). Subjects were told that they could pause to prepare or to reflect and comment on their responses, and confidentiality was emphasized. The interview lasted 30 min.

Throughout the interview, two other experimenters blind to the experimental hypotheses identified exemplars of each of the four forms of EMG response over the CS muscle region: (a) control—a pseudotrial characterized by stable EMG activity at least 10 s in duration; (b) spike—a unimodal response less than 2 s in duration marked by a sharp onset and offset; (c) mound—a relatively smooth response less than 5 s in duration marked by a gradual onset and offset; and (d) cluster—a multimodal response less than 5 s in duration marked by an abrupt onset and offset (see Figure 2).

There were several prerequisite conditions for the identification of an EMG exemplar. First, subjects had to be speaking about themselves. Second, subjects' eyes had to be closed. Third, EMG activity over the CS muscle region had to indicate that the EMG spike, mound, or cluster was of moderate amplitude (i.e., maxima between 75 and 150 μV) and was discrete (i.e., was preceded and followed by at least 5 s of low and stable EMG activity). The latter was established to ensure that reports obtained during the videotape reconstruction coincided with discrete EMG exemplars. Fourth, EMG activity over other facial muscles (i.e., ZM, MF regions) was used to define a particular context of somatic activity in which exemplars of EMG activity over the CS region were selected (e.g., to ensure that the selected EMG exemplars over the CS region were not associated with obvious variations in EMG activity over these muscle regions or were not simply due to general facial tension). It should be emphasized that EMG activity over the ZM region was elevated substantially during these periods as a result of articulation. One implication is that subtle differences in EMG activity over the ZM region that might have covaried with the subjects' mild or transient affective states could easily be masked by the larger and nearly continuous variations in EMG activity due to the contraction of the proximal musculature during speech production. In sum, EMG activity over the ZM and MF regions was monitored to avoid identifying EMG exemplars over the CS muscle region when activity over the ZM and MF regions was atypical. Finally, both raters had to agree that a particular segment of the polygraph record met all of the preceding criteria for the segment to be eligible for videotape reconstruction. At least five exemplars of each of the four forms of EMG response over the CS region were identified during each interview.

Immediately following the interview, subjects were moved to a second testing room where they twice viewed the videotape of their interview. During the first presentation, subjects were told to try simply to recapture their thoughts, feelings, ideas, and images as they viewed the videotape. The entire videotape was presented without interruption to allow subjects to recapture their thoughts and feelings. The videotape reconstruction was conducted during the second presentation. Subjects were instructed that, whenever the videotape was paused, they should provide as honest and complete a description as possible of everything—every thought, feeling, or image—that went through their heads at that point during the interview. The video recording was then shown again in its entirety with the exception that it was paused at five randomly selected exemplars from each of the four facial EMG response-forms identified above. At each pause, subjects were asked to think aloud about what their thoughts, feelings, and images were during that segment of the actual interview. These 20 recollections constituted the verbal protocols subsequently rated by subjects.

The session had lasted approximately 2.5 hr by this point; another 15 min was required to remove the electrodes. Also, the subjects' ratings (described later), debriefing, and consent to score the videotapes required an additional 40 to 50 min to obtain. Hence, we decided following pilot testing to excuse subjects at this point in the procedure and to reschedule them to return within 24 to 48 hr to rate each of these 20 verbal protocols, obtain a debriefing, and consider giving consent to score the videotapes (all subjects consented). The decision to separate the interview from the ratings of the interview, if anything, worked against finding any relationship between transient EMG responses over the CS region and the subjects' ratings of their emotions during specific segments of the interview.

Upon returning to the laboratory, subjects were seated and listened to their verbal protocols. Following the presentation of each protocol, subjects rated the extent to which their feelings during this segment of the interview could be characterized along eight abbreviated Differential Emotions (DE) scales (1 = *not at all*, 7 = *very strongly*): (a) merry/gleeful/amused, (b) warmhearted/joyful/elated, (c) sad/downhearted/blue, (d) irritated/angry/mad, (e) fearful/scared/afraid, (f) tense/anxious/nervous, (g) disgusted/turned-off/repulsed, and (h) contemptuous/scornful/disdainful (cf. McHugo et al., 1982). In addition, to gauge the degree of self-disclosure present in each of the verbal protocols, subjects indicated with whom they had previously shared this information (1 = mere acquaintances, 2 = casual friends or distant relatives, 3 = close friends or relatives, 4 = intimate friends or relatives, 5 = no one) and rated the degree to which their thoughts reflected a personal insight (1 = *none at all*, 7 = *very much*). Each subject's response on each scale across the 20 trials was converted to a *Z*-score. This was done to minimize variability in the subjects' ratings attributable to individual differences in their use of each of the DE scales. Preliminary analyses revealed that the order of the means and the general pattern of significant effects were unchanged by this transformation although, as expected, the *F*-ratios were greater in analyses using the *Z*-scores.

Results

Can EMG Responses Over the Corrugator Supercilii Muscle Region Mark Variations in Emotions During an Interview?

Because relatively few nonemotional antecedents were thought to exist for EMG clusters over the CS muscle region during an interview, the emotional experiences marked by EMG clusters were predicted to differ from those marked by basal levels, and the emotional experiences marked by EMG spikes and mounds over the CS muscle region were predicted to fall between these extremes. To avoid inflating the experimentwise error rate, a preliminary multivariate analysis of variance (MANOVA) was performed to determine whether subjects' ratings of their feelings and emotions varied as a function of the form of the EMG response over the CS muscle region during the interview. Specifically, a 4 (EMG form: cluster, mound, spike, control) × 5 (trials) repeated measures MANOVA was conducted in which the subjects' ratings along the eight DE scales served as the dependent measures, and Wilks's lambda was used to evaluate statistical significance. Cell means are summarized in Figure 3. Results revealed a significant main effect for EMG form, $F(24, 102.11) = 1.63, p < .05$. Neither the main effect for trials nor the interaction approached statistical significance.

To identify more specifically which emotions varied as a function of the blocking factor, a separate 4 (EMG form: cluster, mound, spike, control) × 5 (trials) repeated measures MANOVA (O'Brien & Kaiser, 1985) was conducted for each of the eight DE scales ratings. Wilks's lambda was again used to evaluate statistical significance. Results revealed a significant main effect for EMG form on these dimensions: merry, $F(3, 12) = 7.97$, $p < .004$; warmhearted, $F(3, 12) = 3.87, p < .04$; sad, $F(3, 12) = 12.12, p < .001$; and fearful, $F(3, 12) = 5.16, p < .02$. No other effect for EMG form approached significance ($ps > .30$) (see Figure 3).

Our predictions called for the ratings of emotional experience associated with clusters over the CS muscle region to be contrasted with the ratings of emotional experience associated with control (basal levels) of EMG activity over the CS muscle region; the emotions associated with mounds and spikes to be contrasted with each other; and the emotions associated with mounds and spikes together to be contrasted with controls. Because of previous research demonstrating increased EMG activity over the CS muscle region as a function of emotional stimuli, however, it was also of interest to determine first whether any form of increased EMG activity over the CS muscle region was associated with more negative emotions than basal levels of EMG activity over the CS region. Individual contrasts comparing the emotions associated with controls with those associated with clusters, mounds, and spikes together were significant for these dimensions: merry, $F(1, 14) = 9.87, p < .007$; warmhearted, $F(1, 14) = 9.40, p < .008$; sad, $F(1, 14) = 16.15, p < .001$; and fearful, $F(1, 14) = 14.67, p < .002$. Inspection of Figure 3 confirms previous research showing that increased EMG activity over the CS region was associated with lower reports of positive emotions and higher reports of negative emotions.

Also consistent with expectations, no contrast comparing the emotions associated with mounds versus spikes reached significance. The contrasts comparing the emotions associated with clusters versus mounds and spikes together revealed the following results: merry, $F(1, 14) = 14.40, p < .002$; warmhearted, $F(1, 14) = 3.97, p < .066$; sad, $F(1, 14) = 10.21, p < .006$; and fearful, $F(1, 14) < 1$ (see Figure 3). Given the preceding pattern of contrasts, the tests contrasting the emotions associated with clusters and controls were obviously highly significant for merry, $F(1, 14) = 22.72, p < .001$; warmhearted, $F(1, 14) = 13.28, p < .003$; sad, $F(1, 14) = 38.69, p < .001$; and fearful, $F(1, 14) = 14.24, p < .002$. In sum, as hypothesized, the cluster was associated with the lowest reports of positive emotions and the highest reports of negative emotions.[3]

Can an Observer Distinguish the Valence of the Facial Expressions Associated With the EMG Response Forms Used to Index Emotions?

Subsequently, a judge trained in Ekman and Friesen's (1978) Facial Action Coding System and blind to the treatment conditions and hypotheses used a 7-point scale (1 = *very negative*, 7 = *very positive*) to provide global judgments of the subjects' emotional state based on his viewing of the videotape segment (without sound) associated with each EMG form. A second judge, blind to conditions and hypotheses, rescored the videotapes of 6 of the 15 subjects, selected at random, to assess the generalizability of the first judge's ratings of these 6 subjects (i.e., stimulus persons). A 2 (judges) × 4 (EMG form) × 5 (trials) × 6 (subjects) analysis of variance (ANOVA) was used to assess the replicability of the judges' ratings. This procedure was selected because variance in the judges' ratings could be

[3] For purposes of thoroughness, it might be noted that contrasts comparing controls versus spikes and mounds together approached statistical significance for merry, $F(1, 14) = 3.99, p < .066$; warmhearted, $F(1, 14) = 4.13, p < .061$; and sad, $F(1, 14) = 4.18, p < .06$; and reached significance for fearful, $F(1, 14) = 12.33, p < .003$.

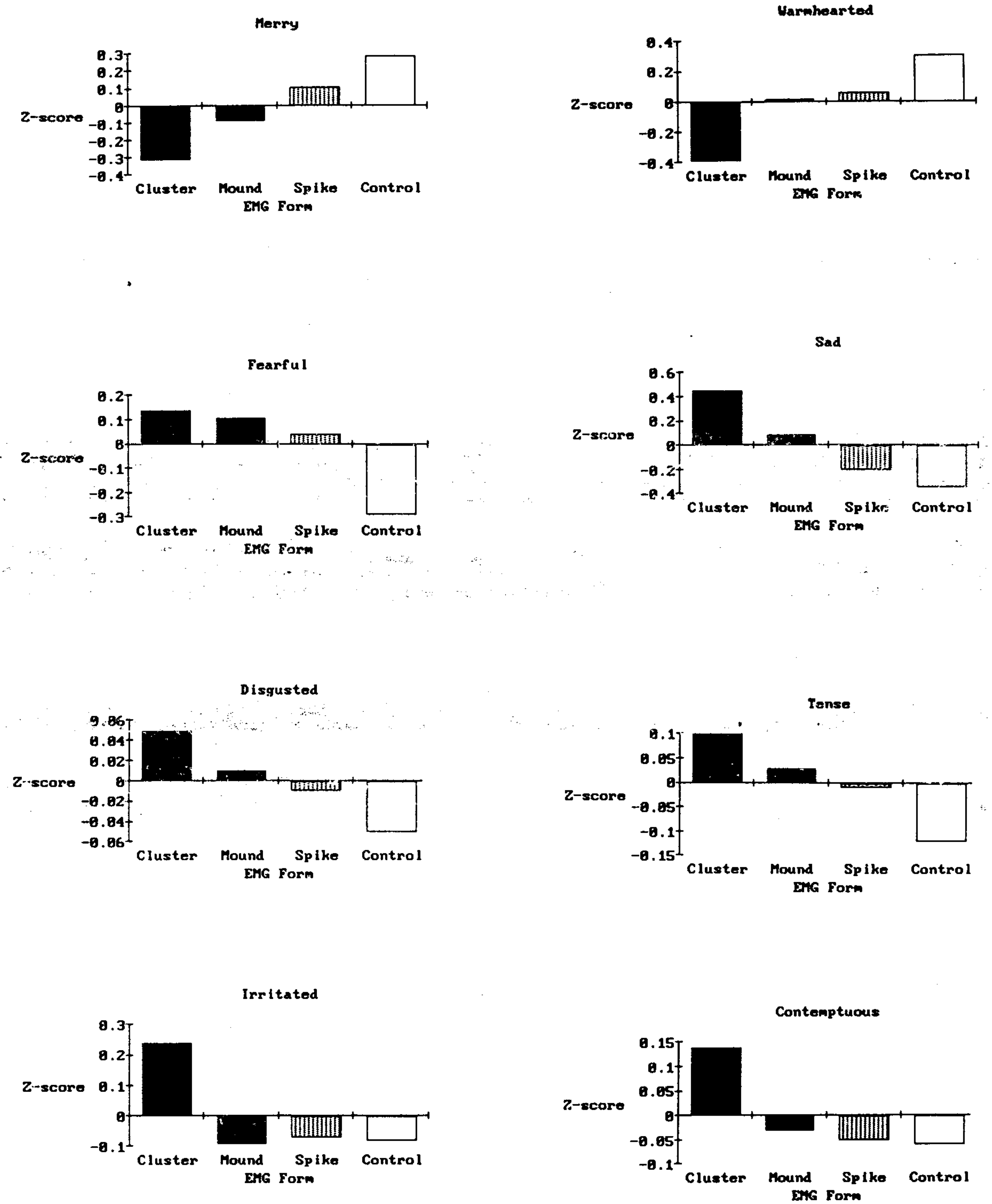

Figure 3. Mean ratings of the feelings aroused during segments of the interview marked by particular forms of electromyographic response over the corrugator supercilii muscle region. (Ratings were expressed on scales labeled merry/gleeful/amused, warmhearted/joyful/elated, fearful/scared/afraid, sad/downhearted/blue, disgusted/turned-off/repulsed, tense/anxious/nervous, irritated/angry/mad, and contemptuous/scornful/disdainful. Each subject's ratings on each scale were standardized across the 20 segments of the interview during which she was asked to express how she felt.)

attributed to EMG form, trials, and subjects (i.e., stimulus person) as well as to judges. In addition, we expected the EMG responses over the CS muscle region, which were used as blocking variables, to be visually imperceptible. This fact, in combination with the selection of exemplars based on at least grossly equivalent levels of EMG activity over the ZM and MF muscle regions, means that the facial expressions across trials and EMG forms should be indistinguishable to the judges. Hence, a correlational approach to assess interjudge reliability would be uninformative because a low interjudge correlation would be expected even if their ratings were reliable. The ANOVA approach, on the other hand, provides specific information about the sources of variance contributing to the judges' ratings of the videotapes. The analyses indicated none of the effects or interactions approached statistical significance ($ps > .35$). Next, the initial judge's ratings of the videotapes of all 15 subjects were submitted to a 4 (EMG form) × 5 (trials) × 15 (subjects) ANOVA to determine whether there were any socially perceptible differences in the expressions that subjects evinced involving the blocking factor of EMG form. Again, none of the tests approached significance ($ps > .40$).

Did the Level of Self-Disclosure Differ as a Function of the EMG Response Forms Used to Index Emotions?

A 4 (EMG form) × 5 (trials) repeated measures MANOVA was performed on the subjects' ratings of how revealing each of the 20 segments of the interview marked by an EMG exemplar was; a second repeated measures MANOVA was performed on their ratings of how insightful their thoughts about each segment of the interview were. Results revealed that neither the extent of self-disclosure nor the insight reflected by the disclosures varied across conditions ($ps > .30$). Hence, the observed differences in feelings and emotions across EMG forms are unlikely to reflect differences in the level of self-disclosure.

With What Frequency Was Each of the Emotions Felt Most Strongly During Segments of the Interview Rated by Subjects?

It is possible that EMG responses over the CS muscle region were unrelated to a subset of the emotions about which subjects were asked because these emotions were seldom or only weakly felt during the segments of the interview. To examine this possibility, each subject's original ratings across the eight DE scales for each of the 20 videotape segments were inspected to determine which emotion was rated as being felt most strongly, and a frequency count for each emotion was calculated. When a subject rated two or more emotions highest, the count for each emotion was incremented by the appropriate fraction. The observed frequencies, which are summarized in the top panel of Figure 4, differed significantly from the distribution expected by chance, $\chi^2(7) = 87.8, p < .001$. Perhaps not surprisingly, the emotions of contempt, fear, and disgust were only infrequently felt strongly during the subjects' self-descriptions. The frequencies across EMG forms within each of the eight emotions were also inspected and are displayed in the bottom panel of Figure 4. Although this analysis is less sensitive than the preceding parametric analyses which used all of the data, the pattern of results is strikingly similar to that depicted in Figure 3. Chi-square tests revealed that the observed frequencies deviated significantly from chance for the emotion sadness, $\chi^2(3) = 8.64$, $p < .05$, and marginally from chance for the emotion merry, $\chi^2(3) = 6.59, p < .10$.

Discussion

Previous research has varied individuals' emotional states and measured the consequent EMG response, whereas in this study EMG activity was allowed to vary naturally during an interview and specific forms of response were used to predict individuals' emotional states. In addition, whereas prior research has focused on the spatial patterning of facial actions, this study focused on the form of the EMG activity over the corrugator supercilii muscle region that unfolded over time while matching on the general (and visually perceptible) levels of facial EMG activity observable elsewhere. Consistent with the notion that expressive/behavioral components of emotions are "sometimes brought unconsciously into momentary action by ludicrously slight causes" (Darwin, 1872/1965, p. 184), small amplitude responses over the corrugator supercilii muscle region were observed using EMG to covary with subtle variations in emotion during an interview. The extent of this covariation differed across the form of EMG response over the corrugator supercilii muscle region—and across the eight emotions rated by subjects—even though the facial expressions evinced by these individuals were rated similarly across conditions by observers. Each of these issues is discussed in turn.

Facial EMG as an Index of Emotion

The comparison contrasting the feelings associated with clusters, mounds, or spikes against those associated with ongoing levels of EMG activity over the corrugator supercilii muscle region (i.e., pseudotrials) revealed that subjects felt less positive and more negative emotions when EMG activity was elevated in one form or another. This finding extends in a crucial respect the previous research showing that EMG activity over the corrugator supercilii muscle region increases following the imagination or presentation of negative stimuli. If we let E represent people's emotional experiences and F represent facial EMG activity, it is clear from probability theory that P(F/E) could differ dramatically from P(E/F). Previous research bears on P(F/E), whereas this study bears on P(E/F); it is the latter that is of interest if facial EMG activity is to be used as an index of emotions. Our results provide the first evidence that facial EMG activity can serve in this capacity, at least in selected assessment contexts.

An additional premise underlying this research was that specific forms of EMG response would serve particularly well as an index of emotions during social interaction. The rationale for this premise can also be explicated in terms of probability theory. Because P(E/F) = P(E, F)/[P(E, F) + P(Not-E, F)], it can be seen that F's usefulness as a marker of E is weakened by the occurrence of F in the absence of E. We reasoned that variations in emotions were associated with EMG responses over the corrugator supercilii muscle region, including the forms labeled clusters, mounds, and spikes, and that mounds and spikes occurred more frequently in the absence of variations in emotion than did clusters. That is, we reasoned that

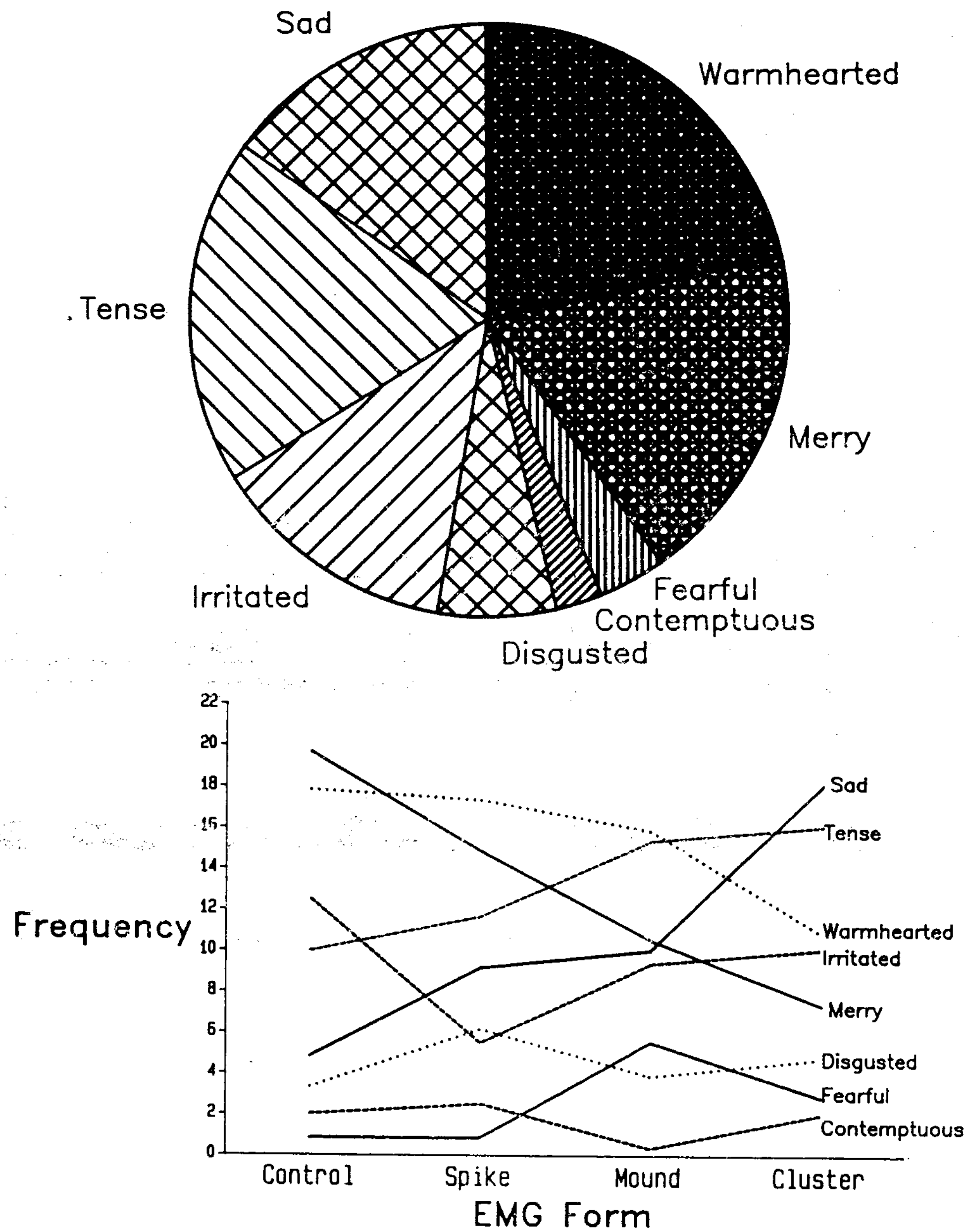

Figure 4. Profiles depicting the frequency with which each emotion was rated as having been felt more strongly than any other emotion during a specific 10-s segment of the interview. (Top: proportion of times each of the eight categories of emotion was rated maximally. Bottom: frequency counts across the four categories of EMG forms.)

P(E, F) was greater than zero for each of the EMG forms, but that P(Not-E, F) was greater for mounds and spikes than for clusters. Hence, clusters were predicted to be associated with lower ratings of positive emotions and higher ratings of negative emotions than occurred during pseudotrials, and spikes and mounds were predicted to fall between these extremes. Results were consistent with these predictions. The ratings of emotions were equivalent for spikes and mounds over the corrugator supercilii muscle region; clusters were associated with stronger negative emotions and weaker positive emotions than were spikes and mounds, and much stronger negative emotions and weaker positive emotions than were pseudotrials. Also, spikes and mounds, in contrast to pseudotrials (i.e., controls), were associated with stronger feelings of fear, and tended to be associated with more negative and less positive emotions generally. Thus, results supported expectations that EMG activity over the corrugator supercilii muscle region is sensitive to variations in emotion, and that the specificity of this relationship is greater for EMG clusters than for EMG spikes and EMG mounds.

Facial EMG as an Index of Specific Emotions

Although the EMG responses over the corrugator supercilii muscle region differentiated globally between a person's positive and negative emotions, not all emotions were predicted equally by these EMG responses. The ratings along the dimensions labeled warmhearted/joyful/elated, merry/gleeful/amused, sad/downhearted/blue, and fearful/scared/afraid were consistently related to EMG activity over the corrugator supercilii muscle region, whereas ratings along the dimensions labeled tense/anxious/nervous, contemptuous/scornful/disdainful, disgusted/turned-off/repulsed, and irritated/angry/mad were not. From a theoretical perspective, only a subset of emotions may be associated with activity over the corrugator supercilii muscle region—or at least with the forms of EMG response investigated here. For instance, research on overt facial expressions of emotion has linked the facial action achieved by the contraction of the corrugator supercilii muscle to strong feelings of sadness/grief, anger/rage, fear/terror, and reflection (Darwin, 1872/1965; Ekman & Friesen, 1978; Frois-Wittman, 1930). Moreover, research using facial EMG has revealed that the induction of positive emotions can also lead to a reduction in the extant level of activation of the corrugator supercilii muscle region (e.g., Cacioppo, Petty, et al., 1986; Schwartz et al., 1976). Hence, the observed associations between EMG activity over the corrugator supercilii muscle region and the emotions of warmheartedness, merriment, sadness, and fearfulness are to be expected.

Less explicable from this theoretical perspective is the failure of EMG responses over the corrugator supercilii muscle region to predict the remaining negative emotions, especially ratings along the dimension labeled angry/irritated/mad. Analyses of the frequency with which emotions were felt strongly revealed that these were among some of the less frequently felt. However, fearfulness, which was predicted by the form of EMG activity, was also among the emotions subjects infrequently reported feeling strongly while they talked about themselves. It is possible, therefore, that EMG activity over the corrugator supercilii muscle region is unrelated to mild variations in these negative emotions, or at least that different forms of EMG response over the corrugator supercilii muscle region than those investigated here are related to them. Given the consistency in the pattern of means depicted in Figure 3, however, it also remains possible that interactions that evoke more frequent feelings of disgust, irritation, tension, and contempt—or experimental situations that use a briefer lag between the emotional experience and its rating—would reveal significant relations mirroring those found for sadness, fear, warmheartedness, and merriment.

Socially Indistinguishable Microfacial Expressions of Emotion

Whereas this line of research owes a theoretical debt to Darwin, his observations and principles of emotional expressions have been considered to apply primarily or only to overt, socially perceptible expressions owing to their role in natural selection. As Chevalier-Skolnikoff (1973) articulated: "Animals who had a genetically based tendency to substitute facial displays (e.g., threats) for more dangerous actions (e.g., fighting) probably had a higher survival ratio, thus passing this propensity on to their descendants" (p. 32; see also Fridlund, in press). Our finding that low-level efferent neural volleys result in specific forms of EMG response that predict the valence of the emotions experienced during ongoing self-disclosures therefore provides an interesting and important extension.

Such an extension is, of course, completely compatible with a Darwinian view. Darwin (1872/1965) believed that there were no sharp discontinuities between the evolution of the species and that behaviors as well as biological structures were in part genetically determined. He focused on the expression of emotions in man and animals to illustrate the latter, and his principles were based on the supposition that the forces underlying distinctive expressions of the primary emotions were the same as those that underlie sneezes, shivering, yawns, and goosebumps—natural selection acting on genetically determined or predisposed variations in organismic response. In the case of behavior, the organismic response is mediated by the somatic nervous system and expressed by the actions of the striated muscles, such as the muscles of facial expression. Although Darwin's (1872/1965) observations were necessarily focused on overt actions, his proposal that "whenever the same state of mind is induced, however feebly, there is a tendency through the force of habit and association for the same movements to be performed, though they may not be of the least use" (p. 28) can easily accommodate observations using electromyography of microfacial expressions of emotion.

This line of reasoning also suggests an extension of current thinking about fixed-action patterns—at least as applied to expressions of emotion. Research across diverse cultures; in children blind since birth; and in anencephalic, hydrocephalic, and normal neonates has supported Darwin's (1872/1965) proposition that emotional expressions, such as frowning and smiling, are built on a stereotyped set of movements (e.g., see review by Fridlund, Ekman, & Oster, 1987). However, inborn, stereotyped sequences of motor movement that are inherited (i.e., fixed-action patterns) are thought to act in an all-or-none fashion (e.g., see review by Kupfermann, 1985). Once one begins to swallow, for instance, the sequence of actions of the various muscles involved proceeds stereotypically (Doty & Bosma, 1956). This does not appear to be the case, however, for the actions underlying emotional expression in facial EMG studies of subtle emotional arousal. Schwartz and his colleagues (e.g., Brown & Schwartz, 1980; Schwartz, 1975; Schwartz et al., 1976) reported that the induction of distinctive emotions through imagery results in facial EMG activity that differentiates positive from negative emotions, but does not differentiate among the negative emotions even though surface EMG recordings were obtained over muscle regions involved in the production of distinctive overt expressions of emotion (cf. Ekman & Friesen, 1978; Fridlund et al., 1984). That is, research by Schwartz and his colleagues indicates that the induction of weak emotions does not produce miniature versions of full-blown, differentiated expressions of emotion. Inspection of Figure 3 suggests a similar picture.[4]

[4] McCanne and Anderson (1987) attempted to manipulate the EMG activity recorded over the corrugator supercilii and zygomaticus major muscle regions through EMG feedback. Although their results can be interpreted in terms of experimental demands (Fridlund & Izard, 1983) or the operation of a third factor that influenced facial EMG activity and emotions independently (e.g., cognitive set), they are also consistent with the view that low-level EMG responses are related to, and possibly influence, the intensity and valence of the emotions rather than to dis-

Continuous Flow of Emotion

It may be of general interest, therefore, that the continuous flow conception of human information processing (Eriksen & Schultz, 1979; cf. Coles, Gratton, Bashore, Eriksen, & Donchin, 1985) can accommodate the accumulated data on subtle emotions and facial efference. According to this conception, the information extracted early in the processing of a stimulus is consistent with a range of possible responses, and each of these responses receives initial activation. As information continues to accumulate, activation continues to accumulate in response channels that remain viable. A given response is evoked when the activation of its channel exceeds criterion. An explicit assumption of this conception, therefore, is that rudimentary (e.g., initial) levels of processing may result in the partial activation of multiple response channels, resulting in response competition and reciprocal inhibition. The greater the response competition, the longer the latency of the correct response tends to be (see Coles et al., 1985).

The continuous flow conception can explain affect-laden information processing and facial efference with the following assumptions. First, the responses in emotional processing include expressions of emotion. Second, the continuous flow conception would normally anticipate similar increases in EMG activity over the facial muscles involved in the expression of the various negative primary emotions rather than more focused increases over one or a subset of these regions (e.g., the corrugator supercilii region). To accommodate these data within the continuous flow conception, one needs only to assume that the predominant information transferred from rudimentary emotional processing to response channels for emotional expression concerns the threat/assurance or positive/negative nature of the evocative event or stimulus (Zajonc, 1980). In terms of this conceptualization, more emotionally evocative stimuli result in the flow of greater and more detailed information to correspondent response channels, resulting in accumulated levels of activation that exceed the threshold for overt response (e.g., distinctive expressions of emotion; blends of emotional expressions). This conception, therefore, can explain the graded, semistochastic, subthreshold activation of one or more of the muscles of mimicry during weak, negative emotions. Questions such as why particular muscle regions are focal points for preliminary response activation during subtle emotions, however, continue to elude all but speculative answers (e.g., in terms of inhibitory processes being weaker for the brow region; the importance of the visual system in responding to threats; see Darwin, 1872/1965).

It may be noted that a slight variation of the continuous flow model, the parallel–discrete model of human information processing (Miller, 1982), offers a similar explanation for these data (cf. Coles et al., 1985). According to the parallel–discrete model, information is not transferred continuously between processing stages, nor is it transferred only when a given stage of processing is completed. Instead, a transfer is performed when a stage has completely processed a grain of information. The transfer of information represented by the grain is discrete, and the number of grains of relevant information is assumed only to be finite. When all of the information is contained in a single grain, the model reduces to a serial model; when it is contained in more than one, the model becomes parallel. The parallel–discrete model, therefore, implies that the first grain of information transferred from emotional processing to response channels for emotional expression contains chiefly information about the threat/assurance or positive/negative nature of the evocative event or stimulus. More emotionally evocative stimuli result in more grains of information being transferred to relevant response channels and accumulated levels of activation that finally exceed the threshold for an overt response (e.g., a fixed-action pattern).

Summary

This research points to the value of adopting psychophysiological and ethological analyses to enrich rather than to compete with traditional theoretical and situational analyses of social behavior. Results provide support for the notion that specific forms of facial EMG response can provide objective and continuous probes of emotional processes that are too subtle or fleeting to evoke expressions observable during social interactions. We should emphasize, however, that we do not wish to imply that only the actions of the corrugator supercilii muscle are involved or important in emotions (cf. Cacioppo, Losch, et al., 1986), or that emotions are linked cross-situationally or invariantly to specific facial actions such as burstlike EMG responses over the corrugator supercilii muscle region (cf. Cacioppo, Petty, & Tassinary, in press).

It is important when specifying the limits of any psychophysiological relationship involving the somatic nervous system to recognize that the pattern of efference is not always as intended (e.g., when one performs clumsily), not always a veridical reflection of goals (e.g., when one deceives), not always obvious (e.g., when one hides feelings), and not always in the service of emotion (e.g., when one raises the brows to communicate a point). For instance, McCanne and Anderson (1987) provide evidence suggesting individuals could learn, through the use of augmented EMG feedback, to suppress EMG activity over the corrugator supercilii muscle region during negative emotional imagery. Thus, it is no more reasonable to assume facial EMG activity is linked invariantly or is a cross-situational correlate of emotion as it is to assume that response latency is invariantly linked to or a correlate of mental processes. Each can be used in theoretical thinking and in carefully conceived paradigms to provide insights regarding psychological processes not easily or otherwise attainable, and each offers little promise in advancing theory when invariance is assumed. It was precisely our concern over the multiplicity of factors that can evoke somatovisceral responses that led us to (a) use EMG responses as blocking rather than dependent variables in this research, and (b) investigate the efficacy of particular forms of EMG response in predicting variations in emotional experience during the interview. This study, of course, is only a beginning. Additional research

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tinctive positive and negative emotions per se. Moreover, Ekman, Levenson, and Friesen (1983) have argued that distinctive facial expressions—not verbal reports of emotion—should serve as the criterion measure for distinctive emotional states. It should be recognized that their position may minimize classification error and, therefore, be important even though it does not preclude the possibility that the arousal of very weak but distinctive emotional states manifests similarly in the activation of the response channels for emotional expression.

using this paradigm may uncover yet more specific links between forms and patterns of EMG activity (e.g., spikes over the corrugator supercilii region; coincident changes over the zygomaticus major region that are discernible when subjects are not speaking) and psychological or behavioral states (e.g., fleeting negative thoughts or images that are poorly encoded in long-term memory). Hence, the present paradigm promises to aid in the identification of the ranges of validity of physiological markers of processes that underlie human interaction and social behavior.

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