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Effects of positive and negative affect on electromyographic activity over *zygomaticus major* and *corrugator supercilii*

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Abstract

Pleasant stimuli typically elicit greater electromyographic (EMG) activity over *zygomaticus major* and less activity over *corrugator supercilii* than do unpleasant stimuli. To provide a systematic comparison of these 2 measures, the authors examined the relative form and strength of affective influences on activity over *zygomaticus major* and *corrugator supercilii*. Self-reported positive and negative affective reactions and facial EMG were collected as women ($n = 68$) were exposed to series of affective pictures, sounds, and words. Consistent with speculations based on known properties of the neurophysiology of the facial musculature, results revealed a stronger linear effect of valence on activity over *corrugator supercilii* versus *zygomaticus major*. In addition, positive and negative affect ratings indicated that positive and negative affect have reciprocal effects on activity over *corrugator supercilii*, but not *zygomaticus major*.

Descriptors: Facial electromyography, Positive affect, Negative affect, Pleasure, Emotion

Although affective processes are often assessed via self-reports, psychophysiologists have recognized that self-reports may be biased by such factors as social desirability concerns (e.g., Vanman, Paul, Ito, & Miller, 1997) or may simply be insensitive to faint vicissitudes of affect (Öhman & Soares, 1994). Thus, researchers have sought physiological measures that differentiate pleasant and unpleasant states. As the face is the locus of a great deal of emotional expression, researchers have been particularly interested in facial electromyographic measures of activity over *zygomaticus major*, which pulls the corners of the mouth back and up into a smile, and *corrugator supercilii*, which draws the brow down and together into a frown.

The use of *corrugator supercilii* and *zygomaticus major* to study affect originated with pioneering research by Schwartz. In a series of directed imagery experiments, Schwartz and his colleagues found that whereas unpleasant imagery elicited greater activity over *corrugator supercilii* than did pleasant imagery, pleasant imagery elicited greater activity over *zygomaticus major* (Brown & Schwartz, 1980; Schwartz, Fair, Salt, Mandel, & Klerman, 1976a,b). Schwartz's imagery tasks have been shown to generalize to a variety of affective tasks. In a study of persuasion, for example, Cacioppo and Petty (1979) reported that counterattitudinal messages elicited greater activity over *corrugator supercilii* and less activity over *zygomaticus major* than did proattitudinal and neutral messages. Similarly, pictures of unpleasant scenes (Cacioppo, Petty, Losch, & Kim, 1986; Lang, Greenwald, Bradley, & Hamm, 1993) and faces (Dimberg, 1990) elicit more activity over *corrugator supercilii* than do pleasant scenes and faces, but less activity over *zygomaticus major* (for reviews, see Bradley, 2000; Cacioppo, Berntson, Larsen, Poehlmann, & Ito, 2000; Tassinary & Cacioppo, 2000).

As the bipolar valence dimension ranging from pleasant to unpleasant is a prominent aspect of affective processing (e.g., Cacioppo & Berntson, 1994; Lang, Bradley, & Cuthbert, 1990), it would be useful to understand whether bipolar valence has a stronger effect on activity over *corrugator supercilii* or *zygomaticus major*. Several aspects of the neurophysiology of facial movements suggest a stronger effect size for activity over *corrugator supercilii*. For example, *corrugator supercilii* is sparsely represented in the motor cortex and is therefore less likely to be involved in such fine voluntary motor behaviors as articulation and nuanced display rules designed to mask affective reactions (Ekman & Friesen, 1975). Conversely, the cheek and other regions of the lower face are well represented in the motor cortex, affording *zygomaticus major* greater involvement in display rules and other fine voluntary motor behaviors. Moreover, like the muscles of the abdomen and back, *corrugator*

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supercilii tends to be bilaterally innervated, another characteristic that impedes fine voluntary motor control. In contrast, *zygomaticus major*, like the dexterous muscles of the fingers, shows greater contralateral innervation (Rinn, 1984). The topography of the facial musculature may also make the effect of bipolar valence on activity over *corrugator supercilii* more pronounced. Most regions of the face contain partially overlapping muscle groups and the cheek region represents a particularly crowded region. *Zygomaticus major* lies in close proximity to a variety of muscle groups including *buccinator*, *masseter*, and *zygomaticus minor* (Tassinary & Cacioppo, 2000), rendering surface recordings of *zygomaticus major* especially susceptible to cross talk.

Although the relative sensitivity of *corrugator supercilii* and *zygomaticus major* has not been directly addressed, Lang, Greenwald, Bradley, & Hamm (1993) provided supportive evidence for the superiority of activity over *corrugator supercilii*. They observed a stronger linear effect of valence on activity over *corrugator supercilii*, due in part to insensitivity of activity over *zygomaticus major* to substantial portions of the valence dimension and the apparent tendency for the two or three most aversive pictures to potentiate activity over *zygomaticus major*. Comparing results from the two sites is difficult, however, because most analyses of activity over *zygomaticus major* focused on the quadratic effect of valence rather than the linear effect. These analyses revealed that the magnitude of the quadratic relationship between valence and activity over *zygomaticus major* was comparable to that of the linear relationship between valence and activity over *corrugator supercilii*. As quadratic relationships allow for nonmonotonicity, a main purpose of the current research was to replicate Lang et al.'s analyses with an emphasis on the relative strength of the linear effects of valence on activity over both *corrugator supercilii* and *zygomaticus major*.

A second purpose was to examine the generalizability of facial EMG reactions across affective tasks. Extending their research on pictures, Bradley and Lang (2000) studied affective reactions to sounds. Their results replicated the linear effect of valence on activity over *corrugator supercilii* observed with pictures (e.g., Cacioppo et al., 1986; Lang et al., 1993). Interestingly, however, they showed no reliable effects of valence on activity over *zygomaticus major*. In the current research, we examined similarities and differences among affective pictures, sounds, and words tasks.

One implicit assumption of most facial EMG research on affect is that affective processes operate along a bipolar valence dimension ranging from pleasant to unpleasant. According to Cacioppo and Berntson's (1994; Cacioppo, Gardner, & Berntson, 1997, 1999; Cacioppo, Larsen, Smith, & Berntson, in press) evaluative space model, however, the bipolar valence dimension represents the integration of two separable and partially distinct components of the affect system, one attuned to nurturance and appetition (i.e., positivity), and the other attuned to threat and aversion (i.e., negativity), which combine to motivate behavior toward or away from the object. Supportive evidence comes from Davidson's (e.g., 1998) findings that left and right frontal cortex are differentially involved in approach and avoidance, respectively. Moreover, in contrast to the predictions of Russell and Carroll's (1999) prominent bipolar model of affect, Larsen, McGraw, and Cacioppo (2001) recently found that roughly half of their respondents surveyed at the end of their college graduation ceremony and other emotionally complex situations experienced mixed feelings of happiness and sadness. Such findings demonstrate that it may be more useful to treat positive and negative affect as separable components of the affect system, rather than as opposite ends of a bipolar valence continuum (for an extensive review of evidence, see Cacioppo and Gardner, 1999).

Whereas prior research has examined the effect of bipolar valence on activity over *zygomaticus major* and *corrugator supercilii*, the ESM's expanded conceptualization of affective processes allows us to examine the potentially distinct effects of positive and negative affect. It is important to note that according to the ESM, the organization of affective processes depends in part on the level of the neuraxis, such that affect is more capable of bivariate organizations in rostral regions (e.g., cortex) than in more caudal regions (e.g., brain stem; Cacioppo et al., 1999). Whereas Larsen et al.'s (2001) study of mixed feelings investigated the separability of positive and negative affect at the level of subjective emotional states, which are presumably mediated by more rostral neural regions, the facial muscles' final common pathway originates in the brain stem at the level of the pons (Rinn, 1984). Thus, affective responding in the facial musculature may be more likely to be organized in a bipolar fashion.

Evidence consistent with this hypothesis comes from Cacioppo et al.'s (1986) and Lang et al.'s (1993) findings that activity over *corrugator supercilii* is both potentiated by unpleasant pictures and inhibited by pleasant pictures. Nevertheless, findings that affective stimuli (e.g., pictures) do not necessarily elicit mutually exclusive feelings of positive *or* negative affect, and can instead elicit mixed feelings of positive *and* negative affect in a reciprocally activated fashion (Ito, Cacioppo, & Lang, 1998), renders the linear effect of valence ambiguous. If positive pictures tend to be not only more appealing but also less aversive than more middling stimuli, then one would expect a linear effect of valence even if activity over *corrugator supercilii* was uniquely sensitive to negative affect. By this account, it may be *decreases* in negative affect, rather than *increases* in positive affect, that inhibit activity over *corrugator supercilii*. Thus, a final purpose of the current research was to examine the potentially distinct effects of positive and negative affect on facial EMG responding.

Method

Participants

Sixty-eight University of Chicago undergraduate women who responded to posted fliers participated for an hourly wage. Testing only women allowed us to use the same set of stimuli for all participants, as an additional goal of this project (to be reported elsewhere) was to study individual differences in affective processing. Participants were between the ages of 18 and 25 ($M = 19.9$; $SD = 1.3$) and 67%, 15%, 7%, and 3% reported being European-American, Asian-American, Latino, and African-American, respectively. In addition, participants were fluent in English, healthy, and not currently taking any medication that might affect emotional functioning (e.g., antidepressants). Three participants were removed from the sample because they failed to return for the second session. In addition, a total of six data files from one or the other session were lost due to equipment malfunction or experimenter error. In these cases, data from the relevant task were removed but data from the other two tasks were retained. As a result, the final sample contained 63, 62, and 64 participants for the pictures, sounds, and word tasks, respectively.

Stimulus Materials

Sixty-six affective pictures, sounds, and words were chosen from standardized stimulus sets. Affective color pictures, sound clips, and words were selected from the International Affective Picture Show (IAPS; Center for the Study of Emotion and Attention, 1999; Lang, Bradley, & Cuthbert, 1999), International Affective Digitized Sounds (IADS; Bradley & Lang, 1999b), and Affective Norms for English Words (ANEW; Bradley & Lang, 1999a), respectively, based on each stimulus set's normative valence ratings. Stimuli were selected to fall into 11 valence categories (each containing six stimuli) that spanned the bipolar valence dimension and varied widely in content.[1] Pictures were representative of most of the affective categories described by Bradley, Codispoti, Cuthbert, and Lang (2001) and included mutilated bodies, accidents, household objects, people, foods, sports, and so forth. Sounds included animal noises, alarms, vehicle engines, children playing, laughter, music, and so forth. Words included insults, the names of mundane objects, terms of endearment, and so forth.[2]

Procedure

Participation entailed a preliminary visit to the laboratory followed by two physiological testing sessions. During the preliminary session, which occurred 1 week before the first physiological testing session, participants received a computerized tour of the lab, were familiarized with the tasks and instructions, and completed several questionnaires. The two physiological testing sessions were separated by approximately 14 days ($M = 15.35$ days, $SD = 4.53$).

On each physiological testing session, a female experimenter attached electrodes and other sensors for recording facial EMG and additional measures to be reported elsewhere, including cardiovascular indices, respiration, and skin conductance. Facial EMG was recorded over *corrugator supercilii* and *zygomaticus major* on the right side of the face with 4-mm standard silver/silver-chloride electrodes. Participants were then seated in a comfortable reclining chair in a sound attenuated, electrically shielded, and dimly lit room. Pictures and words were projected at eye level onto a white wall approximately 275 cm in front of the participant; pictures covered an area approximately 140 cm × 180 cm. Sounds were presented binaurally via ceiling-mounted speakers with a volume of 58 dB at the head of the chair. Prior to the experimental tasks, participants completed surveys to foster adaptation to the testing environment (Jennings, Kamarck, Stewart, Eddy, & Johnson, 1992) and then completed a 5-min relaxation exercise.

In each of the two sessions, all participants completed the pictures, sounds, and word tasks, and an additional task to be reported elsewhere.[3] The three tasks were presented in the following random orders: words, pictures, sounds (Session 1), and sounds, pictures, words (Session 2). For all participants, the 66 stimuli in each task were presented in the same order in Session 1 and in another random order in Session 2.[4] Participants were instructed to attend to each stimulus while it was presented. Trials consisted of a 3,000-ms baseline period, a 6,000-ms stimulus period, and a 3,000-ms recovery period.

Self-Reported Affective Reactions

Following the recovery period, participants rated their positive and negative reactions to each stimulus with the *affect matrix* (Larsen, Norris, & Cacioppo, 2003). The affect matrix is a two-dimensional grid in which participants move the mouse to rate how positively and negatively they feel about a stimulus on the x- and y-axes, respectively. Five levels of positive affect ranging from *not at all* to *extremely* are crossed with five levels of negative affect, resulting in 25 demarcated cells. Positive and negative affect scores range from 0 to 4 depending on where the participant moves the mouse. Following the affect matrix, participants rated how arousing the stimulus was on a 9-point scale ranging from *not at all* to *extremely*.

Data Reduction

EMG signals were relayed through shielded cable to Biopac amplifiers (Biopac Systems, Inc., Santa Barbara, CA), where signals were amplified 5,000×. Signals were digitized at 1000 Hz, then recorded and displayed on a laboratory computer. To monitor artifact (e.g., due to movement), the experimenter inspected incoming EMG data as well as video feed of the participant's head and torso from a video camera that was mounted inside an inconspicuous 5-in. smoke-colored dome in a corner of the ceiling. Offline, data were submitted to a 15-Hz high-pass filter to reduce movement and blink-related artifact, then full-rectified. Data were then visually inspected, and data with remaining artifact were excluded from subsequent analysis. To correct for the positive skew inherent to EMG data, all data were then subjected to a square-root transformation. Following Lang et al. (1993), EMG reactivity was measured as the difference between activity during the 6,000-ms stimulus period and the 1,000 ms immediately prior to stimulus onset.

[1]Normative valence ratings range from 1 (*unpleasant*) to 9 (*pleasant*). Arousal ratings range from 1 (*low*) to 9 (*high*). To maximize ecological validity, arousal was not equated for equally extreme negative and positive stimuli. Mean normative valence (arousal) ratings for the 11 categories were as follows. IAPS pictures: 1.52 (6.53), 2.31 (6.04), 2.91 (5.89), 3.59 (5.61), 4.40 (4.90), 5.01 (2.70), 5.59 (4.70), 6.39 (5.29), 7.11 (5.25), 7.69 (6.47), and 8.45 (4.92); IADS sounds: 2.29 (7.19), 2.73 (7.12), 3.31 (5.90), 3.95 (5.84), 4.50 (5.13), 5.05 (4.65), 5.59 (4.30), 6.09 (5.40), 6.57 (5.39), 7.21 (5.90), and 7.84 (6.16); ANEW words: 1.50 (6.81), 2.15 (5.88), 2.85 (4.84), 3.58 (5.46), 4.31 (4.56), 5.00 (3.72), 5.71 (5.26), 6.43 (4.86), 7.14 (4.30), 7.84 (6.48), and 8.51 (6.38).

[2]IAPS stimuli numbers: 1052, 1121, 1274, 1660, 1710, 1750, 1930, 2050, 2057, 2208, 2340, 2661, 2800, 3100, 3130, 3160, 3250, 3261, 3400, 4000, 4004, 4230, 4302, 4520, 4534, 4571, 4598, 4641, 4656, 4680, 4770, 4800, 5300, 5731, 5910, 5920, 5971, 5972, 6150, 6260, 6561, 6610, 6930, 7002, 7006, 7010, 7050, 7217, 7430, 7460, 7600, 8060, 8080, 8185, 8210, 8260, 8311, 8370, 8460, 8501, 9102, 9500, 9520, 9560, 9570, and 9810. IADS stimuli numbers: 105, 106, 109, 110, 111, 112, 113, 116, 120, 130, 132, 133, 152, 171, 201, 202, 205, 206, 215, 216, 220, 221, 226, 230, 251, 252, 261, 262, 280, 290, 292, 310, 319, 320, 322, 325, 351, 353, 358, 360, 361, 380, 400, 403, 420, 422, 425, 500, 501, 502, 602, 625, 700, 701, 702, 706, 708, 709, 711, 722, 725, 730, 802, 810, 815, and 826. ANEW stimuli numbers: 005, 016, 069, 077, 112, 152, 167, 198, 206, 212, 241, 261, 301, 335, 337, 385, 391, 393, 394, 403, 423, 424, 433, 435, 437, 438, 447, 456, 472, 478, 482, 486, 498, 503, 530, 541, 549, 570, 571, 573, 638, 644, 664, 675, 677, 682, 683, 731, 734, 743, 757, 758, 759, 772, 777, 829, 845, 854, 878, 884, 890, 897, 908, 958, 964, and 979.

[3]The additional task was one component of our investigation of individual differences in affective processing and involved spatial memory for valenced pictures. The spatial memory task was administered prior to the pictures, sounds, and words tasks, but none of the pictures included in the spatial memory task were also presented during the pictures task.

[4]Order of task and stimuli were held constant in each session because an additional aim of the research was to investigate individual differences in affective processing.

Results

Strength and Form of the Effect of Valence on Facial EMG

During picture viewing, Lang et al. (1993) demonstrated a negative linear effect of valence on EMG reactivity over *corrugator supercilii*, as well as positive linear and quadratic effects of valence on EMG reactivity over *zygomaticus major*. Our first goal was to replicate and extend these analyses to other affective tasks. As correlations between the net difference of the affect matrix's positive and negative affect ratings and traditional bipolar valence ratings have been found to approach unity (Larsen et al., 2003), we employed this derived measure (i.e., P − N) as an index of valence.[5] For each task, we collapsed each participant's valence and EMG data for each stimulus across the two sessions. We then ranked valence ratings, sorted EMG data on these ranks, and computed mean EMG reactivity at each rank by collapsing across all participants' data. Thus, these data reflect EMG reactivity as a function of valence and are not responses to particular stimuli (Lang et al., 1993). Reactivity data for pictures, sounds, and words are plotted as a function of ranked valence in the top, middle, and bottom panels of Figure 1, with separate panels for activity over *corrugator supercilii* (left panels) and *zygomaticus major* (right panels).[6]

Pictures. As shown in the top left panel of Figure 1, a strong linear effect of valence on activity over *corrugator supercilii* activity, $r(66) = -.94$, $p < .001$, replicates that of Lang et al. (1993). The linear effect of valence on activity over *zygomaticus major*, $r(66) = .52$, $p < .001$, was much less pronounced (see Figure 1, top right panel). To examine nonlinearities in these relationships, we also fit the reactivity data to quadratic models. The quadratic effect on activity over *corrugator supercilii* was no stronger, $r(66) = .94$, $p < .001$, but, consistent with Lang et al., the quadratic effect of valence on activity over *zygomaticus major*, $r(66) = .83$, $p < .001$, was much stronger than the linear effect. Inspection of the right panel of Figure 1 reveals that the modest linear and strong quadratic effects of valence on activity over *zygomaticus major* was obtained because this site was largely insensitive to most of the valence range and was only potentiated by the most appealing pictures. In other words, activity over *zygomaticus major* appears to be characterized by a *threshold effect* and few stimuli in the current study exceeded that threshold. In addition to the threshold effect, slightly greater activity to the most aversive stimuli than to neutral stimuli yielded a J-shaped distribution and contributed to the quadratic effect (see Figure 1, top right panel).

[5]Whereas both neutral and ambivalent stimuli would be assigned middling valence ratings (e.g., 0) according to our scheme, middling ratings are often assumed to imply neutrality. To the contrary, middling ratings on traditional bipolar scales merely imply that the stimulus elicited comparable levels of positive and negative affect (e.g., P = 4, N = 4); they do not imply that the stimulus elicited *no* affect (i.e., P = 0, N = 0; see Cacioppo & Berntson, 1994; Kaplan, 1972; Klopfer & Madden, 1980; Scott, 1968). In previous research with the affect matrix, for example, Larsen et al. (2003) found that whereas some attitude objects were rated as both positive and negative (e.g., capital punishment) and others were rated as neither positive nor negative (e.g., wallpaper), both ambivalent and neutral objects were given equally middling ratings on bipolar evaluative scales.

[6]In our sample, the most negatively rated stimuli were a picture of a victim of severe burns (IAPS #2800), the sound of a fight (IADS #290), and the word *war* (ANEW #482). The most positively rated stimuli were a picture of a trio of puppies (IAPS #1710), music from Beethoven (IADS #810), and the word *sweetheart* (ANEW #424).

Sounds. Bradley and Lang (2000) reported a strong linear effect of valence on activity over *corrugator supercilii*, but no effect of valence on activity over *zygomaticus major*. Replicating the findings of Bradley and Lang, the sounds task revealed a strong linear effect of valence on activity over *corrugator supercilii*, $r(66) = -.86$, $p < .001$, and no stronger quadratic effect, $r(66) = -.86$, $p < .001$ (see Figure 1, middle left panel). The effect of valence on activity over *zygomaticus major* was weaker, but in contrast to Bradley and Lang, still quite strong, $r(66) = .68$, $p < .001$ (see Figure 1, middle right panel). In addition, the quadratic effect was somewhat stronger, $r(66) = .75$, $p < .001$, due to an apparently linear effect of valence among more appealing stimuli and little effect among less appealing stimuli.

Words. The bottom panels of Figure 1 reveal weaker effects of valence in the words task than in the other tasks. Nonetheless, the linear effect of valence on activity over *corrugator supercilii* was pronounced, $r(66) = -.62$, $p < .001$, and the quadratic effect was no stronger, $r(66) = -.62$, $p < .001$. In contrast, there was little effect of valence on activity over *zygomaticus major*, $r(66) = .21$, $p = .10$, quadratic $r(66) = .25$, $p < .05$.[7]

Individual Differences in the Effect of Valence on EMG

In all three tasks, valence had a stronger effect on activity over *corrugator supercilii* as opposed to *zygomaticus major*. Activity over *zygomaticus major* may nevertheless be linearly related to valence for a substantial proportion of participants. One possibility, for example, is that the linear effect of valence on activity over *zygomaticus major* was bimodally distributed, such that one cluster of participants showed a strong positive, linear effect of valence, but another cluster showed a negligible or even negative effect of valence, thereby attenuating the linear positive correlation. To examine this possibility, we correlated valence ranks with EMG reactivity for each participant's data from each task (see Figure 2).

Figure 2 reveals that the correlations were fairly normally distributed for all three tasks and there appears to be no discrete subset of participants with a strong positive effect of valence on activity over *zygomaticus major*. In the pictures task, valence had a significant negative effect on activity over *corrugator supercilii* for 43 participants (65%), but had a significant positive effect on activity over *zygomaticus major* for only 16 participants (24%), $\chi^2(1) = 26.04$, $p < .001$ (see Figure 2, top panel). Similarly, in the sounds task, 30 participants (48%) showed a significant negative correlation between activity over *corrugator supercilii* and valence, whereas only 12 participants (19%) showed a corresponding positive correlation between activity over *zygomaticus major* and valence, $\chi^2(1) = 11.12$, $p < .001$. Fewer participants had reliable correlations between EMG and valence in the words task (see Figure 2, bottom panel), but there was still a trend for

[7]Separate analyses on data from each session revealed little habituation in the pictures and sounds tasks. In the words task, the effect of valence on activity over *corrugator supercilii* dropped from $r(66) = -.69$, $p < .001$, in Session 1 to $-.27$, $p < .05$, in Session 2. As the words task occurred early in the first session but late in the second session, this may reflect habituation to the words in particular or to the experimental session in general. In any event, in both sessions valence had a weaker effect on activity over *zygomaticus major*, $r(66) = .22$, $p < .10$ (session 1) and $r(66) = .09$, n.s. (session 2), than on activity over *corrugator supercilii*.

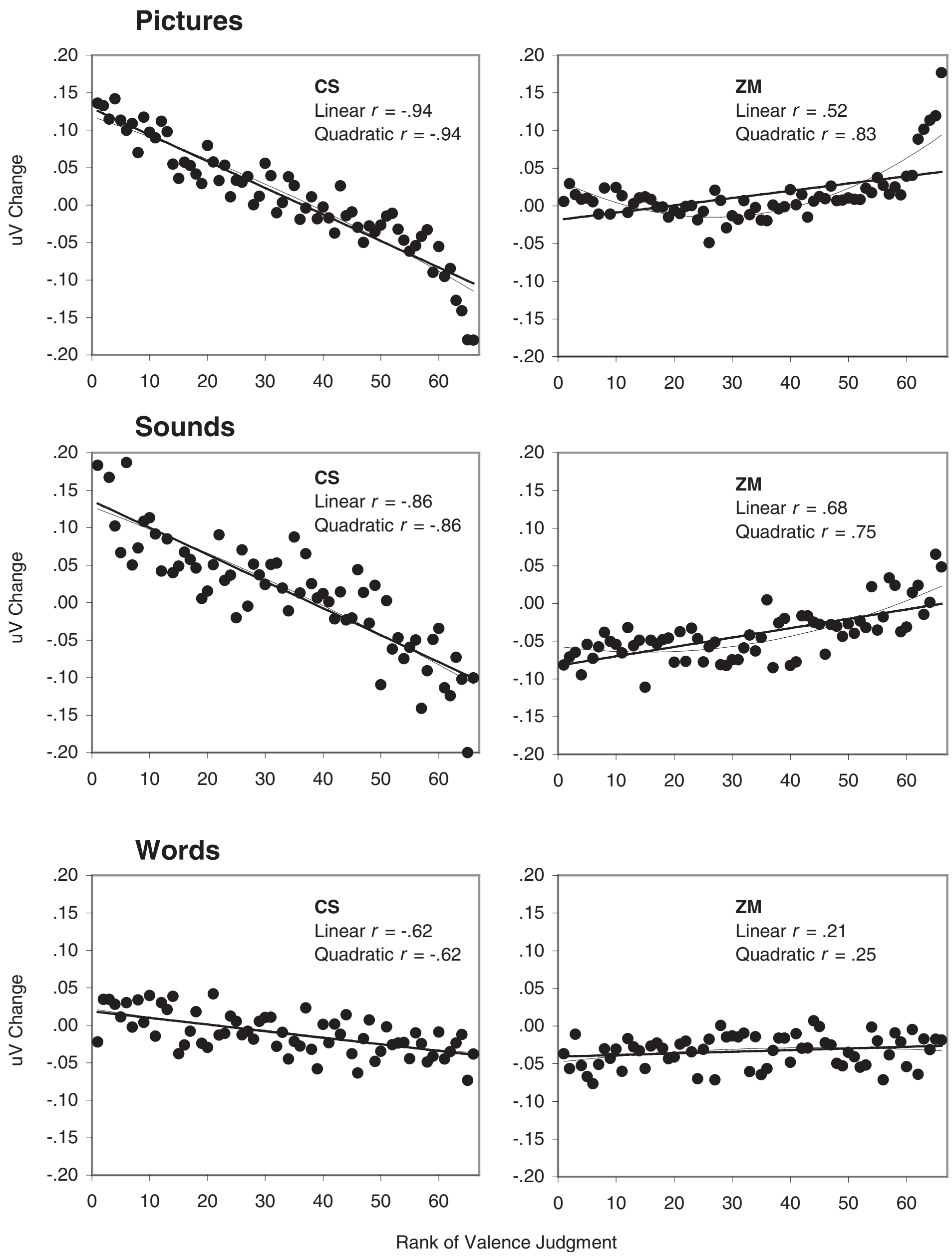

Figure 1. Correlation of valence judgments with activity over *corrugator supercilii* (left panel) and *zygomaticus major* (right panel) in the pictures, sounds, and words tasks. In each task, valence judgments are rank ordered for each participant; the graphs depict mean responses at each rank collapsed across participants. CS: *corrugator supercilii*, ZM: *zygomaticus major*.

more participants to show a significant negative effect of valence on activity over *corrugator supercilii* ($n = 10$; 16%) as opposed to *zygomaticus major* ($n = 3$; 5%), $p = .06$ by the binomial distribution.[8]

Relationships among Unipolar Measures of Affect and EMG

The consistent finding that bipolar valence has a linear effect on activity over *corrugator supercilii* raises the possibility that activity over *corrugator supercilii* is not only potentiated by negative affect, but also inhibited by positive affect. Nevertheless, this inference only holds if stimuli elicited positive and negative affect in a mutually exclusive fashion. As shown in Figure 3, however, a substantial proportion of stimuli elicited mixed feelings of positive and negative affect in a largely reciprocal fashion. For the average participant, 27% of pictures, 29% of sounds, and 36% of words elicited ambivalence. As the presence of ambivalent stimuli raises the possibility that decreases in negative affect, rather than increases in positive affect, may inhibit activity over *corrugator supercilii*, we conducted additional analyses on those stimuli that were rated as exclusively negative or positive. For each task and session we aggregated each participant's EMG data across the stimuli they had rated as univalently (i.e., exclusively) negative or positive. Specifically,

[8]Chi-square could not be estimated due to low cell frequencies.

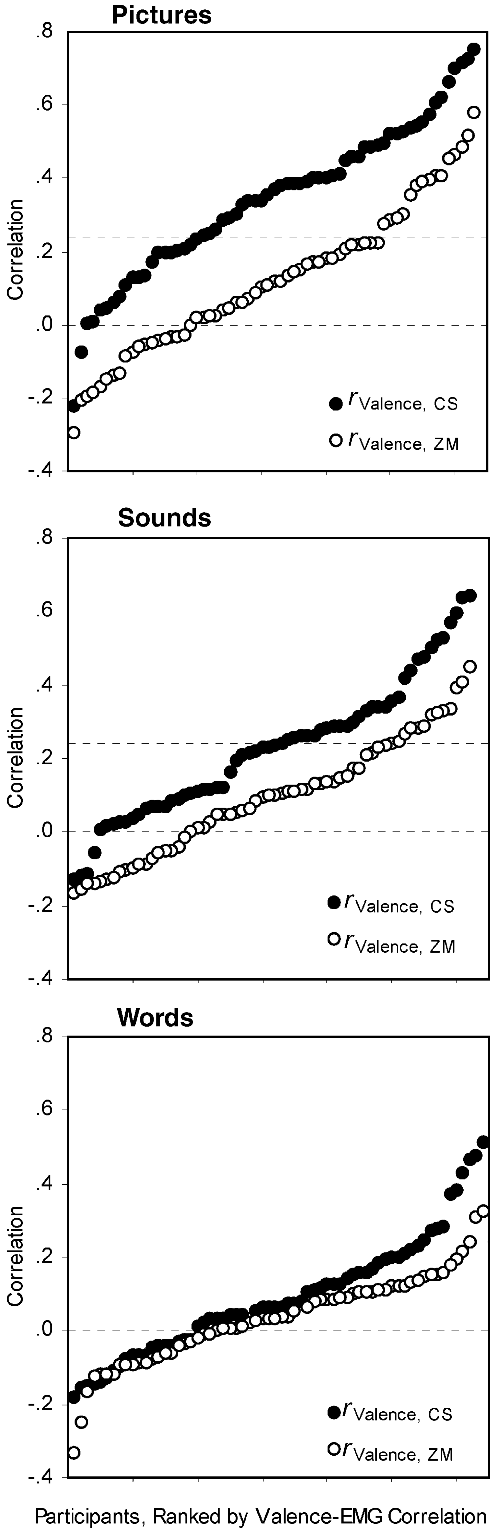

Figure 2. Individual differences in the effect of valence on activity over *corrugator supercilii* and *zygomaticus major* in the pictures, sounds, and words tasks. Each point represents one participant's Pearson correlation between valence ranks and facial EMG responses to the 66 stimuli. Correlations between valence and *corrugator supercilii* are multiplied by -1. Correlations above the top line, $r = .24$, are statistically significant at $p < .05$, those between the lines are in the predicted direction but not significant, and those below the lower line are not in the predicted direction. CS: *corrugator supercilii*, ZM: *zygomaticus major*.

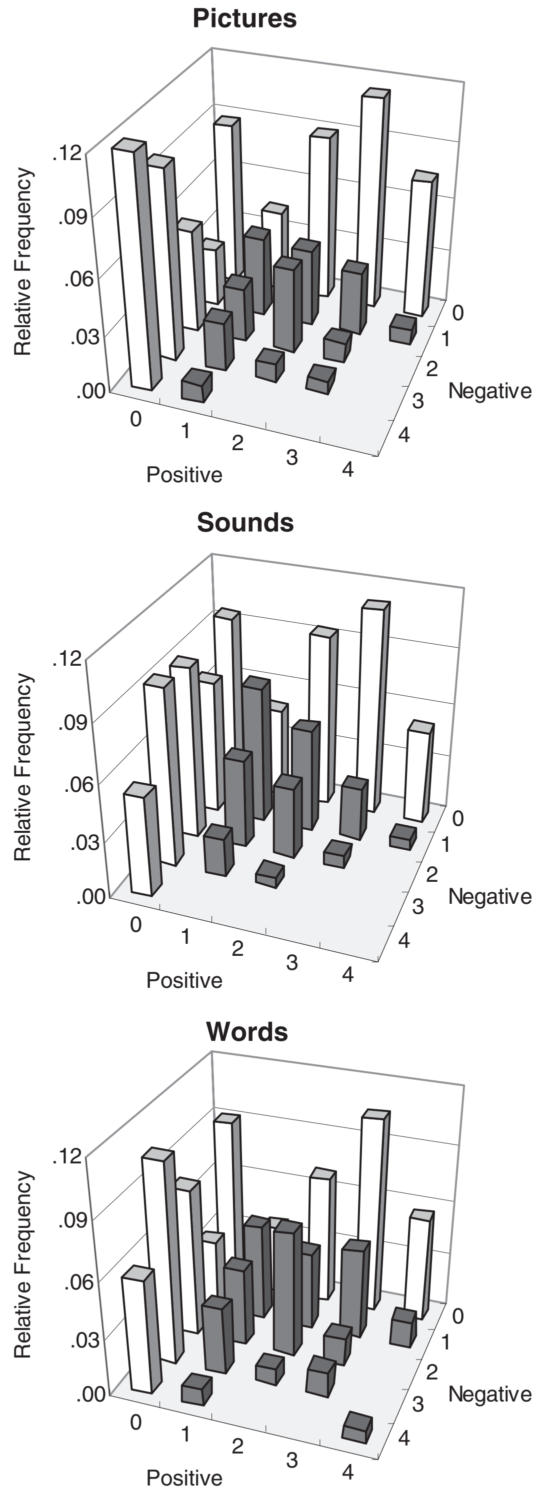

Figure 3. Bivariate frequency distributions of positive and negative affect ratings in the pictures, sounds, and words tasks. Shaded bars denote mixed feelings of positive and negative affect. For ease of interpretation, bars with values $< .005$ are omitted.

averages were constructed for stimuli rated as very negative (P = 0, N = 3–4), moderately negative (P = 0, N = 1–2), moderately positive (P = 1–2, N = 0), and very positive (P = 3–4, N = 0). For comparison, a fifth set of averages was constructed for stimuli rated as neutral (N = 0, P = 0).[9] Mean activations are plotted in Figure 4 as a function of task and valence. Activity over *corrugator supercilii* data from each task were submitted to 2 (session) $\times$ 5 (valence) within-subjects ANOVAs. This analytic strategy also allowed us to examine more directly the effects of positive and negative affect on activity over *zygomaticus major*. To that end, we submitted these data from each task to equivalent ANOVAs.

Pictures. The ANOVA on the activity over *corrugator supercilii* data revealed a main effect of valence, $F(4,57) = 10.58$, $p < .001$, which was driven by a significant linear trend, $F(1,60) = 35.96$, $p < .001$, but no quadratic trend, $F(1,60) = 0.03$, n.s. (see Figure 4, top panel).[10] One-sample t tests indicated not only that very negative and mildly negative pictures both potentiated activity over *corrugator supercilii*, $t(60) = 4.42$ and 2.52, respectively, both ps $< .05$, but also that very positive pictures significantly diminished activity, $t(60) = -5.09$, $p < .001$ (see Figure 4, top panel). Coupled with the negligible activity associated with neutral pictures, simple contrasts indicated that very negative and mildly negative stimuli elicited greater activity over *corrugator supercilii* than did neutral pictures, $F(1,60) = 22.90$ and 5.42, respectively, both ps $< .05$, and that very positive pictures elicited less activity than did neutral pictures, $F(1,59) = 25.21$, $p < .001$. Thus, even when negative affect is held constant at minimal levels, positive affect inhibits activity over *corrugator supercilii.*

The activity over *zygomaticus major* data revealed a main effect of valence, $F(4,57) = 6.37$, $p < .001$, which was driven by both linear and quadratic effects, $F(1,60) = 16.54$ and 25.68, both ps $< .001$ (see Figure 4, top panel). One-sample t tests indicated that only very positive pictures potentiated activity over *zygomaticus major*, $t(60) = 4.39$, $p < .001$, and that neutral pictures inhibited activity, $t(60) = -2.47$, $p < .05$. Due to this inhibition, not only very positive, but also mildly positive and very negative pictures elicited greater activity over *zygomaticus major* than did neutral pictures, $F(1,60) = 23.07$, 4.95, and 7.40, respectively, all ps $< .05$. Though both positive and very negative pictures elicited greater activity than neutral stimuli, only very positive pictures actually potentiated activity over *zygomaticus major*.

Sounds. The ANOVA on the activity over *corrugator supercilii* data revealed a main effect of valence, $F(4,56) = 12.04$, $p < .001$, which was due to both a linear trend and a small, but significant, quadratic trend, $F(1,59) = 42.36$ and 4.17, respectively, both ps $< .05$ (see Figure 4, middle panel). Very negative, mildly negative, and even neutral sounds potentiated activity over *corrugator supercilii*, $t(59) = 5.81$, 3.33, and 3.62, respectively, all ps $< .01$, and very positive stimuli attenuated activity, $t(59) = -4.73$, $p < .001$. Follow-up contrasts indicated that very negative sounds elicited greater activity than neutral sounds, $F(1,59) = 19.83$, $p < .001$, but mildly negative sounds did not, $F(1,59) = .19$, n.s. In contrast, and as shown in the middle panel of Figure 4, both very positive and mildly positive sounds elicited less activity than did neutral sounds, $F(1,59) = 38.34$ and 6.43, respectively, both ps $< .05$. Thus, as in the pictures task, activity over *corrugator supercilii* appears to be sensitive to negative affect as well as positive affect. Indeed, activity over *corrugator supercilii* was actually more responsive to positive affect than to negative affect in the sounds task.

The activity over *zygomaticus major* data revealed a main effect of valence, $F(4,56) = 4.86$, $p < .01$, which was again driven by both linear and quadratic trends, $F(1,59) = 18.76$ and 8.74,

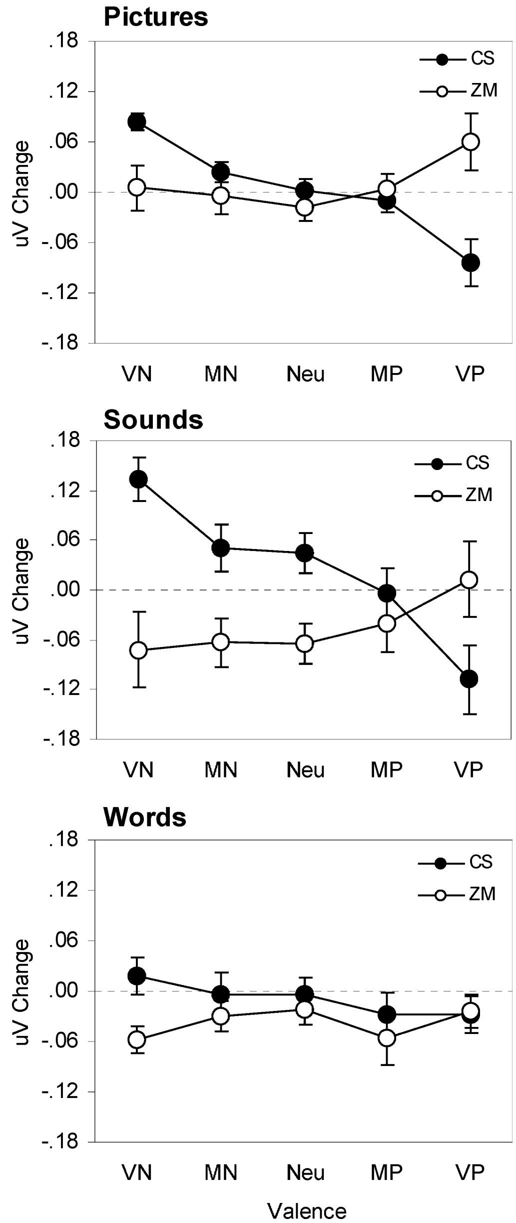

Figure 4. Mean activity over *corrugator supercilii* and *zygomaticus major* to pictures (top panel), sounds (middle panel), and words (bottom panel) ideographically rated as univalently negative, neutral, or univalently positive. Error bars represent 2 standard errors. CS: *corrugator supercilii*, ZM: *zygomaticus major*, VN: Very Negative, MN: Mildly Negative, Neu: Neutral, MP: Mildly Positive, VP: Very Positive.

[9]Some participants had an empty cell in one or the other session of a given task. In these cases, missing values were replaced by the mean of the two adjoining categories. Four participants had missing data in the very negative or very positive cells. Another 2 participants had missing data in two or more cells in one ($n = 1$) or two ($n = 1$) tasks. Data from these participants were removed from the relevant task. As a result, sample sizes for these analyses were $n = 61$, 60, and 61 for the pictures, sounds, and words tasks, respectively.

[10]The Wilks's lambda approximation is reported for all F statistics involving independent variables with three or more levels.

both $ps < .01$. As shown in the middle panel of Figure 4, very positive sounds elicited negligible activity over *zygomaticus major*, $t(59) = 0.63$, n.s., and all remaining categories inhibited activity, $t(59) = -2.60$ to -5.43, all $ps < .05$. Contrasts indicated that very positive sounds elicited significantly greater activity than did neutral sounds, $F(1,59) = 12.63$, $p < .01$, and that mildly positive sounds showed a similar trend, $F(1,59) = 2.79$, $p = .10$. Thus, in contrast to the pictures task, activity over *zygomaticus major* was only potentiated by positive sounds in the current study. Coupled with the findings that very positive and mildly negative sounds elicited comparable activity as did neutral sounds, these results indicate that only positive affect affected activity over *zygomaticus major*.

Words. The ANOVA on the activity over *corrugator supercilii* data showed a main effect of valence, $F(4,57) = 2.63$, $p < .05$, which was driven by a linear trend, $F(1,60) = 7.20$, $p < .001$, but no quadratic trend, $F(1,60) = 0.43$, n.s. (see Figure 4, bottom panel). No stimulus categories potentiated activity over *corrugator supercilii*, but very positive and mildly positive words inhibited activity, $F(1,60) = -2.44$ and -2.08, respectively, both $ps < .05$. Although no follow-up contrasts were significant, very negative stimuli tended to elicit greater activity than did neutral stimuli, $F(1,60) = 3.70$, $p = .06$, whereas both very and mildly positive stimuli tended to elicit less activity, $F(1,60) = 3.16$ and 3.66, respectively, both $ps < .09$. These data suggest that whereas positive and negative affect have weaker effects on activity over *corrugator supercilii* in the words task than in the other tasks, the form of these relationships are similar.

Finally, the activity over *zygomaticus major* data revealed a main effect of valence, $F(4,57) = 4.42$, $p < .01$, but neither the linear nor quadratic trends were reliable, $F(1,60) = 3.38$ and 1.00, $p = .07$ and .32, respectively. As shown in the bottom panel of Figure 4, all categories inhibited activity over *zygomaticus major*, $t(1,60) = -2.5$ to -7.31, all $ps < .05$. Moreover, follow-up contrasts revealed no clear pattern of differences. Very negative and mildly positive words yielded greater inhibition than neutral words, $F(1,60) = 9.91$ and 4.59, both $ps < .05$, but very positive words yielded no greater activation than did neutral words, $F(1,60) = 0.02$, n.s.

Discussion

The goals of this research were to assess the form and strength of the effect of positive and negative affect on EMG activity over *zygomaticus major* and *corrugator supercilii*. We were primarily interested in the relative strength of the linear effect of self-reported valence on activity over the two sites. In addition, we hoped to examine the generalizability of our findings across several different affective tasks. Finally, we sought to extend previous analyses of the effect of bipolar valence on facial EMG activity by considering the potentially separable effects of the positive and negative affective processes underlying the bipolar valence dimension.

The Relative Effects of Valence on Activity over Zygomaticus Major and Corrugator Supercilii

Based on the neurophysiology of the facial musculature and other evidence, we speculated that under private viewing conditions affect would have a greater effect on activity over *corrugator supercilii* as opposed to *zygomaticus major*. Consistent with this hypothesis, the pictures task, for example, revealed that valence had a substantially stronger effect on activity over *corrugator supercilii*. In addition, more participants showed a reliable linear effect of valence on activity over *corrugator supercilii*. Teasing apart the roles of such factors as the cortex's relatively sparse efferentiation and afferentiation of the *corrugator supercilii* and *corrugator supercilii*'s reduced susceptibility to cross talk from other muscles would likely require practically unfeasible psychobiological experimentation, but our findings are consistent with known neurophysiological differences between *corrugator supercilii* and *zygomaticus major* (Rinn, 1984).

Results were quite similar across the three tasks. There was a weaker effect of valence on EMG in the words task than in the other two tasks, presumably because words elicit milder affective reactions. More important, valence had a stronger effect on *corrugator supercilii* than on *zygomaticus major* in all three tasks. Even in the words task, for example, there was a substantial linear effect of valence on *corrugator supercilii*, but no reliable effect on activity over *zygomaticus major*. In addition, the form of the relationships generalized across tasks, with largely linear effects of valence on activity over *corrugator supercilii* in all three tasks and similar quadratic effects on activity over *zygomaticus major* in the pictures and sounds tasks. A slight J-shaped effect of valence on *zygomaticus major* emerged in the pictures task, such that the most unpleasant stimuli elicited more activity than more middling stimuli (Lang et al., 1993), but there was no evidence of such a J-shaped effect in the sounds task. Following Lang et al.'s observation that unpleasant stimuli rated as disgusting were those that elicited activity over *zygomaticus major*, one possibility is that the unpleasant sounds we included elicited little disgust.

The Effects of Positive and Negative Affect on Facial EMG

In addition to proposing that positive and negative affective processes represent separable components of the affect system, the ESM holds that the level of the neuraxis represents an important boundary condition for the relationship between positivity and negativity (Cacioppo et al., 1999). Specifically, affective processes are thought to be organized in a more bipolar fashion in caudal areas of the neuraxis (e.g., the brain stem). Thus, positive and negative affect would be expected to have reciprocal effects on facial EMG measures. Consistent with this hypothesis, increases in self-reported negative affect (holding positive affect constant at 0) potentiated activity over *corrugator supercilii*, whereas increases in self-reported positive affect (holding negative affect constant at 0) inhibited activity.

On the other hand, increases in positive affect potentiated activity over *zygomaticus major* in the pictures and sounds tasks, but increases in negative affect had little effect. This finding might suggest that *zygomaticus major* is not reciprocally activated by positive and negative affect. Thus, with respect to affective variables (e.g., negative affect, positive affect), activity over *zygomaticus major* may offer greater specificity than activity over *corrugator supercilii*. Yet there are several caveats to such an interpretation. First, though activity over *zygomaticus major* may offer greater specificity with respect to affective variables, the neurophysiology of facial EMG and research reviewed above indicates that activity over *zygomaticus major* offers less specificity when nonaffective variables are considered. Nuanced display rules, for example, are manifest more often in the cheek than in the brow. In addition, the generality of *zygomaticus major*'s greater specificity may be limited. We observed lower baseline recordings over *zygomaticus major* than *corrugator supercilii*, so even greater inhibition of activity over *zygomaticus major* in response to unpleasant stimuli may be unlikely. In less artificial situations (e.g., outside the laboratory), however, baseline *zygomaticus major* activity is likely to be higher, thereby allowing the possibility of *zygomaticus major* inhibition in response to unpleasant stimuli. Consider, for example, the changing facial expression of an individual whose enjoyment of a radio program is interrupted by the announcement of a tragedy. This individual's smile will likely disappear in reaction to the bad news, resulting in an effect of negative affect on activity over *zygomaticus major*.

In addition to raising questions about the distinct effects of positive and negative affect on facial EMG, the ESM raises questions about the effect of ambivalence on facial EMG. Unfortunately, there were not enough ambivalent stimuli in this study to allow meaningful statistical analysis. Nevertheless, if we assume additive effects of positive and negative affect on facial EMG, we can speculate about the effect of ambivalence by extrapolating from the current findings. Our findings that positive affect decreases and negative affect increases activity over *corrugator supercilii* suggests that an ambivalent stimulus may have antagonistic effects on activity over *corrugator supercilii*, resulting in little change in activity. In contrast, our findings that positive affect increased and negative affect had no effect on activity over *zygomaticus major* suggests that ambivalent stimuli may increase activity over *zygomaticus major*.

In sum, this research investigated the transfer functions between affective valence and intensity and facial EMG activity and, in particular, the distinct effects of unipolar and bipolar affective reactions on facial EMG. Though the results were quite clear, we urge caution in generalizing these results to all contexts. As we have speculated, negative affect may inhibit activity over the *zygomaticus major* region in settings where a floor effect is not operating. Moreover, based on the neurophysiology of facial expression, there may be contexts in which valence has a greater effect on activity over *zygomaticus major* as opposed to *corrugator supercilii*. Our participants were alone in a quiet, darkened room, where facial signaling had no purpose. In daily life, however, other people are among the most emotionally evocative stimuli, and facial expressions may serve an important function as communicative displays. Accordingly, the volitional fine motor control over the muscles of the *zygomaticus major*, in contrast to *corrugator supercilii*, may render the former particularly active in response to emotional events that are shared with others. Consistent with this speculation, Kraut and Johnston (1979) observed that smiles occur more frequently in social situations. In one study, they found that after bowling a strike, bowlers were more likely to smile after turning to their partners than while facing the fallen pins. In social situations, then, valence may have a stronger effect on activity over *zygomaticus major*. Whether this is simply due to communicative intent coupled with the greater voluntary control of *zygomaticus major* or a more subtle set of mechanisms is a question we leave to future research.

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