Affect dynamics of facial EMG during continuous emotional experiences

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ABSTRACT

Emotional experiences are complex, multi-component processes that unfold over time. Accordingly, it is crucial to understand the temporal dynamics of these constituent components. Here we studied the dynamics of one of the core emotional systems, i.e., facial muscle activity, during continuous emotional experiences, elicited by movies. We found that transient zygomatic fluctuations were narrowly tuned to a positive emotional experience. During a positive but not a negative movie, zygomatic response patterns were consistent across participants, tracked with subjective ratings and co-varied with emotional dynamics. Corrugator activity evidenced a broader affective profile and larger individual variability. It was coordinated with tonic changes in emotional negativity and inversely coupled with transient changes in positive affect. Taken together, our results confirmed previous findings on the affective profiles of facial responses and extended them to temporal dynamics. They further uncovered important differences in temporal response characteristics of zygomatic and corrugator measures.

1. Introduction

Contemporary approaches highlight the dynamic nature of emotions, suggesting that emotional experiences emerge as a result of interactions between multiple components and continuously change over time (Barrett, Mesquita, Ochsner, & Gross, 2007; Boiger & Mesquita, 2012; Frijda, 1988; Scherer, 2009). A growing research effort is invested in understanding the temporal dynamics of emotional processes and its constituent components (Hollenstein & Lanteigne, 2014; Kuppens, 2015; Sander, Grandjean, & Scherer, 2005; Schuyler et al., 2014; Waugh, Shing, & Avery, 2015). We add to this effort by investigating the dynamics of facial activity, a prominent emotional response system, during continuous emotional experiences. While abundant previous research has demonstrated that facial activity measured via electromyography (EMG) serves as a reliable and valence specific measure of affect (Cacioppo, Petty, Losch, & Kim, 1986; Lang, Greenwald, Bradley, & Hamm, 1993; Larsen, Norris, & Cacioppo, 2003; Tassinary & Cacioppo, 1992), this research has been mainly confined to short-term emotional stimuli and measures aggregated across time. Consequently, systematic investigation of EMG dynamics and their temporal and affective characteristics is lacking.

1.1. Affect-specificity of facial responses

Facial expressions have long been considered to serve an essential emotional function (Darwin, Ekman, & Prodger, 1998; Ekman & Rosenberg, 1997; Fridlund & Cacioppo, 1986), accompanying emotional experiences and conveying them to others (Ekman & Scherer, 1984; Ekman, 1992). Assessment of electrical activity from facial muscles (EMG) provides a reliable and valence specific measure of emotional expressions (Dimberg, 1990; Fridlund & Cacioppo, 1986), capable of revealing activity too subtle to detect visually (Tassinary & Cacioppo, 1992). Specifically, activation of the zygomaticus major muscle, which pulls the corners of the mouth into a smile, is consistently associated with positive emotions, while activation of the corrugator supercilii muscle, which draws the brows into a frown, is potentiated by unpleasant and attenuated by pleasant emotional states (Cacioppo et al., 1986; Dimberg, 1990; Lang et al., 1993; Larsen et al., 2003; Sato, Fujimura, Kochiyama, & Suzuki, 2013; Tan et al., 2012).

The vast majority of previous EMG research has been based on quantifying average EMG responses elicited by short emotional inputs, such as pictures or sounds. While recent studies have begun to unravel the temporal characteristics of EMG responses to short emotional events (Cholnowiecki et al., 2016; Heerey & Crossley, 2013; Korb, Grandjean, & Scherer, 2010; Lapate et al., 2014; Van Reekum et al., 2011), the dynamics of EMG activity during complex emotional experiences...
unfolding over time have not been systematically studied.

1.2. Reliability of facial dynamics

To elicit naturalistic emotional experiences in the lab, research frequently employs emotional films (Rottenberg, Ray, & Gross, 2007). Excerpts of cinematic movies have been shown to evoke powerful emotional states (Rottenberg et al., 2007) as well as consistent physiological changes (Kreibig, Wilhelm, Roth, & Gross, 2007; Kreibig, 2010), which are shared across observers. For instance, studies have shown that positively valenced movies evoke enhanced zygomatic activation across participants, while negative movies lead to increased corrugator responses (Codispoti, Surcinelli, & Baldaro, 2008; Hess, Banse, & Kappas, 1995; Wilhelm et al., 2017). This research has been conducted from a state-oriented perspective on emotions, using measures aggregated across time. Yet, movies involve a series of succeeding emotional events at varying temporal scales, providing a continuous stream of affective information with unique temporal characteristics. Currently, little is known about whether and how these emotional dynamics are reflected in continuous, moment-to-moment changes of EMG response patterns.

Reactivity measures, commonly used to study emotions, lack the temporal information necessary to investigate dynamics. As an alternative, previous research on complex physiological dynamics has often employed measures of response similarity across individuals exposed to identical stimuli. Such temporal alignment of physiological fluctuations across individuals has been used as an index of stimulus-response reliability (i.e. reproducibility), when assessing activity over time (Hasson, Malach, & Heeger, 2010). For example, imaging studies have demonstrated that naturalistic emotional stimuli, such as movies or musical pieces, elicit common neural dynamics in participants’ emotional brain circuitry (Jääskeläinen et al., 2016; Nummenmaa et al., 2012, 2014; Singer et al., 2016; Trost, Frühholz, Cochrane, Cojan, & Vuilleumier, 2015). Similar results were obtained for the autonomic nervous system measures (ANS), demonstrating significant temporal alignment of ANS responses across observers while watching emotional movies (Golland, Keissar, & Levit-Binnun, 2014; Golland, Arzouan, & Levit-Binnun, 2015). EMG activity reflects the end result of the nervous system activity, being shaped by multiple emotional and cognitive factors as well as by social display rules (Hess et al., 1995; Scherer & Ellgring, 2007). In addition, spontaneous facial responses seem to exhibit significant inter-individual variability (Duran, Reisenzein, & Fernandez-Dols, 2017; Fernandez-Dols, Sanchez, Carrera, & Ruiz-Belda, 1997). Accordingly, whether a continuous stream of complex affective processing elicits consistent fluctuations in EMG responses and whether these fluctuations are similar across participants remains an open question.

1.3. Temporal alignment with affect dynamics

Although there is a common consensus that facial expressions reliably represent subjective emotional experiences (1993, Ekman, 1992), literature on this matter is inconclusive. While some studies report strong correlations between emotional reports and facial EMG activations (Bradley & Lang, 2000; Lang et al., 1993; Larsen et al., 2003; Sato et al., 2013; Tan et al., 2012), recent meta-analyses fail to find consistent links (Kappas, 2003; Reisenzein, Studtmann, & Horstmann, 2013). Given the dynamic nature of emotional experiences and facial behavior (Cunningham, Dunfield, & Stillman, 2013; Krumhuber, Kappas, & Manstead, 2013; Kuppers, 2015), investigation of the temporal correspondence between facial behavior and fluctuations of affect may contribute significantly to the aforementioned issue (Hollenstein & Lanteigne, 2014; Krumhuber & Scherer, 2011). This approach has been pioneered by the early works in facial emotional responses (Cacioppo, Martzke, Petty, & Tassinary, 1988; Rosenbek & Ekman, 1994) which provided initial evidence for the temporal coherence between the expressive and the experiential emotional systems. A recent study has directly assessed temporal correspondence between facial expressions and subjective experience during a mixed emotion movie, containing distinctive sadness and amusement episodes (Mauss, Levenson, McCarther, Wilhelm, & Gross, 2005). Using a clever approach in which moment-by-moment changes in the intensity of amusement and sadness facial expressions were coded by external raters, this study has demonstrated that facial behaviors show within-person correlations with the momentary changes in corresponding subjective feelings. This study has provided evidence that EMG activity is linearly coupled with fluctuations of affect within participants. However, the robustness of this result is unclear as it could reflect dichotomic switches between highly distinctive emotional states (that is sadness and amusement), rather than a continuous unfolding of emotional dynamics. In addition, this study was based on a holistic encoding of sadness and amusement expressions, potentially involving multiple facial and body features. Accordingly, whether zygomatic and corrugator response patterns reliably represent continuous affective dynamics is unclear. Finally, although the most consistent evidence for the EMG-affect correspondence has arrived from the dimensional studies of emotion (Bradley & Lang, 2000; Lang et al., 1993; Larsen et al., 2003; Sato et al., 2013; Tan et al., 2012), the correspondence of continuous facial activity with changes on the valence dimensions (as opposed to distinct emotional categories, such as sadness) has not been tested.

1.4. Methodological considerations in the temporal domain

Emotional dynamics can occur at multiple temporal scales, spanning from seconds to minutes and even hours (Levenson, 2014; Rottenberg et al., 2007). When measured over time, short-term distinct emotional events are expected to elicit transient fluctuations in affect dynamics while more gradual emotional changes, unfolding over minutes, may induce tonic components in the designated measures (Hamaker, Ceulemans, Graisman, & Tuerlinckx, 2015; Waugh et al., 2015). Accordingly, prolonged physiological dynamics elicited in affective context may reflect phasic fluctuations, tonic changes or a combination of both (Cacioppo et al., 1988; Wang, Liu, Yiannı, Azis, & Stein, 2004). While these time-related considerations are acknowledged in emotion research (e.g., Butler, 2011), they are rarely assessed systematically in physiological studies. Centrally, the temporal sensitivity of facial EMG dynamics to phasic and tonic affective fluctuations is unknown.

1.5. The present study

In the present study we aimed to conduct a systematic investigation of the facial EMG dynamics, elicited by continuous emotional experiences. To study affect dynamics, consistent fluctuations in emotional responses should be reliably elicited to begin with. Previous research has demonstrated the efficiency of commercial movies in producing potent emotional responses, which are similar across observers (Golland et al., 2014; Nummenmaa et al., 2012; Rottenberg et al., 2007). Here we employed pre-tested excerpts from emotional movies, which targeted a positive and a negative emotional experiences. The positive movie, depicting a performance of a child, elicited warm feelings and joy, strongly associated with zygomatic activations. The negative movie, taken from a horror film, induced fear and distress. A series of previous studies reported consistent corrugator activations in response to fear stimuli (Codispoti et al., 2008; Dimberg, 1986; Magné, Stekelenburg, Kemner, & de Gelder, 2007). Fear was chosen over sadness, since it is more prone to evoke phasic emotional events and was shown to elicit higher corrugator activation as compared to sadness in a previous study employing movies (Kreibig et al., 2007). Finally, we validated that both emotional movies elicited transient changes as well as tonic modulations of emotional experience (Fig. 1, Supplementary Fig. 1).

As a first step, we assessed the temporal response characteristics of continuous EMG time-courses, while differentiating between its phasic
and tonic components. The dynamics of EMG responses may manifest slow modulations, i.e., general tonic increases, or phasic changes, i.e., transient fluctuations on a time scale of seconds. Since previous research on the temporal properties of facial EMG is lacking, we employed a data-driven approach, which defies the need for a priori hypotheses. To assess the susceptibility of zygomatic and corrugator signals to slow, tonic changes we computed their autocorrelation functions, i.e. correlation of a signal with itself as a function of time shift. Higher presence of slow components induces higher dependency of consecutive observations, i.e. slower declines of autocorrelation function in time. Autocorrelation width was computed for both emotional movies and for non-emotional physiological baseline. To examine whether zygomatic and corrugator signals differed in their tonic predominance we compared the width of their autocorrelation functions within each experimental condition. To examine whether tonic changes were linked with distinctive emotional states we compared the autocorrelation width across experimental conditions. In addition, we investigated whether phasic EMG fluctuations reliably reflect emotional dynamics. For that aim we performed the below described analyses both on the original EMG signals and on the de-trended signals, lacking the slow, tonic components.

Central to the present study, we investigated whether EMG fluctuations are reliably driven by the emotional movies. Past research has demonstrated that emotional movies evoke consistent neural and autonomic temporal responses patterns which are time-locked across participants (Golland et al., 2014; Golland, Levit-Binnun, Hendler, & Lerner, 2017; Hasson et al., 2010; Nummenmaa et al., 2012). As evidenced by a previous study (Golland et al., 2014) and by a preliminary test (Supplementary Fig. 1), the emotional movies, employed in the current research, elicited robust emotional dynamics, which were similar across participants. Here we examined whether these movies induced reliable facial response patterns over the zygomatic and corrugator sites. For that aim, we conducted an inter-subject correlation (interSC) analysis, which quantifies response similarity across participants viewing the same movie (Golland et al., 2014; Hasson, Nir, Levy, Fuhrmann, & Malach, 2004; Nummenmaa et al., 2012). Given the consistent links of zygomatic responses with positive affect, we expected to find enhanced reliability, i.e. interSC, of the zygomatic response fluctuations during the positive movie as compared to the negative movie or non-emotional baseline. The corrugator responses tend to exhibit a linear correlation with valence, being activated by the negative affect and inhibited by the positive affect (Lang et al., 1993; Larsen et al., 2003). However, whether such response patterns are preserved during continuous emotional experiences was not studied before. We expected both the negative and the positive emotional dynamics to induce reliable corrugator fluctuations, leading to higher interSC during the emotional movies as compared to non-emotional baseline.

Finally, we examined whether continuous changes in zygomatic and corrugator EMG measures were temporally coordinated with the movie-driven fluctuations of emotional experience on a valence dimension. Specifically, we asked whether EMG fluctuations were linearly aligned with the movie-driven emotional fluctuations. The emotional timelines of the movies were assessed in an independent sample of participants (Fig. 1, Supplementary Fig. 1). We expected to find enhanced zygomatic alignment with fluctuations of positive affect and enhanced corrugator alignment with fluctuations of negative affect. Furthermore, we expected the corrugator dynamics to be negatively correlated with positive valence fluctuations.

2. Methods

2.1. Participants

Forty four female students (age: M = 23, SD = 2.94) participated in the study for course credits (the current experiment was part of a larger
research, which prescribed a reliance on female participants). Experimental procedures were approved by the institutional ethics committee. Written informed consent was obtained after the procedures had been fully explained.

The current research was part of a larger project (details are specified in a Procedure subsection), which determined the collected sample size, to ensure 80% power to detect effect size, \( f \), of 0.30 at \( p < .05 \) (Faul, Erdfelder, Buchner, & Lang, 2009), while taking into account ~ fifteen percent dropout, due to corrupted physiological signals.

2.2. Emotional movies

Two movie excerpts, taken from the horror film “Paranormal Activity” (394 s), used in our previous study (Golland et al., 2014) and the popular entertainment TV show "Britain's Got Talent" (364 s) were used in this study to elicit negative and positive emotions, respectively. As was validated in a pre-test, the emotional timelines of these movies were comparable in their temporal characteristics, containing both gradual increases of affect and distinctive phasic emotional events (Fig. 1).

2.3. Dynamics ratings of valence in pre-test participants

The emotional timelines of the chosen positive and negative movies were assessed using continuous ratings of valence, obtained in an independent sample of participants. Fifteen female students arrived to the lab to participate in a behavioral rating test. They were explained that the goal of the experiment is to assess momentary changes in their emotional experience while viewing movie excerpts. Following a short practice trial, the positive and the negative movies were presented in a random order. Participants continuously rated how positive or negative they have felt on a horizontal sliding valence scale, ranging from very negative to very positive. The scale was positioned at the bottom of the screen and allowed participants to update their affect ratings at any point by moving a visible marker with a mouse. A Matlab-based inhouse software was used to present the movies and collect ratings (2 Hz sampling rate) (for a similar method see Raz et al., 2012; Zaki, Bolger, & Ochner, 2009). Individual ratings are presented in Supplementary Fig. 1. As can be seen from the figure, raters showed substantial agreement among them (positive: \( r = 0.3 \pm 0.29 \); negative: \( 0.68 \pm 0.12 \)), providing further support for the existence of a common emotional timeline in the presented movies.

2.4. Procedure

Participants were introduced to the lab, connected to physiological sensors and sat quietly with their eyes open for five minutes while the physiological baseline measures were collected. After that, they participated in an implicit emotional experiment (similar to Van Reekum et al., 2011), lasting for ~15 min, during which they viewed emotional IAPS pictures (Lang, Bradley, & Cuthbert, 1999). This experiment was not part of the current study and is not reported here. Following a short rest, the participants viewed a positive and a negative movie. Each emotional movie was preceded by a ten seconds countdown screen and the order of the movies was counterbalanced across participants. Movies were presented using the Matlab’s Psychophysics Toolbox extensions, integrated with the physiological recording system. Following each movie, participants rated their emotional experience using self-report questionnaires. This procedure yielded physiological and facial measures from three experimental conditions: non-emotional physiological baseline (baseline), positive emotional movie (positive) and negative emotional movie (negative).

2.5. Measures

2.5.1. Behavioral measures

2.5.1.1. Self-reports of emotional experience. Participants rated the intensity to which they experienced distinct emotions (joy, warmth, fear, and distress), using a 9-point Likert scale. They also reported their level of arousal, positive valence and negative valence, using unipolar scales. The reports on the positive and negative items after viewing the positive and the negative movies, respectively, exhibited high levels of reliability (Positive movie: positive valence, joy, warmth – Cronbach’s \( \alpha = 0.88 \); Negative movie: negative valence, fear, distress - Cronbach's \( \alpha = 0.89 \)). We therefore combined them into two composite scores of positive and negative emotions.

2.5.1.2. Movies’ emotional time-lines. The movies’ emotional timelines were assessed using continuous ratings of valence in pre-test participants (\( N = 15 \), all females), as described above. This approach capitalizes on the fact that emotional movies elicit distinctive emotional timelines, which are commonly shared across participants, as shown both in previous research (Golland et al., 2014; Nummenmaa et al., 2012, 2014, 2017) and for the current raters. It thus allows to assess stimulus-response regularities, beyond individual differences in emotional responses. Since the majority of ratings during the positive movie were limited to the positive portion of the scale and those during the negative movie to the negative portion of the scale (Supplementary Fig. 1), individual ratings time-series were converted to unipolar positive and negative scores, respectively. Ratings obtained during the negative movie were further multiplied by \(-1\) to ease interpretation and comparisons. For further analysis, positive and negative emotional time-lines were computed by averaging individual ratings across participants for the positive and the negative movies (Fig. 1). Notably, the averaging procedure allowed for highlighting moments of common agreement among raters and diminishing the impact of individual differences in ratings.

2.5.2. Physiological measures

2.5.2.1. Collection. Continuous physiological measures were recorded with a Bionomadix (Biopac Systems Inc., Santa Barbara, CA) MP150 data acquisition system and Biopac’ AcqKnowledge 4.4 software at 1000 Hz sampling rate.

Facial electromyography (EMG) data from the zygomaticus major and corrugator supercilii sites were collected from the left facial sites in accordance with published guidelines (Fridlund & Cacioppo, 1986). The sensor regions were cleaned using 70% isopropyl alcohol, then slightly abraded using ELPREP skin preparation gel prior to sensor placement to reduce skin impedance to an acceptable level (below 20 kΩ). Raw EMG signals were filtered with a 50 Hz notch filter. Manual inspection for artifacts was made using custom software (Beniczky et al., 2013). All artifact-free data was subjected to a Fast Fourier Transform analysis to derive estimates of spectral power density (\( \mu V^2/Hz \)) in the 45–200 Hz frequency band in 1 s windows (Heller, Lapate, Mayer, & Davidson, 2014; Lapate et al., 2014; Van Reekum et al., 2011). Finally, the resulting values were log-transformed to normalize the data. This analysis yielded continuous 1 Hz EMGzyg and EMGcorr time-series. The first 20 s and the last 5 s were cropped from the resulting time series to remove non-specific accommodation effects and preprocessing artifacts.

For the mean level analysis, we computed reactivity scores by subtracting the mean activity of the immediately preceding countdown screen from the mean activity during each movie.

2.5.2.2. Slow trend removal. To examine the temporal resolution of facial EMG dynamics, we performed the analysis routines described below for the original time-courses and after removal of slow components. A slow trend was assessed by fitting a polynomial of 2nd degree to the original signal, using a ‘least-squared’ method via polyfit Matlab function (Barbosa, Barbosa-Filho, de Sá, Barbosa, & Nadal, 2014).
De-trending was done by subtracting the slow trend from the original data. De-trended EMG and emotional time-courses are shown in Supplementary Fig. 2.

2.5.2.3. Missing data. In the preprocessing stage, data was monitored for 1) low signal quality across conditions 2) excessive artifacts, such as multiple non-specific spikes or motion artifacts in specific conditions. The overall percent of missing data points for each channel was 18% for EMGZYG and 5% for EMGCORR. While analysis was always conducted on all available data points, the number of participants who had all measures in all experimental conditions was thirty-five.

2.6. Data analysis

2.6.1. Assessment of tonic component

We assessed tonic predominance in EMG signals by 1) computing autocorrelations for individual zygomatic and corrugator measures within each experimental condition and 2) quantifying the temporal lag at which signals’ autocorrelation drops to half (i.e. r = 0.5). Larger lags signify slower declines of autocorrelation, i.e. higher level of tonic component. The lag statistic was calculated across EMG sites and across experimental conditions. Physiological baseline condition was used to assess tonic predominance during a non-emotional time period.

2.6.2. Sliding windows cross-correlation approach

An assessment of temporal similarity between response time-courses is central to the current work. To assess temporal correspondence we applied a cross-correlation analysis, which provides a measure of similarity between two series as a function of temporal displacement of one relative to the other. This approach has allowed us to examine the cross-correlation functions for a typical form of interdependency, peaking around zero and subsiding as the time shift between signals increases. In addition, we validated that no consistent temporal shifts existed between the designated time-series, allowing to extract zero lag correlations as a reliable measure of temporal correspondence. Since the degree of temporal correspondence during fluctuating emotional state might vary in time, we applied a sliding windows approach, computing cross-correlations in short (30 s) partially overlapping (15 s) temporal windows. Notably, sliding windows approach does not assume stationarity of correlations in time (Boker, Rotondo, Xu, & King, 2002) and focuses on local temporal dynamics. As such it serves as a conservative estimate of correspondence between signals. The sliding windows cross-correlation approach was applied in reliability analysis and in correspondence with emotional timeline analysis, as specified below.

2.6.3. Assessment of EMG reliability through inter-subject correlation (interSC)

To assess the reliability (i.e. reproducibility) of EMG dynamics across participants, we employed inter-subject correlation measures (interSC), by quantifying similarity between individual responses and the average response pattern. The interSC approach was successfully used by us (Golland et al., 2007, 2014, 2017) and others (Hasson et al., 2010; Jääskeläinen et al., 2008; Nummenmaa et al., 2012, 2014; Trost et al., 2015) in previous studies investigating stimulus-driven temporal dynamics of physiological signals. Importantly, this approach does not assume a canonical response form, and thus accounts for the fact that response patterns can be specific to a given physiological channel and to a particular movie timeline.

All response time-courses were z-normalized and then divided into short (t = 30 s), partially overlapping (Δt = 15 s) time windows. For each participant j, within each temporal window t, we computed cross-correlation between x_j, the response time-course of participant j, and \[ x_j = \frac{1}{N-1} \sum_{i=1}^{N} x_t \], the response time-course averaged across all participants except j. Individual cross-correlation functions were then averaged across temporal windows. Performing the cross-correlation analysis on a variety of window sizes (ranging from 120 s to 6 s) allowed us to validate that the main results of the cross-correlation analysis are not distinctively dependent upon window size parameters (Supplementary Fig. 3).

For further statistical analyses, we extracted individual zero lag correlation values (hereafter, interSC) from these averaged cross-correlation functions. Individual interSC scores were used in analyses of variance, after applying r-to-z Fisher transformations. The above procedure has yielded interSC indexes for the zygomatic and corrugator measures (interSCZYG, interSCCORR), during three experimental conditions (baseline, positive, negative).

2.6.4. Temporal correspondence of EMG signals with the emotional timeline of the movies

To assess temporal correspondence of EMG dynamics with the movie-driven emotional dynamics, we computed similarity of individual EMG responses with dynamic ratings of valence. EMG response time-courses as well as valence time-courses were z-normalized and divided into short (t = 30 s), partially overlapping (Δt = 15 s) time windows. For each participant j, within each temporal window t, we computed cross-correlation between x_j, the response time-course of participant j, and \( \bar{v} \), the average valence time-course. The resulting cross-correlation functions were averaged across windows. Individual zero-lag correlations (EMG-valence correlations) were then extracted and r-to-z transformed. Using repeated measures ANOVAs, we compared the temporal correspondence of corrugator and zygomatic responses with the positive and the negative emotional timelines.

In addition to the group analysis, described above, we examined the statistical likelihood of individual EMG-valence correlations. To control for various factors (i.e. autocorrelations) which can significantly inflate correlation values, we conducted a non-parametric bootstrapping procedure. Specifically, we quantified control chance correlations for each individual subject by computing the above described EMG-valence correlations using emotional time-lines, in which temporal windows were shuffled in time. Experimental correlations signify correspondence with the presented emotional timeline. In contrast, control chance correlations signify spurious correlations with random emotional timelines with similar temporal characteristics. This procedure was performed for 1000 iterations, allowing to assess the statistical likelihood of obtaining experimental EMG-valence fluctuations by chance.

3. Results

3.1. Manipulation check: positive and negative movies elicited distinctive emotional and facial profiles

To validate that the presented emotional movies elicited distinctive emotional profiles, we conducted a repeated measures ANOVA on the reported scores of positive and negative valence. As expected, we found significant valence (positive, negative) by condition (positive movie, negative movie) interaction (F(1,47) = 575.8, p < 0.001). High levels of positive feelings (M = 6.7 ± 1.55) and low levels of negative feelings (M = 0.5 ± 1.1) was reported for the positive movie. High levels of negative feelings (M = 6.64 ± 1.59) and low levels of positive feelings (M = 0.75 ± 1.2) was reported for the negative movie. Positive movie elicited joy (M = 6.42 ± 1.43) and warmth (M = 6.13 ± 1.92), while negative movie elicited fear (M = 6.33 ± 1.93) and stress (M = 6.21 ± 2.03).

To validate that the presented emotional movies differentially affected the zygomatic and the corrugator activations, we conducted a repeated measures ANOVA on EMG reactivity scores and found an expected EMG site (zygomatic, corrugator) by condition (positive, negative) interaction (F(1,35) = 30.49, p < 0.001). EMGZYG was potentiated by the positive (M = 0.32 ± 0.73) movie and attenuated by the negative movie (M = −0.31 ± 0.52, p < 0.001), while EMGCORR
was higher during the negative (M = 0.33 ± 0.47) as compared to the positive movie (M = 0.02 ± 0.55, p < 0.001).

3.2. Temporal characteristics of the zygomatic and corrugator dynamics

Central to the present study, we assessed whether emotional movies elicited consistent EMG response patterns. Fig. 1A presents average zygomatic and corrugator response time-courses (upper panel) and dynamic ratings of valence (lower panel) for the emotional movies condition. As evident in the figure, zygomatic and corrugator dynamics showed profoundly different temporal response characteristics. The zygomatic activity evoked by the positive movie exhibited clear phasic modulations along the timeline of the movie. In contrast, the corrugator activity during the negative movie was predominantly tonic, showing slow increases as the movie progressed. To further explore the apparent discrepancy in the temporal characteristics of zygomatic and corrugator activity we computed autocorrelations for these signals (Fig. 1B), and assessed the autocorrelation width by calculating the temporal lag at which signals’ autocorrelation dropped to half (Fig. 1C). A larger width signifies slower declines of autocorrelation as a function of lag, i.e. higher level of slow tonic changes. Repeated measures ANOVA on the lag statistic with site (corrugator, zygomatic) and condition (baseline, positive, negative) factors, showed significant main effects of site (F(1,66) = 27.3, p < 0.001), experimental condition (F(2,66) = 18.66, p < 0.001) as well as site by condition interaction (F(2,66) = 11.3, p < 0.001). As can be seen in Fig. 1C, corrugator as compared to zygomatic responses contained more slow components across all conditions (all ps < 0.02). In addition, autocorrelation width of corrugator signals was significantly larger during the negative compared to the positive movie (t(41) = 4.83, p < 0.001), rising from 10.5 ± 9.4 s to 23.7 ± 20.8 s, suggesting that tonic increases in corrugator activity are linked with increases in negative affect. No such pattern was evident for the zygomatic autocorrelation width which wasn’t different between the positive (6.5 ± 2.7) and the negative (5.7 ± 4.6) movies (p > 0.5).

3.3. Across-subjects reliability of EMG dynamics

To assess whether emotional movies elicited reliable EMG dynamics, which were time-locked across participants, we employed the inter-subject correlation (interSC) analysis. The interSC approach assesses the extent to which the same response pattern is reliably observed across all participants, by quantifying similarity between individual responses and the average response pattern (Methods). Fig. 2A presents average cross-correlation functions, as well as zero lag correlations (interSCs) for the zygomatic (left panel) and the corrugator (right panel) responses. As can be seen in the figure, the zygomatic cross-correlation during the positive, but not during the negative movie or baseline, exhibited the typical interdependency form, peaking around lag zero and subsiding as the temporal lags increased. As for the corrugator, cross-correlation was highest during the negative movie and lowest during baseline. Descriptive statistics for the interSC scores are presented in Table 1.

Repeated measures ANOVAs on the interSC scores, revealed a significant effect of condition both for the zygomatic (F(2,66) = 84.8, p < 0.001) and for the corrugator (F(2,66) = 18.8, p < 0.001) indexes. Post-hoc analyses showed clear affective patterns in the zygomatic and corrugator dynamics. The reliability of zygomatic responses (interSCZYG) was significantly larger during the positive movie compared to both negative movie and baseline (all ps < 0.001), which were not significantly different. The reliability of corrugator responses (interSCCORR) was highest during the negative movie and lowest during baseline with significant differences among all three conditions (all ps < 0.001).

We next asked whether the above affective profiles persist for phasic EMG dynamics, after a removal of slow components from EMG signals. We repeated the interSC analysis for the de-trended EMG signals (Supplementary Fig. 2). InterSCs for the de-trended signals are presented in Fig. 2A (dashed bars). As can be seen in the figure, removal of slow components did not affect neither the degree (all ps > 0.25) nor the affect-specificity of zygomatic dynamics, which still yielded higher interSC during the positive, as compared to the negative movie (t(35) = 10, p < 0.001). In contrast, it significantly reduced the interSCs of the corrugator signals across conditions (F(1, 38) = 29.3, p < 0.001). Both positive and negative movies elicited significantly higher corrugator interSCs as compared to non-emotional baseline (ps < 0.001). However, de-trending disrupted the corrugator’s specificity for negative affect, as interSCCORR during the negative movie (r = 0.22 ± 0.16) was now lower than the interSCCORR during the positive movie, at marginally significant level (t(41) = 1.9, p = 0.061). Taken together, the above analyses demonstrate that transient fluctuations in zygomatic EMG were reliably controlled by the positive movie. Zygomatic reliability (i.e. interSC) was specific to the positive condition and was driven by phasic response modulations. The reliability of corrugator EMG fluctuations was higher during the negative movie but was significant during the positive movie as well. An enhancement of corrugator reliability by negative emotions was exclusively driven by tonic modulations during the negative movie. A removal of slow changes from the corrugator responses resulted in significant drop of interSCs in general and lower interSC scores during the negative as compared to the positive condition.

3.4. Controlling for facial mimicry

The emotional movies used here involved human protagonists, which are known to elicit strong emotional states in observers (Codispoti et al., 2008; Hess et al., 1995; Kreibig et al., 2007; Wilhelm et al., 2017). It could be suggested that protagonists’ facial expressions
elicited facial mimicry (Dimberg, Thunberg, & Elmehed, 2000; Hess & Bourgeois, 2010; Sato et al., 2013), hence biasing the results of EMG interSC analysis. To control for the effects of facial mimicry we coded the movie times in which positive and negative facial expressions were clearly evident in the positive and the negative movies, respectively. We then conducted the interSC analysis in narrow temporal windows (window size = 10 s, overlap = 5 s) and computed average interSC scores, limiting the computation to the temporal windows which didn’t include vivid emotional expressions (Supplementary Fig. 4 presents the full details of facial exclusion analysis). The analysis was done for the de-trended EMG signals, focusing on the reliability of phasic responses. The results demonstrated that the affective profiles of EMG dynamics were not exclusively driven by facial mimicry, since a removal of facial expressions didn’t modify the interSC patterns observed for the full movies’ timelines. Specifically, the zygomatic interSC was significantly higher during the positive (M = 0.47 ± 0.28) as compared to the negative movie (M = 0.12 ± 0.11, t(35) = 6.8, p < 0.001). The corrugator interSC was still lower during the negative movie (M = 0.17 ± 0.13) as compared to the positive movie (M = 0.36 ± 0.31, t(41) = 3.33, p < 0.002).

3.5. Association with subjective ratings

We assessed whether individual differences in average interSC scores were associated with subjective emotional ratings, reported by participants, showing negligible or even negative correlations. This association was found for the original (p < 0.02) but not for the de-trended (p = 0.36) corrugator measures. No consistent associations were found between the corrugator reliability indexes and negative feelings.

Table 1
Upper part presents descriptive statistics for the interSC scores in each experimental condition.

<table>
<thead>
<tr>
<th></th>
<th>Original signals</th>
<th>De-trended signals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>baseline</td>
<td>positive</td>
</tr>
<tr>
<td></td>
<td>baseline</td>
<td>positive</td>
</tr>
<tr>
<td>InterSC_{ZYG}</td>
<td>0.03 ± 0.13</td>
<td>0.5 ± 0.20</td>
</tr>
<tr>
<td></td>
<td>0.52 ± 0.20</td>
<td>0.13 ± 0.10</td>
</tr>
<tr>
<td>InterSC_{CORR}</td>
<td>0.11 ± 0.2</td>
<td>0.4 ± 0.38</td>
</tr>
<tr>
<td></td>
<td>0.81 ± 0.14</td>
<td>0.31 ± 0.28</td>
</tr>
</tbody>
</table>

Correlation with subjective emotional ratings

<table>
<thead>
<tr>
<th></th>
<th>baseline</th>
<th>positive</th>
<th>negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>InterSC_{ZYG}</td>
<td>0.42 (0.008)</td>
<td>0.26 (0.11)</td>
<td>0.46 (0.003)</td>
</tr>
<tr>
<td></td>
<td>−0.34 (0.02)</td>
<td>−0.13 (0.42)</td>
<td>−0.14 (0.36)</td>
</tr>
</tbody>
</table>

Zygomatic correspondence with valence was different for the positive and the negative movies (t(35) = 4.2, p < 0.001), showing significant positive correlations with positive emotional fluctuations (t(35) = 5.8, p < 0.001) but not with the negative ones (t(35) = −0.7, p > 0.25). Corrugator correspondence showed a complementary pattern (t(41) = −3.47, p < 0.001), demonstrating high positive correlation with fluctuations of negative (t(41) = 7.02, p < 0.001) but not positive affect (t(41) = 1.1, p > 0.25).

We next examined whether a removal of tonic components from EMG dynamics modified its alignment with emotional fluctuations (Supplementary Fig. 2 presents the de-trended signals). De-trending had profoundly different impact on the zygomatic and corrugator correspondence (Fig. 3B, dashed bars, Table 2). The zygomatic correspondence with positive emotional fluctuations wasn’t modified by de-trending (t(35) = −1.62, p = 0.113), and was still higher than its correspondence with negative affect (t(35) = 5.9, p < 0.001). In contrast, de-trending significantly modified corrugator’s correspondence with both emotional timelines. First, it significantly reduced corrugator’s correspondence with negative emotional fluctuations (t(41) = 5.1, p < 0.001). Second, it revealed a negative correspondence with positive emotional fluctuations, which was significantly different from zero (t(41) = −4.53, p < 0.001).

Taken together, these results suggest that continuous changes in emotional experience elicited corresponding fluctuations in EMG dynamics. Zygomatic activity was time-locked to the positive emotional timeline and this correspondence was driven by phasic fluctuations. In contrast, corrugator’s coupling with negative emotional timeline unfolded at a slower temporal scale, such that gradual changes in negativity elicited tonic changes in corrugator activity. Furthermore, transient corrugator fluctuations were inversely correlated with changes in positive affect, during the unfolding of the positive movie.

3.7. Individual differences in EMG-valence correspondence

The above analysis suggested that the coordination of phasic corrugator activity with transient changes in negative affect is diminished. However, such group-level lack of correspondence might be driven by a subset of participants, showing negligible or even negative correlations with fluctuations of negative affect. To examine this possibility, we assessed the distribution of individual EMG-valence correlations, and computed their statistical significance, using non-parametric bootstrapping procedure (Methods). Fig. 4A presents the individual EMG-valence correlations, ranked ordered within each experimental condition and marked for statistical significance. As can be seen in the figure, this analysis revealed substantial sub-groups in EMG response patterns. Descriptive statistics of EMG-valence subgroups are presented in Table 3.

Individual zygomatic responses evidenced highly consistent temporal correspondence with positive affect fluctuations, with 86% of participants exhibiting significant EMG-valence correlations during the positive movie. Interestingly, a sub-group of participants (36%) also
showed positive correspondence with negative valence fluctuations during the negative movie. In sum, individual level analysis of zygomatic measures confirmed the group-level results showing consistent zygomatic correspondence with positive valence for the majority of participants and extended them to show significant zygomatic correlations with positive valence in a subset of sample participants.

Individual corrugator correlations exhibited substantial individual variability, with 40% of participants showing significant positive correlations with phasic fluctuations of positive affect and only 9% showing positive corrugator-valence correlations. In sum, individual level analysis of corrugator correspondence with emotional fluctuations confirmed the consistent inhibitory effect of positive affect fluctuations on corrugator responses, which was evident in the larger portion of our sample. It also shed additional light on the apparent lack of corrugator correspondence with negative valence, showing that 40% of our sample did show such correspondence while the remaining part didn’t.

4. Discussion

The main goal of the present work was to investigate facial EMG dynamics during continuously unfolding emotional experiences. Our results indicated that zygomatic and corrugator dynamics exhibited clearly distinctive affective profiles as well as different temporal characteristics.

4.1. Affect dynamics in the zygomatic response system

The dynamics of EMG activity measured over zygomaticus major facial area showed robust links with positive affect. First, the positive movie elicited reliable zygomatic fluctuations, which were time-locked across participants. Individual differences in such response reliability were associated with the intensity of reported positive experience. Second, transient zygomatic fluctuations were significantly coupled with changes in positive affect as the movie unfolded, and such coupling was significant in the majority of sample participants. Taken
Dynamic ratings of valence.

Activity and these experience elicited corresponding phasic groups larger than 20% of the sample.

Table presents the number and the proportion of sample participants showing significant positive and negative correspondence with dynamic ratings of valence.

<table>
<thead>
<tr>
<th></th>
<th>Positive Movie</th>
<th>Negative Movie</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>correlation</td>
<td>correlation</td>
</tr>
<tr>
<td>Zygomatic EMG</td>
<td>31 (86.1%)</td>
<td>1 (2.8%)</td>
</tr>
<tr>
<td>Corrugator EMG</td>
<td>0.3 ± 0.1</td>
<td>0.23 ± 0.06</td>
</tr>
<tr>
<td>EMG&lt;sub&gt;zyc&lt;/sub&gt;-valence</td>
<td>4 (9.5%)</td>
<td>25 (59.5%)</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>0.25 ± 0.09</td>
</tr>
</tbody>
</table>

Table 3: Sub-groups showing significant positive and negative correspondence with dynamic ratings of valence.

Together, these results demonstrate that momentary changes in positive experience elicited corresponding phasic fluctuations in zygomatic activity and these fluctuations were similar across participants. Our results extend the previous findings on affective zygomatic profile (Larsen et al., 2003, Bradley & Lang, 2000; Lang et al., 1993) to dynamic measures, showing that transient zygomatic fluctuations systematically reflect the unfolding of positive emotions over time. Notably, while negative emotional experience didn’t elicit consistent zygomatic response patterns at the group-level, thirty percent of participants showed significant zygomatic alignment with negative affect fluctuations. These findings come in line with previous research showing zygomatic activation during extremely negative emotional stimuli (Lang et al., 1993; Larsen et al., 2003). They further highlight the importance of individual differences in facial expressions.

The robust reliability and affect specificity of transient zygomatic fluctuations suggest that this response system can provide a viable physiological measure of positive affective dynamics during complex emotional experiences. Given the important role played both by positive affect and by emotional dynamics in psychological well-being and psychopathology (Fredrickson & Losada, 2005; Houben, Van Den Noortgate, & Kuppens, 2015, 2015; Kuppens, Stouten, & Mesquita, 2009; Wichers, Wigman, & Myin-Germeys, 2015), dynamic measures of zygomatic EMG hold a potential to significantly advance the understanding of temporal regularities and individual differences in positive affect dynamics.

4.2. Affect dynamics in the corrugator response system

The dynamics of EMG activity measured over corrugator supercillii showed a broader affective profile. Corrugator activity exhibited highest reliability during the negative movie. Furthermore, it was temporally aligned with slow changes in emotional negativity, hence demonstrating the links of corrugator dynamics with negative affect.

In addition, corrugator activity evidenced a substantial reliability during the positive movie as compared to the resting baseline. Previous studies have suggested that corrugator responses are systematically attenuated by positive emotional events (Lang et al., 1993; Lapate et al., 2014; Larsen et al., 2003). In particular, Larsen and colleagues have demonstrated a linear effect of positive valence on event-related corrugator de-activations. Our results fully replicate this previous research and extend it to temporal emotional processes. Specifically, we found that phasic fluctuations of corrugator activity during the positive movie were both reliable and inversely correlated with the fluctuations of positive affect. In other words, the ups and downs of positive affect exerted dynamic cycles of inhibition and recovery upon corrugator responses, leading to a significant time-lock across participants. Such inverse correlation with positive affect was evident in sixty percent of our sample participants.

Taken together, these results suggest that in contrast to zygomatic activity, which was narrowly tuned to positive affect dynamics, the activity of corrugator facial muscles was driven by tonic increases in emotional negativity as well as by inhibitory phasic effects of positive affect.
affect dynamics.

4.3. Temporal characteristics of the corrugator and the zygomatic responses

Emotional processes can unfold over different timescales, including transient responses to specific events alongside more gradual dynamics reflecting tonic affective processes. Systematic investigation of the temporal response characteristics, undertaken in this work, revealed profound differences in the temporal resolution of the zygomatic and the corrugator affective dynamics.

Zygomatic responses elicited by the positive movie exhibited clear phasic modulations which evolved over seconds. These transient modulations were coupled with momentary changes in positive affect elicited by the unfolding of the movie. These findings suggest that zygomaticus major is a phasic response system reflecting transient changes in individuals’ positive feelings and expressions. The phasic capabilities of the zygomatic system resonate with the profound communicative function of positive facial expressions, which signal social intents to others (Fischer & Manstead, 2008; Fridlund, 1991; Frijda & Mesquita, 1994; Hess et al., 1995). Since abrupt perceptual changes are better detected than gradual ones (David, Lalouy, Devue, & Cleeremans, 2006; Simons & Rensink, 2005), the prominence of phasic responses in zygomatic activity, might be beneficial for a swift detection of positive facial responses by social environment. Indeed, happy facial expressions are faster detected and more accurately recognized in comparison to other emotions (Ambadar, Schooler, & Cohn, 2005; Calvo & Lundqvist, 2008). Moreover, such superiority is driven by the mouth region, due to its saliency and diagnostic value (Calvo & Nummenmaa, 2008; Calvo, Nummenmaa, & Avero, 2010; Calvo, Fernández-Martín, & Nummenmaa, 2014).

In comparison with the zygomatic responses, corrugator dynamics demonstrated clear susceptibility to tonic increases across all experimental conditions, including non-emotional baseline. Previous research has suggested that beyond its affective properties, corrugator responses are influenced by such factors as cognitive effort and goal conduciveness (Aue & Scherer, 2008; Kappas, 2003), which might underlie the overall propensity of corrugator responses to tonic changes observed in the current study. Our results also showed tonic effects which were specific to negative affect. Thus, during the negative movie, corrugator’s tonic modulations were particularly pronounced and coordinated with the movie-driven changes of negativity. These results highlight the need to carefully differentiate between affect-driven tonic corrugator responses and drifts arising from non-affective sources in future research of facial affect dynamics. In addition, further research is needed to understand whether the observed differences in corrugator and zygomatic susceptibility to tonic modulations is grounded in the physiology of this responses system or is carved by higher-order factors, such as display rules or social functions.

4.4. Phasic corrugator dynamics during negative emotional experience

The analysis of phasic corrugator dynamics evidenced a complex picture. First, while the reliability of phasic corrugator responses during the negative movie was significant, it was somewhat lower as compared to the positive movie. Second, corrugator responses showed diminished correspondence with transient changes in negative affect. Taken together, these findings could suggest that phasic corrugator responses exhibited impoverished representation of transient changes in negative emotional experience. As such, they come at odds with previous research showing linear effects of valence on corrugator activation (Larsen et al., 2003). However, assessment of individual differences in corrugator correspondence with valence dynamics shed additional light on these findings. Specifically, we found that forty percent of participants exhibited significant positive correlations with transient fluctuations of negative affect while the remaining of sample didn’t. Thus, rather than showing a generally reduced correspondence with negative emotional fluctuations, corrugator activity evidenced a substantial inter-subject variability in such correspondence.

Given that the negative movie used in the current study elicited strong feelings of fear, several plausible explanations of the observed variability in corrugator responses can be suggested. First, people may vary in the degree to which their corrugator muscles are involved in a manifestation of transient fear dynamics. Notably, the frowning expression, subserved by the corrugator activation, is only one of the facial features representing the prototypical configuration of fear (Friesen & Ekman, 1978). Accordingly, different individuals may enact fearful expressions via different facial muscles. In support, studies investigating spontaneous facial responses have reported significant variability among individuals in the facial expressions of negative emotions (Duran et al., 2017; Fernandez-Dols et al., 1997; Namba, Kabir, Miyatani, & Nakao, 2017; Reisizen et al., 2013). Moreover, a study focusing on the dynamics of prototypical facial expressions didn’t find frowning among facial configurations characterizing the apex of fear (Krumhuber & Scherer, 2011). Second, highly negative scenes in the movie could have elicited other subjective feelings, such as contempt, anger or surprise, hence increasing facial variability. Finally, previous research employing the same negative movie (Golland et al., 2014) has shown that its high negative scenes were marked by autonomic arousal. While negative arousal could have significantly shaped the subjective ratings, corrugator responses are weakly associated with the arousal dimension (Lang et al., 1993; Sato et al., 2013; Tan et al., 2012). Taken together, the above scenarios highlight the complexity of factors potentially affecting spontaneous facial responses during emotional experiences. In particular, they suggest that future studies of facial affective dynamics can benefit from combining both dimensional (such as valence) and categorical (such as fear, disgust) measures of emotions.

4.5. Limitations

The current research taps into a largely uncharted territory of the facial production dynamics (Scherer, Mortillaro, & Mehu, 2013). While it revealed a series of novel results, their generalizability should be taken with caution and awaits future replications, accounting for the methodological limitations of the present study. First, we employed physiological baseline measures to approximate an emotionally neutral condition. However, several non-emotional factors could potentially impact the observed differences, including timing of measurement and demand characteristics. Neutral movies, presented together with emotional ones, should be used as a control condition in future studies. Second, due to methodological constraints, the current study was based on female participants. Since gender differences might play a significant role in emotional responding (Codispoti et al., 2008; Dimberg & Lundqvist, 1990; Hall, Carter, & Horgan, 2000), it is necessary to replicate current results in mixed gender samples. Third, an employment of a broader range of emotional stimuli can significantly improve the generalizability of current findings. Here we found that fear inducing film elicited substantial variability in corrugator response patterns. Whether such variability exists for other negative emotions, such as anger and sadness, remains to be uncovered. In addition, future research should control for the effects of facial mimicry on EMG dynamics. The emotional states of other people elicit powerful emotional states in observers, and are thus frequently employed as emotional elicitors in facial research, including the current one (Codispoti et al., 2008; Hess et al., 1995; Kreibig et al., 2007; Wilhelm et al., 2017). However, such strategy hinders the interpretation of results, which reflect both emotional and social processes. While it might be challenging to elicit powerful phasic modulations of affect without employing human protagonists, such an effort should be made, to differentiate between these two processes. Finally, in the current research we employed a between-subjects approach, asking whether facial dynamics are consistently modulated by the emotional timelines of the movies.
above and beyond individual differences. However, given the variabil-
ity in emotional responding (Stemmler & Wacker, 2010) as well as
individual differences in corrugator dynamics observed in the current
study, within-subject measures of facial and subjective emotional
fluctuations (Mauss et al., 2005) may be essential to fully uncover the
degree to which facial dynamics reflect subjective feelings.

4.6. Conclusions

Using continuous measures of facial EMG we demonstrated that
fluctuations of facial activity, elicited by naturally unfolding emotional
experiences, exhibit consistent, affect specific temporal response pat-
terns. Across analyses, transient zygomatic dynamics were narrowly
tuned to positive emotional experiences. A subset of participants also
showed consistent zygomatic correlations with fluctuations of negative
affect. The corrugator responses showed a clear susceptibility to tonic
changes. Overall, corrugator dynamics showed temporal alignment with
slow changes in emotional negativity and inverse correlation to
phasic changes in positive affect. Corrugator’s correspondence with
transient fluctuations of negative affect showed substantial differences
between participants. Taken together, the findings and the methodo-
logical approach employed in the current research open novel possi-
bilities for studying the involvement of facial response system in
dynamic processes of affect generation, expression and communication.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the
003.

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