Using facial EMG to track emotion during language comprehension: past, present, and future

Jos J.A. van Berkum[1], Marijn Struiksma[1] & Björn 't Hart[1]
[1] Utrecht Institute of Linguistics OTS, Utrecht University, Utrecht, The Netherlands

Correspondence: Prof. Dr. Jos J.A. van Berkum, UiL OTS, Utrecht University,
Trans 10, 3512 JK Utrecht, The Netherlands   j.vanberkum@uu.nl

Abstract

Beyond recognizing words, parsing sentences, building situation models, and other cognitive accomplishments, language comprehension always involves some degree of emotion too, with or without awareness. Language excites, bores, or otherwise moves us, and studying how it does so is crucial. This chapter examines the potential of facial electromyography (EMG) to study language-elicited emotion. After discussing the limitations of self-report measures, we examine various other tools to tap into emotion, and then zoom in on the electro-physiological recording of facial muscle activity. Surveying psycholinguistics, communication science, and other fields, we provide an exhaustive qualitative review of the relevant facial EMG research to date, exploring 55 affective comprehension experiments with single words, phrases, sentences, or larger pieces of discourse. We discuss the outcomes of this research, and evaluate the various practices, biases, and omissions in the field. We also present the *fALC* model, a new conceptual model that lays out the various potential sources of facial EMG activity during language comprehension. Our review suggests that facial EMG recording is a powerful tool for exploring the conscious as well as unconscious aspects of affective language comprehension. However, we also think it is time to take on a bit more complexity in this research field, by for example considering the possibility that multiple active generators can simultaneously contribute to an emotional facial expression, by studying how the communicator's stance and social intention can give rise to emotion, and by studying facial expressions not just as indexes of inner states, but also as social tools that enrich everyday verbal interactions.

Table of contents

1. INTRODUCTION

One of the most interesting features of us humans is that we can communicate through language. We do so seemingly effortlessly, for many, many hours a day, as we for example engage in conversation, check our social media, read a book, or listen to the news. The speed of language processing is astounding, with an average reading speed of 3-5 words per second for adults, depending on the language at hand (1), and an estimated average speaking -- and hence also listening -- speed that is only slightly lower and that can go up dramatically, depending on circumstances (2). Psycholinguists interested in language comprehension have long realized that to understand this rapid and intricately orchestrated skill, they need measures that can keep track of reading or listening as language input unfolds. It is for this reason that the research field makes heavy use of temporally sensitive measures like self-paced reading, eye tracking, electroencephalography (EEG), and magnetoencephalography (MEG).

The use of such measures has contributed a lot to our understanding of the many cognitive aspects of language comprehension that psycholinguistics has traditionally been interested in, like word recognition, syntactic parsing, or situation model construction (see 3, 4, 5, and this volume, for reviews). However, language researchers have recently also begun to ask questions about the relationship between language and emotion (e.g., 6, 7, 8, 9, 10, 11, 12, 13, 14). This new focus in language research raises an important question: what measurement tools should we use to keep track of the *emotional* aspects of language comprehension as the words are coming in? How can we measure, during reading or listening, the emotional impact of, say, a piece of gossip, a good joke, a political slogan, a medical information leaflet, or an engaging bit of narrative fiction?

In this chapter, we address exactly this question. After examining the various options for measuring emotion during language comprehension, we focus on one particularly promising method: facial electromyography, the electrophysiological recording of facial muscle activation. We explain the method, provide an exhaustive review of the language-relevant facial EMG research to date, present a conceptual model for future EMG research in this domain, and discuss the challenges and opportunities ahead. Our focus in all of this will be largely conceptual, for a methods-oriented review of facial electromyography in the language sciences and beyond, see 42 in this volume.

2. MEASURING EMOTION

2.1 Why self-report is not enough

At first sight, emotion seems to be about how people *feel*. Emotion is therefore often measured by asking people about this conscious experience, either via an open-ended "how do you feel" question, or, more commonly, via a constrained self-report format. For example, researchers can ask participants in their study to rate the presence and intensity of specific emotions, such as joy, shame, or compassion (e.g., via the Geneva Emotion Wheel, 15). They can also ask participants to rate their conscious experience on one or more emotion-relevant dimensions. An often used dimension is

subjective valence, the degree to which the emotion, or the elicitor of that experience, is experienced as positive or negative (cf. the smiley-based valence scale used to assess customer satisfaction). Ratings can also be collected on two orthogonal dimensions, often crossing subjective valence and subjective arousal, the experienced degree of bodily activation (e.g., SAM, 16), but sometimes also crossing experienced positivity and experienced negativity (the Affect Matrix, 17). Furthermore, researchers can systematically ask people to report on various other things, such as what triggered the emotion (18), or the amount of activity they feel in different parts of the body (19).

These various self-report methods can all help explore how people feel. However, they are not particularly useful for tracking emotion *as linguistic input unfolds*, for two very different reasons. On the practical side, researchers simply cannot ask for a self-report at each word or sentence, at least not without seriously disrupting the processes under study. The second and much more fundamental reason is that, just like with other domains of the human mind, many aspects of emotion are simply inaccessible to consciousness, at least initially (13, 20, 21, 22, 23, 24). In everyday life, people use the terms "emotion" and "feeling" in interchangeable ways. However, research has shown that emotion can sometimes do all of its work 'behind the scenes', nudging us without us being aware of the stimulus or of what it brings about (e.g., 25, 26). Furthermore, even in the case where conscious experience or "feeling" does arise, there is a lot more to the emotion at hand than what people have conscious access to -- feeling is usually just the tip of the iceberg, and important motivational, cognitive, physiological and expressive aspects of an emotion will inevitably escape self-report. How to tap into those?

Motivational and cognitive aspects. Because emotions always come with particular motivations ('action tendencies', 27), and can also for example affect the speed and focus of cognitive processing (e.g., via emotion-induced attention), familiar behavioral measures developed within cognitive psychology and psycholinguistics, such as two-choice response time, self-paced reading and eye tracking can in principle be used to pick up on these aspects of language-induced emotion, independent of whether those are accessible to consciousness or not. For example, it is possible to detect very subtle approach or avoidance tendencies when reading words with strong positive or negative valence (28, 29). Also, because motivational and cognitive aspects of emotion require neural computation, brain measures such as EEG, MEG and fMRI can also help track these aspects of emotional responding during language processing, independent of whether people are aware of them or not (e.g., 30; see 31 and 7 for reviews).

Physiological and expressive aspects. One highly convenient feature of emotions, however, is that they are "fundamentally embodied" (32), or, more poetically, "play out in the theatre of the body" (33), in two interesting ways. First, because emotions usually prepare the body to act (e.g., to approach or avoid, to explore, embrace, or hide), they come with various rapid physiological changes that prepare for and support the intended actions, such as changes in heart rate, sweating, or hormone levels. Although brain measures might be able to pick up on the neural control or neural feedback associated with these physiological changes, the changes themselves can be measured as well (see 34, for a review of the utility of recording cardiovascular, respiratory, skin conductance, and other physiological parameters). And they can be measured not just when actually facing, say, a hairy spider, or a loved one, but also when *reading or hearing* about them (e.g., 35; see 36 and 37 for reviews).

Second, emotions are often expressed in the face, in the voice, and in the movements or posture of the rest of the body (see 38 for review), sometimes deliberately, and sometimes involuntarily. Such expressions probabilistically inform others about how we evaluate things and what state we are in, as well as about what we might do, right now, or in the future (39, 40). Responding to an insult with an angry face and voice, for example, informs the offender and/or others that we probably dislike seeing our rights or properties infringed upon, that we may well strike back in some way or the other, and that it is therefore probably wise to back off. Responding to a sad story of a friend with a compassionate face and voice tells him or her that we are probably concerned with his or her fate, and that we might well be willing to help. And responding to a mistake with a facial expression and posture of embarrassment or shame informs others that we probably agree we messed up, feel bad about it, and are somehow committed to not let it happen again. Although the specific ingredients of emotional expressions need not all have evolved for communication originally (41; see also 42), it is clear that like other primates, we express our emotions to others, and that doing so plays a crucial role in solving the many problems of social life (43). Again, brain measures might be able to pick up on the required neural control. But just like the physiological embodiment of emotion, the expressive embodiment itself can also be measured. One way to do so is by recording facial EMG.

2.2 Measuring emotion via facial electromyography
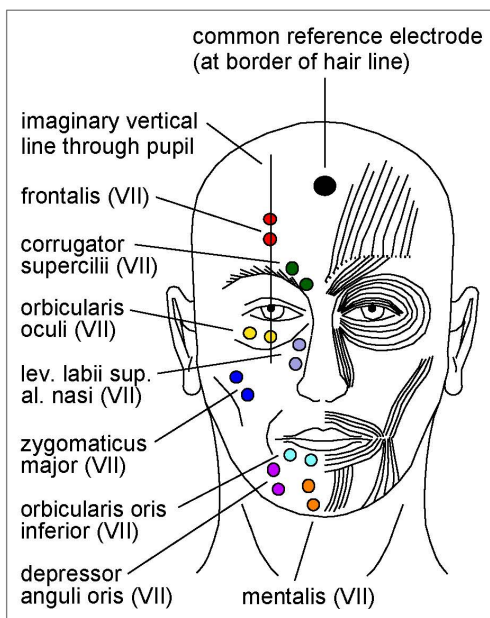
Facial expressions are generated by contracting and/or relaxing specific subsets of the ~30 muscles in the human face. Facial muscles are not only involved in expressing emotion, but also needed for other things, such as eating and drinking, improving visual acuity, and speaking. During non-invasive facial electromyography, all such emotional and/or non-emotional facial activity can be recorded with high temporal resolution, by means of small electrodes attached to the skin over particular target muscles. Figure 1 displays standard electrode positions for recording EMG from specific facial muscles, including, for example, the corrugator supercilii (involved in frowning), the levator labii superioris (involved in wrinkling the nose to express disgust), and the zygomaticus major and orbicularis oculi (involved in smiling; see 44, 42, 45).

Figure 1: EMG electrode locations for measuring activity in several muscles that play a role in facial expressions. Figure courtesy of Anton van Boxtel (see also 44).

Facial EMG has been used to study many things, including the facial correlates of physical and cognitive effort (e.g., 46, 47, 48, 49), and the patterns of lip movement during articulation (e.g., 50, 51). However, building on earlier work that used facial EMG to track covert articulation during reading, Schwartz and colleagues (e.g., 52) were the first to use EMG to keep track of *emotion*: when participants were asked to imagine happy, sad, and angry situations, the researchers observed increased corrugator activity during sad and angry emotional imagery as well as decreased corrugator

activity during happy emotional imagery. Importantly, Schwartz and colleagues also videotaped the participants while they were engaging in emotional imagery, and reported that the patterns of activity recorded via EMG "were not readily detected on the overt face". In line with physiological knowledge about the imperfect coupling of facial muscle activation and visible skin movement (see 53), this showed that facial EMG can track very subtle, non-overt changes in emotional state.

Following up on this clinical work, Cacioppo and Petty (54) pioneered the use of facial EMG to track emotional state in a *verbal communication* setting, as part of a larger social-psychological research program that explored attitude-relevant processing. In the critical study (experiment 2), undergraduate participants listened to pro- and counter-attitudinal messages (e.g., on alcohol use) while EMG was recorded over the corrugator to assess the degree of frowning, and over the zygomaticus and depressor anguli oris (upper and lower cheek muscles) to assess the degree of smiling (to track covert pronunciation, the mentalis also was recorded). In contrast to Schwartz et al. (52), who related their EMG findings to specific emotions, Cacioppo and Petty looked for EMG traces of emotional *valence*, the degree to which different stimuli elicited positive or negative emotion (which participants may or may not be aware of). Their results suggested that both the corrugator and the zygomaticus were sensitive to message valence, in the expected direction: increased corrugator activity to negative stimuli, and increased zygomaticus activity to positive stimuli. Several follow-up studies confirmed that facial EMG over these and other facial muscles could help assess the valence of language-induced emotional states, and do so even when no overt changes were visible in the face (see 55 for review). As such, this early work paved the way for other attempts to track language-elicited emotion by means of facial EMG. In the next section, we review that work.

3. A REVIEW OF FACIAL EMG RESEARCH ON AFFECTIVE LANGUAGE COMPREHENSION

To explore the potential of facial EMG for our purpose, comprehension studies that explicitly asked about the language-emotion interface *within the field of psycholinguistics* are obviously relevant. However, as illustrated by the pioneering work by Cacioppo and Petty (54), psychologists interested in the neighboring field of *communication* have also been using facial EMG to track emotion to language, albeit without foregrounding a language processing question. We therefore queried the literature to find emotion-oriented facial EMG-research with a psycholinguistic *or* (verbal) communication focus.[1] Our interest was in examining the types of questions addressed, the procedures by which they were addressed (e.g., which electrodes were measured, and why), and the characteristic findings obtained. As can be seen in Table 1, our literature query turned up 55 experiments reported in 50 publications,

---

[1] Psycholinguistically framed research was obtained by querying Scopus with:

TITLE-ABS-KEY (language OR discourse OR text OR story OR stories OR narrative OR conversation OR sentence OR phrase OR word OR lexical OR speech OR prosody) AND

TITLE-ABS-KEY (comprehension OR recognition OR perception OR interpretation OR reception OR processing) AND

TITLE-ABS-KEY ("facial EMG" OR electromyography OR zygomaticus OR corrugator OR frontalis OR levator OR orbicularis OR depressor OR mentalis) AND

TITLE-ABS-KEY (emotion OR valence OR affect OR sentiment)

Research on communication was obtained by querying Scopus with:

TITLE-ABS-KEY (communication) AND

TITLE-ABS-KEY ("facial EMG" OR electromyography OR zygomaticus OR corrugator OR frontalis OR levator OR orbicularis OR depressor OR mentalis) AND

TITLE-ABS-KEY (emotion OR valence OR affect OR sentiment)

The resulting entries were screened for whether they explored facial EMG responses to emotionally relevant linguistic stimuli presented to non-impaired adult participants, and complemented with ad-hoc leads derived from the obtained papers that also passed the above screening. All queries were conducted on May 4, 2019, without setting any date ranges.

mostly in journal articles, but also, occasionally, in published dissertations. We grouped these experiments on the basis of whether they involved single isolated words, phrases and sentences, or multi-sentence discourse -- a standard psycholinguistic criterion that is convenient for now, but to which we will briefly return later.

Table 1: The 55 EMG-studies discussed in our literature review, with, for each study, whether the corrugator supercilii (CS) and zygomaticus major (ZM) was sensitive to a language-driven emotion manipulation (yes, no, undecidable, or not measured/evaluated (-)), whether one of the two muscles was sensitive while the other was not (CS>ZM: CS sensitive, ZM not sensitive; CS<ZM: CS not sensitive, ZM sensitive; CS=ZM: CS and ZM both sensitive, or both not sensitive), and whether any other facial muscles were recorded from. The undecidable case is a study that used a CS-ZM composite measure.

Study	CS emotion-sensitive?	ZM emotion-sensitive?	Comparison	Recorded other muscles
Arias, Belin, & Aucouturier (2018)	yes	yes	*CS=ZM*	
Arndt, Allen, & Greenberg (2001)	yes	-		
Bartholow, Fabiani, Gratton, & Bettencourt (2001)	yes	-		
Baumeister, Foroni, Conrad, Rumiati, & Winkielman (2017)	yes	yes	*CS=ZM*	
Bayer, Sommer, & Schacht (2010)	yes	-		
Borgeat, Elie, Chaloult, & Chabot (1984)	-	-		frontalis
Cacioppo & Petty (1979, study 2)	yes	yes	*CS=ZM*	depressor anguli oris, mentalis
Cikara & Fiske (2012, study 1)	-	yes		
Durso, Geldbach, & Corballis (2012)	yes	no	*CS>ZM*	depressor anguli oris
Fiacconi & Owen (2015)	yes	yes	*CS=ZM*	
Fino, Menegatti, Avenanti, & Rubini (2016)	yes	yes	*CS=ZM*	
Fino, Menegatti, Avenanti, & Rubini (2019)	yes	yes	*CS=ZM*	
Fino (2014, study 3)	yes	no	*CS>ZM*	orbicularis oculi
Foroni (2015)	-	yes		
Foroni & Semin (2009)	yes	yes	*CS=ZM*	
Foroni & Semin (2013)	-	yes		
Gavaruzzi, Sario, Giandomenico, Rumiati, Polato, De Lazarri, & Lotto (2018, study 2)	yes	-		
Hietanen, Surakka, & Linnankoski (1998)	yes	-		orbicularis oculi
Kätsyri, Ravaja, & Salminen (2012)	no	yes	*CS<ZM*	orbicularis oculi
Krumhuber, Tsankova, & Kappas (2016)	no	no	*CS=ZM*	levator labii superioris
Künecke, Somme, Schacht, & Palazova (2015)	yes	no	*CS>ZM*	
Kunkel (2018, study 2, control experiment)	yes	no	*CS>ZM*	levator labii superioris
Kunkel (2018, study 2, discourse experiment)	yes	yes	*CS=ZM*	levator labii superioris
Kunkel (2018, study 3, exp 2, control experiment)	yes	no	*CS>ZM*	
Kunkel (2018, study 3, exp 2, discourse experiment)	no	no	*CS=ZM*	
Larsen, Norris, & Cacioppo (2003)	yes	yes	*CS=ZM*	
Larsen, Norris, McGraw, Hawkley, & Cacioppo (2009, study 4)	yes	yes	*CS=ZM*	
Larson, Hazlett, Chaparro, & Picard (2007)	yes	no	*CS>ZM*	orbicularis oculi
Lee & Potter (2018)	yes	yes	*CS=ZM*	
Leshner, Bolls, Gardner, Moore, & Kreuter (2018)	yes	-		
Levy, Harmon-Jones, & Harmon-Jones (2018, study 2)	yes	-		

Livingstone, Forde Thompson, & Russo (2009)	undecidable	undecidable		
Lucas, Sánchez-Adam, Vila, & Guerra (2019)	yes	yes	CS=ZM	orbicularis oculi
Magnée, Stekelenburg, Kemner, & de Gelder (2007, study 1)	yes	yes	CS=ZM	
Morriseau, Mermillod, Eymond, van der Henst, & Noveck (2017)	no	yes	CS<ZM	frontalis, orbicularis oculi
Neumann, Hess, Schulz, & Alpers (2005, study 1)	yes	yes	CS=ZM	
Neumann, Hess, Schulz, & Alpers (2005, study 2)	yes	no	CS>ZM	
Niedenthal, Winkielman, Mondillon, & Vermeulen (2009, study 1)	yes	yes	CS=ZM	orbicularis oculi, levator labii superioris
Niedenthal, Winkielman, Mondillon, & Vermeulen (2009, study 2)	yes	yes	CS=ZM	orbicularis oculi, levator labii superioris
Ravaja, Aula, Falco, Laaksonen, Salminen, & Ainamo (2015)	no	yes	CS<ZM	
Ravaja, Kallinen, Saari, & Keltikangas-Järvinen (2004)	yes	no	CS>ZM	orbicularis oculi
Ravaja, Saari, Kallinen, & Laarni (2006)	yes	no	CS>ZM	orbicularis oculi
't Hart, Struiksma, van Boxtel, & van Berkum (2018)	yes	-		
't Hart, Struiksma, van Boxtel, & van Berkum (2019)	yes	-		
't Hart, Struiksma, van Boxtel, & van Berkum (submitted)	yes	-		
Thomson, Mackenzie, Leuthold, & Filik (2016)	yes	yes	CS=ZM	
Topolinsky, Likowski, Weyers, & Strack (2009)	yes	yes	CS=ZM	frontalis
Topolinsky & Strack (2015)	yes	no	CS>ZM	frontalis
Tuisku, Ilves, Lylykangas, Surakka, Ainasoja, Rytövuori, & Ruohonen (2018)	yes	-		
Van Leeuwen (2017, chapter 5)	yes	-		
Wassiliwizky, Koelsch, Wagner, Jacobsen, & Menninghaus (2017, study 1)	yes	no	CS>ZM	
Weis & Herbert (2017)	yes	yes	CS=ZM	
Wexler, Warrenburg, Schwartz, & Janer (1992)	yes	no	CS>ZM	
Wise, Kim, & Kim (2009)	yes	-		
Zhu & Suzuki (2018)	yes	yes	CS=ZM	
muscle sensitive to language-driven emotion manipulation =	45	26	22	= nr of CS&ZM-studies with effects in both muscles
muscle not sensitive to language-driven emotion manipulation =	5	14	12	= nr of CS&ZM-studies with effects in CS only
undecidable =	1	1	3	= nr of CS&ZM-studies with effects in ZM only
muscle not measured or not evaluated =	4	14		
total number of studies reviewed =	**55**		**37**	**= total number of studies with CS & ZM**

Facial EMG can in principle also be useful when assessing the role of emotion during language *production* (14). However, echoing a general bias towards comprehension in psycholinguistics, the interest in how emotion affects production lags far behind the interest in how it affects comprehension (e.g., 56). Also, speaking involves facial muscle activation as part of articulation, which greatly complicates the use of EMG to keep track of speaker emotion. Therefore, while psycholinguists interested in language production have used EMG to study articulation (e.g., 50, 51), they have to our knowledge not used it to tap into emotional factors -- even in stuttering research, where emotion has clear relevance, EMG recording focuses on articulation only (e.g., 57, 58).

Our review of studies that used EMG to track emotion during language comprehension does not cover facial EMG studies that use verbal materials *as a vehicle* but whose description does not satisfy the language- and communication-oriented keyword searches in this review (e.g., research with 'vignettes' in social or moral psychology). We also do not cover media-psychological EMG research involving cinematic narrative (e.g., 59) or advertisements with emotionally toned non-verbal materials (e.g., music, 60), work that includes language but does not manipulate verbal materials in ways that are useful to those interested in language processing. Finally, we ignore EMG studies that, in the trail of the pioneering emotional imagery EMG work by Schwartz et al. (52), explored the emotional consequences of *thinking about* linguistically presented materials after reading or hearing it, of *imagining* reading or listening to a text, or of *imagining agreeing or disagreeing* while reading or listening to a text (see, e.g., 61, 62, 63, 64).

3.1 Single-word studies

Manipulations of lexical emotional contents

Following up on the early Cacioppo and Petty research (54), as well as on work that had observed increased *lip* EMG to words when evaluated on valence (46, 47), Larsen, Norris and Cacioppo (17) were the first to directly examine word-elicited positive and negative emotion by means of EMG. Participants read a series of words that spanned a preestablished broad unpleasant-pleasant valence rating continuum, while EMG was recorded over the corrugator and the zygomaticus muscles. The same EMG-participants also saw a series of pictures and heard a series of sounds (e.g., animal noises, alarms, laughter) and after each stimulus, rated how positive and negative they felt about it. When average EMG responses were plotted against the (ranked) average valence ratings provided by participants, a very important result emerged: for pictures, sounds, and words, *corrugator* EMG tracked subjective stimulus valence in a virtually linear way, with stimuli that had been rated more negatively leading to stronger corrugator activity -- see Figure 2A for the word and picture results. The zygomaticus EMG-response was more complex: for pictures and sounds, it tracked subjective stimulus valence in a more U-shaped way (elevated zygomaticus activity for positive stimuli, but also for very negative stimuli), whereas for words, the zygomaticus was not reliably sensitive to subjective valence. These results, which were corroborated by a later reanalysis on *absolute* (rather than ranked) valence ratings (65: study 4) suggested three important things: (a) corrugator EMG is a useful index of the valence of word-induced emotion, (b) corrugator valence effects to words, although smaller, are qualitatively similar to those obtained with pictures and sounds of concrete objects or events, and (c) relative to the corrugator, the zygomaticus is somewhat less suitable for tracking the valence of word-elicited emotion.

Other research also points in this direction. For example, in two recent EMG studies (66 control experiments of studies 2 and 3), corrugator and zygomaticus activity was recorded to written single words and pictures, focusing on negative versus neutral valence, and using two different secondary tasks. Whereas zygomaticus activity did not change in response to valence, corrugator activity was significantly higher to negative compared to neutral words, both when participants were asked neutral questions about the words after each trial (study 3, e.g., did the word have three syllables? Was the animal depicted a sheep?), and when participants were asked to rate the degree to which the same

words emotionally moved them (study 2; in the latter case, the additionally measured levator labii superioris was also sensitive to valence). Interestingly, across the two studies, *picture*-induced effects displayed the same pattern of results. These findings converge with the Larsen et al. (17) results, and also show that word-elicited emotional responding does not *critically* depend on the use of an emotion-focused secondary task.
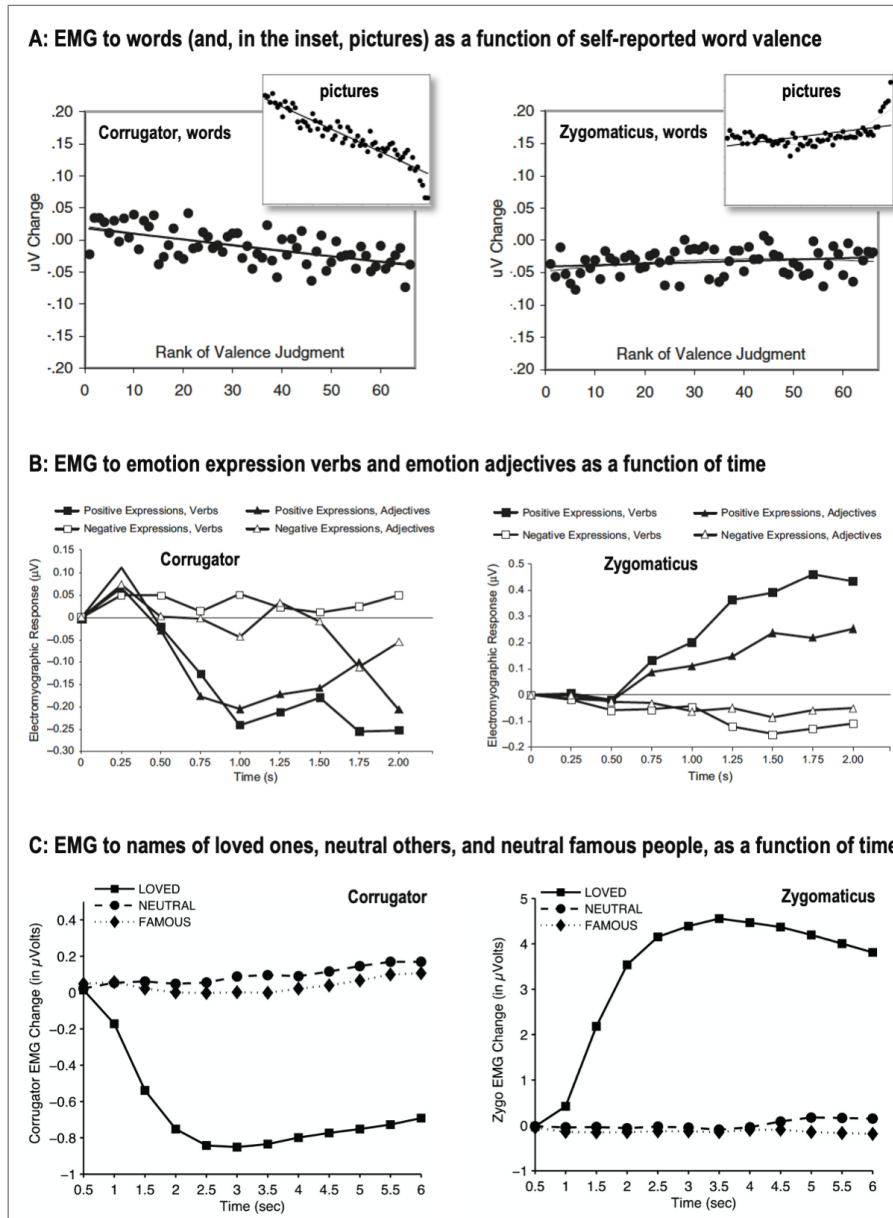

Figure 2: Example corrugator and zygomaticus results from three facial EMG studies with single words. Panel A: corrugator and zygomaticus responses to words ordered along a valence rank dimension (left = most negative, right = most positive; each dot represents a word with a particular valence rank; inset shows the same data for pictures). Panel B: corrugator and zygomaticus responses as a function of time to emotion adjectives and emotion expression verbs of positive or negative valence. Panel C: corrugator and zygomaticus responses as a function of time to names of loved ones, compared to neutral familiar and unfamiliar names. Note the rapid differential EMG-responses in Panels B and C, and, in Panel A, the different way in how corrugator and zygomaticus activity tracks stimulus valence. See text for further explanation. Panels A, B, and C reprinted with permission from 17, 67, and 35 respectively.

The latter idea also received support from a study in which participants were merely asked to *read* single words, *without any additional task*, while corrugator and zygomaticus EMG was recorded (67, see figure 2B). Compared to words associated with positive emotions (e.g., "smiling", "funny"), words associated with negative emotions (e.g., "frowning", "annoying") elicited a rapid relative increase in corrugator activity, as well as a rapid relative decrease in zygomaticus activity, both clearly within 750 ms after word presentation. In another word reading study without a secondary task (35, see figure 2C), seeing the names of loved ones led to increased zygomaticus activity and reduced corrugator activity, relative to seeing control names of unknown or (neutrally rated) familiar persons.

Of course, we cannot exclude that facial behaviour in these studies was in part affected by perceived implicit task demands, an issue to which we'll return later. However, in several EMG studies with *masked* stimuli, words that were acoustically hidden in other stimuli to such an extent that participants did not consciously detect their presence *also* generated reliable EMG-responses, visible in frontalis muscle EMG with sex-related words (68), as well as in corrugator (but not zygomaticus) EMG for other types of valenced words (69; see 70, for a related observation when using written words). Such findings cannot easily be ascribed to task demands.

As might be expected, task and stimulus parameters do sometimes influence language-induced corrugator and zygomaticus EMG. For example, in contrast to studies where task effects did not emerge (66 control experiments of studies 2 and 3), another study (71) did generate a task effect: valence-dependent responses to concrete and abstract written words were obtained in corrugator and zygomaticus EMG (as well as in orbicularis oculi and levator labii superioris EMG) when participants were asked to judge whether the referent of each word was associated with an emotion, but *not* when they were asked to judge whether the word was printed in upper- or lower-case. Using the same emotion-focused judgement task, another study (72) revealed a native language advantage: a valence-dependent corrugator effect only emerged to written words in one's native language (L1) and not to words in a familiar foreign language (L2), and although a valence-dependent zygomaticus effect emerged in both L1 and L2, the effect emerged later and ended sooner in L2. Finally, one study (73) revealed a concreteness effect: the corrugator was sensitive to the valence of written words in the case of *concrete* words, but not in the case of abstract words -- the zygomaticus did not show any effects in this study. The source of these various task and stimulus type effects, as well as their coming and going across studies, is as yet unknown.

An interestingly different approach is illustrated in a study where participants were asked to indicate whether written words were positive or negative by *deliberately* activating the corrugator or zygomaticus, and do so as rapidly as possible (74). Relative to participants instructed to use the corrugator for negative valence and the zygomaticus for positive valence, participants that were instructed to (incongruently) use the corrugator for positive valence and the zygomaticus for negative valence were some 100-150 ms slower in contracting their corrugator or zygomaticus, with the interference emerging at around 500 ms after word presentation. This rapid Stroop-like interference effect indicates that participants simply *cannot stop* words from automatically and rapidly activating valence-congruent facial muscles. Also, when the participants of a follow-up study were simply asked to contract *one* particular muscle as soon as a word appeared on the screen, regardless of valence (e.g., always the zygomaticus in the first half of the experiment, and always the corrugator in the second), the corrugator muscle was again contracted more slowly to positive than to negative words (no such congruency effect was obtained for the zygomaticus). In all, and consistent with the masked word results, this suggests that words can involuntarily trigger valence-congruent activation of the corrugator and, in one study, the zygomaticus. In related written word research (75), a valence-dependent EMG response did not only emerge much earlier in the corrugator than in the zygomaticus, but this early response was also very difficult to suppress, again testifying to a degree of rapid automaticity.

Manipulations of prosodic emotional contents

All studies discussed so far focused on the impact of word meaning. However, words can also be spoken with a particular emotional prosody. In an EMG-study that explored the impact of this (76), participants listened to the single word "Sarah" spoken with an angry, neutral, or mildly positive prosody, while EMG over the corrugator and the orbicularis oculi was measured to obtain an index of negative and positive emotion respectively. Compared to angry as well as neutral prosody, positive prosody led to reduced corrugator EMG. Positive prosody also reliably increased orbicularis oculi EMG relative to neutral prosody, but unexpectedly, angry prosody did so too. So, although clear effects of emotional prosody could be observed in corrugator EMG, the orbicularis oculi results are complex. We return to prosody when examining EMG-research with phrases and sentences.

In all, facial EMG research with single spoken or written words[2] suggests that word-elicited emotional effects can emerge involuntarily and very rapidly, in both input modalities, and in ways that are consistent with the idea that we communicate our affective response to the world around us by means of such things as a frown, or a smile. Of course, although single-word paradigms provide conceptually interesting methodological options (e.g., masked presentation, a comparison to pictures of objects, or other forms of precise stimulus control), everyday language use goes well beyond presenting single words to other people. So what about the use of EMG to track emotional responses to bigger chunks of language? In the remainder of this review, we first examine comprehension research with phrases and sentences that are *not* part of a wider discourse, and then turn to research with larger discourse stimuli.

3.2 Phrase and sentence studies

Manipulations of lexical emotional contents

In one of the first EMG studies focussing on the emotional aspects of sentence comprehension (81), participants were asked to read negative and neutral sentences word by word as their corrugator activity was being measured, and to make a semantic correctness judgement after each sentence. The corrugator EMG elicited by a range of negative and neutral sentence-final verbs was larger for very negatively rated verbs than for neutrally rated verbs, and very rapidly so (significant in the 300-600 ms after verb onset). The negatively valenced verbs involved in this comparison also had higher arousal ratings than the neutral verbs, but a separate comparison, low- and high-arousal words that were matched on valence did *not* differ in corrugator activity. This suggests that, at least in this study, the corrugator effects of subjective valence are not due to a subjective arousal confound.

Pursuing a wider question about embodied language processing, several EMG studies followed up on earlier single-word research (67) by placing the same written emotion expression verbs (e.g.,

---

[2] EMG-studies can also examine the emotional impact of single words by measuring EMG to *subsequently presented other*, non-language stimuli, for which the words serve as context. For example, there is evidence that the very rapid mimicry of emotional facial expressions measured through facia EMG, and emerging in the signal at around 300 ms after face presentation already, can be modulated by subliminally presented congruent or incongruent word primes (77). Emotionally relevant words can also modulate the affective EMG responses to odors (78), as well as the EMG-measured startle blink response to loud sound bursts (using the orbicularis oculi muscle, see 79; 80; 35).

"frowning", "smiling") in a minimal sentential context, again without an additional secondary task. Focusing on the zygomaticus only, one of these studies (82) revealed higher zygomaticus activity to sentences like "I am smiling" than to sentences like "I am frowning", already significant around 400-600 ms after (whole) phrase presentation onset. This finding resembles the original single-word result. A similar but delayed and somewhat weaker pattern emerged with proficient L2 speakers (83), comparable to the attenuated EMG effects for L2-speakers when reading single words (72). In related research (84), corrugator and zygomaticus EMG was recorded to examine the impact of minimal emotional expression or emotional state sentences (e.g., "Mario smiles", "Mario enjoys"), in a paradigm in which participants also had to provide a sentence likeability rating. Corrugator activity was significantly higher to descriptions of negative states and actions than to descriptions of positive states and actions already from 300-600 ms onwards, and zygomaticus activity was significantly higher to descriptions of positive states and actions than to descriptions of negative states and actions from 900-1200 ms onwards. Finally, in a study that compared 1st- and 2nd-person perspectives (85), verb valence affected the corrugator and zygomaticus in the expected direction in 2nd-person phrases ("your fear", your joy"), but *not* in 1st-person phrases ("my fear", "my joy"), a puzzling result that the authors related to the social embedding of language, and that requires further examination.

Sentences also allow for interesting other manipulations, such as negation. Two studies (82, 83) explored the impact of negation in L1 and L2 respectively. In L1, zygomaticus activity was higher to "I am smiling" than to "I am not smiling", from about 200-400 ms after sentence presentation onset, revealing surprisingly rapid effects of the negation. Furthermore, this negation effect disappeared in L2, which echoes the native language advantage in facial EMG sensitivity reported before (72) for single words. Without going into the details here, the full pattern of results obtained in these negation studies (82, 83) does *not* indicate that negation simply inhibits word-elicited muscle activity -- as also testified by the complex pattern of EMG results obtained in another study (85), with phrases like "no fear" or "no joy", the impact of negation seems much more complex. We return to this later in this chapter.

Another option afforded by sentences is to manipulate the identity of the agent involved. In a study on enjoyment over other people's misfortune (Schadenfreude) that paired sentences like "got soaked by a taxi driving through a puddle" with pictures triggering various types of person stereotypes (86), negative event descriptions increased zygomaticus activation only for pictures suggesting an enviable, "cold and competent" person. Furthermore, in a study involving names of well-known ingroup or outgroup politicians (e.g., Italian versions of "Clinton smiles" or "Trump smiles", 87) the corrugator and zygomaticus strongly responded to positive and negative expression or state descriptions involving *ingroup* politicians, but less so, and sometimes not at all, to similar expressions involving *outgroup* politicians. In a related study (88: study 3), comparable results were obtained for the corrugator, with somewhat more ambiguous findings for the zygomaticus and the orbicularis oculi. Finally, in a study where participants read sentences like "Mark is furious when <reason>" or "Mark is happy when <reason>" without an additional task (89: study 3), corrugator activity increased at "furious" compared to "happy" when a previous picture (and accompanying verbal label) had characterized Mark as a good person, but *not* when it had characterized him as a bad person. In line with the negation and perspective studies discussed before, all this suggests that facial EMG is sensitive to much more than just local word meaning, and that combinatorial meaning and affiliation-based evaluation matter as well.

Manipulations of prosodic emotional contents

Three spoken-sentence studies have used corrugator and zygomaticus EMG to explore the impact of affective prosody. In one study (90), participants were asked to rate the 'smiliness' of sentences whose prosody had been digitally modified to convey the speaker was smiling, neutral, or 'unsmiling', while their EMG was being measured. From about about 800 ms after speech onset, corrugator activity was significantly higher to 'un-smiling' prosody than to smiling prosody, and from about about 1100 ms, zygomaticus activity was higher to smiling prosody than to 'un-smiling' prosody. In a study on emotional singing (91), corrugator and zygomaticus EMG was recorded as musically trained participants listened to particular sentences (e.g., "Grass is green in summertime") sung with a happy, sad, or neutral intention. A composite EMG measure revealed emotion-congruent responses in facial EMG as sung sentences were heard. In the third study (92: study 1), participants saw a fearful or happy face while hearing a neutral prepositional phrase spoken with a fearful or happy prosody. Relative to adding a happy voice, adding a fearful voice to a face increased corrugator activity when the face was a fearful one, but not when it was a happy one. Also, relative to adding a fearful voice, adding a happy voice to a face increased zygomaticus activity when the face was a happy one, but not when it was a fearful one. This suggests that when the additional emotional prosody channel is consistent with the facial expression shown, the corrugator and zygomaticus can faithfully track the added affective load.

Manipulations of processing complexity

In addition to exploring the impact of emotional *contents*, facial EMG can also be used to study the potentially affective impact of processing complexity, emerging when sentences stop making sense or express very implausible meanings. In one of the studies already reviewed (81), semantic anomalies of the type typically explored in N400-research did *not* increase corrugator activity. However, in a study on the corrugator-indexed affective consequences of inconsistency (93), such anomalies did increase corrugator activity, in the 1000-2000 ms after critical word onset. Furthermore, in research on the corrugator, zygomaticus and frontalis effects of surprise (94), surprising trivia statements increased corrugator activity in a 0-6000 ms latency range, relative to unsurprising controls. Also, a fluency-oriented study of corrugator, zygomaticus and frontalis activity to semantically coherent or incoherent word triplets (95) showed that, compared to coherent triplets like salt - deep - foam (all sea-related), viewing incoherent triplets like dream - ball - book led to significantly higher corrugator and frontalis activity, as well as lower zygomaticus activity,st in the 1500-3000 ms after critical word onset. These various corrugator effects perhaps all reflect non-emotional effort (49; see also 42). However, because processing dysfluency signals a problem, these effects might also reflect negative emotional valence.

In all, and in line with single-word research, EMG-studies with spoken or written sentences reveal consistent and very rapid valence-dependent facial EMG responses, with the earliest reported significant effects emerging already around half a second after the relevant contents has been presented. Also, facial EMG effects induced by words such as "smile" or "frown" can be modulated by the specific sentential context, as in the case of negation, perspective, and character properties. Although such modulation has sometimes led to complex data patterns, particularly in the case of negation, it does reveal that there is more to language-driven facial EMG than just embodied local word meaning. We will see similar things as we examine, in the next section, the extant facial EMG research with multi-sentence written and spoken discourse.

3.3 Discourse studies

In addition to the pioneering Cacioppo and Petty study (54) on pro- and counter-attitudinal texts (see section 2.2), our literature search generated three clusters of EMG-studies involving multi-sentence discourse: studies involving moral and other social transgressions, media-psychological questions, or various other topics.

Moral and other social norm manipulations

Morality is a rich source of human emotion, and several research teams have examined facial EMG responses to morally loaded narratives. In a pioneering study (96) on the corrugator effects of social unexpectedness, participants read stories that first induced a strong positive or negative trait inference for some character, and then continued with a word-by-word description of trait-consistent or -inconsistent positive or negative character behavior. Relative to descriptions of good behavior, descriptions of bad behavior already led to significantly higher corrugator activity in the 100-300 ms after the critical word, with an additional corrugator activity increase if the bad behavior was trait-inconsistent. The zygomaticus data were deemed suspect, and therefore not analyzed.

In a study on the impact of social norm transgressions in stories (97), EMG activity was recorded in the corrugator and the levator labii (with zygomaticus recording to control for smiling artefacts only). Participants read texts that did or did not involve a social norm violation (e.g., refusing to shake an extended hand, using somebody else's toothbrush). Relative to neutral ones, stories with social norm transgressions elicited stronger activity in the levator labii, but not in the corrugator. The absence of a corrugator effect might be due to the fact that, in contrast to the preceding study (96) as well as the studies discussed below, this study imposed *multiple* secondary tasks (subsequent imagery, and three ratings), a possibly effortful situation that could have driven the corrugator to its upper activity range throughout the study. Also different from other transgression studies, EMG was averaged over 60 seconds of text reading, much of which did not involve critically different descriptions of people and events -- this can lead to phasic effects being 'washed out'.

In the above research, participants knew they would be required to recall or rate the stories after reading. However, in two reading studies that did not impose any other task (98, 99, see Figure 3A), narrative descriptions of bad character behavior (e.g., "Mark accelerates through the puddle on purpose to create a big splash and soak the pedestrian") consistently increased corrugator activity within a second after presentation, relative to descriptions of good character behavior (e.g., "Mark slows down to avoid the puddle, making sure he doesn't soak the pedestrian"). Furthermore, when bad or good events subsequently befell the same character, corrugator activity rapidly increased at negative state descriptions (e.g., Mark is frustrated because..." followed by a reason) compared to positive state descriptions (e.g., Mark is happy because...") in cases where the character had displayed good behavior before, but *not* when he or she had displayed morally bad behavior. This apparent insensitivity to the state of bad characters was observed in both studies, and also replicated in a third, sentential study (89: study 3, see section 3.2). In line with the results of 96 as well as the other sentence work discussed before (86, 87, 88: study 3), this character-dependent corrugator effect reveals that verbal expressions with "frustrated" or "happy" do not merely drive corrugator activity as a function of word-induced embodied language processing -- an issue to which we return in section 4.
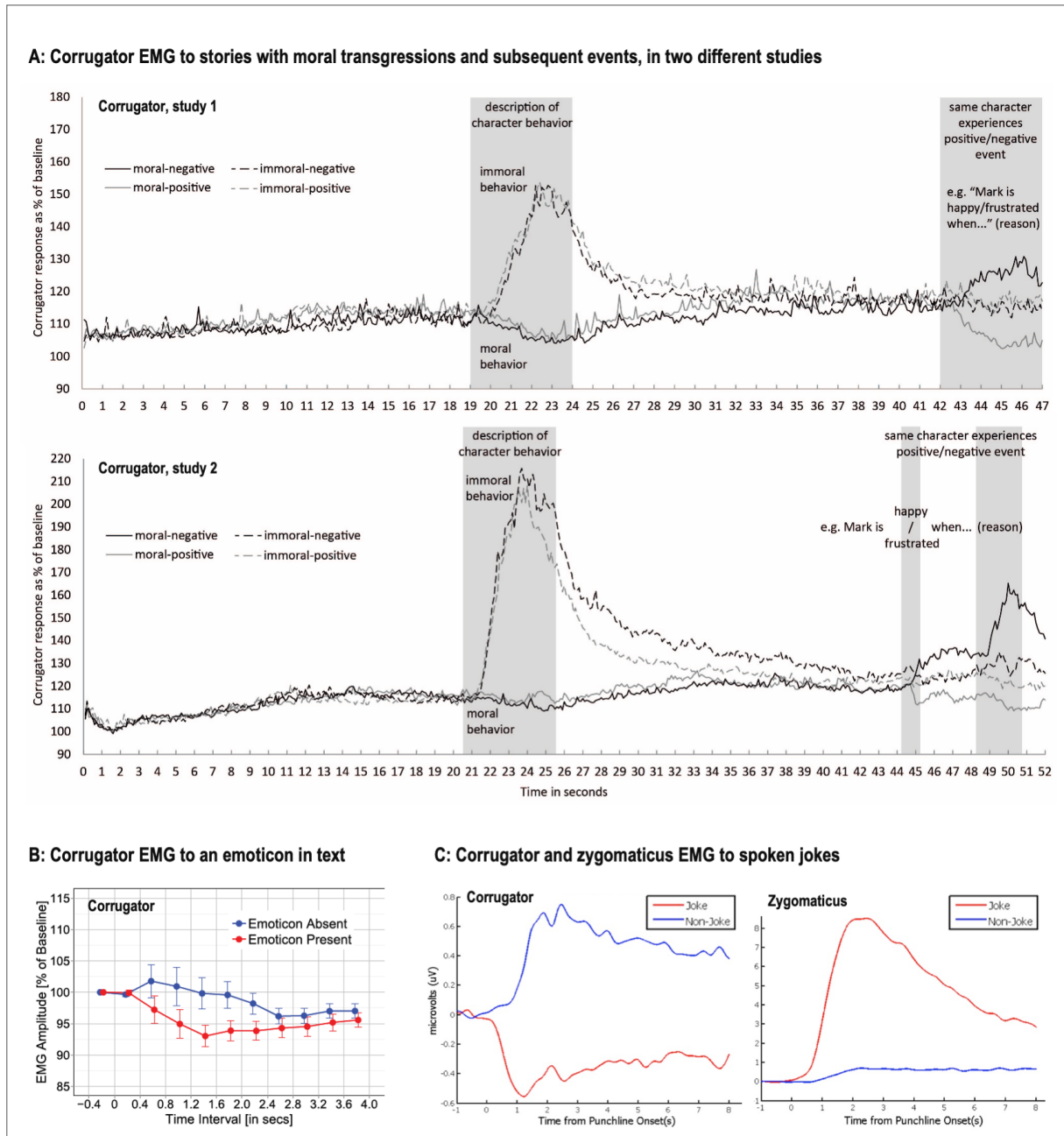
Figure 3: Example EMG results elicited with discourse materials. Panel A: Corrugator EMG as people read morally loaded stories in which the main character first did something moral or immoral and subsequently experienced something good or bad; the signals reveal large corrugator increases to immoral behavior, as well as an apparent insensitivity to the subsequent emotional state of immoral characters. Panel B: Corrugator EMG to sentences that did or did not end with a :P emoticon. Panel C: Corrugator and zygomaticus EMG to the punchline of spoken jokes, compared to non-joke controls. Panel A is a different rendering of the data reported in 98 (upper part) and 99 (lower part), both adapted from 89. Panels B and C reprinted with permission from 100 and 101 respectively.

Two final transgression studies (reported in 66) compared facial EMG activity as participants read descriptions of immoral versus moral actions embedded in wider stories. Without an additional task that focused attention on emotion (66 study 3), the corrugator and zygomaticus did not respond to moral transgressions However, when readers also had to rate the degree to which the story "had

moved them" after every trial (66 study 2), descriptions of morally objectionable actions did lead to higher activity in the corrugator and levator labii, as well as, unexpectedly, in the zygomaticus. The latter effect may be related to other observations that strong negative content can sometimes increase activity of this muscle (e.g., 17). The two studies considered together illustrate the potential impact of a secondary task, with the same materials. Note, though, that as shown by two other studies already discussed studies (98, 99, see figure 3A), facial EMG *can* be sensitive to descriptions of moral transgressions without a secondary task, in a replicable way. Future research will need to determine why these various passive reading studies led to different results.

Media research manipulations

Most of the moral transgression studies were conducted with psycholinguistic questions in mind, as such often focusing on the details of word-by-word processing. However, in the field of media psychology, various researchers have used facial EMG to assess the emotional impact of different types of (verbal) messages, or of the same messages conveyed through different media. For example, several health communication studies have reported complex valence-dependent corrugator effects that vary as a function of particular types of patient narratives (102, 103), or as a function of different styles of veterinarian communication (104).

Other media-psychological EMG-studies have explored the processing of valenced news texts presented in different formats (105, 106, 107, 108, 109), sometimes reporting increased corrugator activity to negative as opposed to positive news (107, 108), as well as increased zygomaticus and/or orbicularis oculi activity to positive as opposed to negative news (107, 105). Interestingly, in one study with corrugator and zygomaticus recording (106), higher zygomaticus activity was elicited by positive news in comparison to negative news when the news involved companies with a good reputation, but when news concerned companies with a *bad* reputation, *negative* news elicited higher zygomaticus activity, a finding that is reminiscent of various studies discussed before (86, 88: study 3, 87, and 98, 99, 89: study 3) observations that it is not (just) *the text as such* that elicits particular facial EMG effects. In the same study (106), negative comments posted on-line to the abovementioned news messages elicited a corrugator activity increase, but no zygomaticus activity change, as compared to positive on-line comments.

Finally, in a media study on in spoken radio advertisements (110), negative, neutral and positive words embedded in these advertisements elicited corrugator differences that faithfully tracked word valence and emerged within 500 ms after spoken word onset. Effects also emerged in the zygomaticus, but they did not faithfully track the valence dimension, with positive words eliciting the highest, neutral words eliciting the lowest, and negative words leading to an intermediate level of zygomaticus activity (cf. 17; see also 66 study 2, discourse experiment).

Other manipulations in discourse

A recent study (100) explored the combined processing of irony and emoticons by asking participants to read texts with a final sentence that praised or criticized somebody in a literal or ironic way (the latter derivable from context), and that was or was not accompanied by a tongue-face emoticon (:P). The irony-induced EMG-effects were complex, and require conceptual replication as well as somewhat

more detailed interpretation than provided in the paper. However, the simple presence of an emoticon generally reduced corrugator activity and increased zygomaticus activity (see Figure 3B for the corrugator), possibly as a sign of higher enjoyment in emoticon-containing communication, or, alternatively, some form of affective resonance with the communicator stance being signaled.

Two studies used facial EMG to explore the emotional impact of jokes. In the first study (101), participants heard jokes which they subsequently rated on funniness. Relative to the final words of non-joke control stories mixed with the jokes in the same session, joke-final 'punch line' words very rapidly increased zygomaticus activity, and reduced corrugator activity, with clear effects emerging well within a second of critical spoken word onset (see Figure 3C).[3] In a second study (112), corrugator, zygomaticus, orbicularis oculi and frontalis EMG was measured as people heard and rated jokes told by speakers of the same or different political affiliation. Joke-elicited EMG was not sensitive to speaker status *during* the joke, but within 4-5 seconds after the joke had ended, the zygomaticus and orbicularis oculi were more activated if the joke had been told by an ingroup speaker than by an outgroup speaker, and activity in these smiling-related muscles correlated strongly with the funniness ratings.

One study used corrugator EMG to explore the affective consequences of speech overlap in conversation (113: chapter 5). Participants overheard synthetic spoken dialogues between a man and a woman that sounded like muffled conversation coming through a room wall. Specific words could not be identified, but people could hear who was speaking as well as his or her specific intonation and rhythm. After each mini-dialogue, participants were asked to rate the degree of affiliation heard in the conversation. Speakers whose response overlapped with the previous speaker were not only rated as less affiliative than those whose 'waited their turn', but their speech also reliably increased corrugator activity. Whether this corrugator effect reflects increased listening effort for more complex stimuli, negative emotion to less fluent processing, or negative emotion to overheard interruptions remains to be explored. Also, whereas speakers whose speech *rhythm* was 'out of sync' also elicited lower affiliation ratings, this did not increase corrugator EMG.

Three remaining studies explore other aspects of language comprehension. In a study on the emotional impact of spoken poetry (114), those fragments of poetry that evoked chills or goosebumps also strongly and consistently increased corrugator (but not zygomaticus) activity, possibly reflecting the 'bittersweet' mixed-emotion state of being moved. In a study on the aesthetic effects of text layout (115), poorer typographic designs led to elevated corrugator activity, but not to effects in zygomaticus or orbicularis oculi activity. Finally, in a study where the corrugator, zygomaticus, and depressor anguli oris were recorded to explore the facial correlates of confusion during story reading (116), corrugator and depressor anguli oris EMG contained information that better predicted confusion than self-reports did, testifying to the fact that EMG can pick up on responses that are not consciously accessible.

---

[3] Strikingly, follow-up research (111) in which the same materials were played to two vegetative state (coma-like) patients revealed qualitatively comparable, if substantially weaker, zygomaticus and corrugator responses in one of the patients.

3.4 Some general observations

Although the number of language- or communication-relevant EMG-experiments found, 55 in all, is somewhat lower than we had expected, it is clear that since the pioneering Cacioppo & Petty study published in 1979 (54), language-elicited emotion has been tracked by means of facial EMG to address a wide variety of research questions, in psycholinguistics, media psychology, and other fields. Stepping back from the individual studies, what general observations can we make? We discuss a few trends in the findings as well as in the conceptual and methodological approach.

Few replications and many different types of analysis. We must begin with an important methodological observation. Most of these studies can be seen as conceptual replications of each other in the sense that they all demonstrate the utility of facial EMG to assess language-driven emotion. However, there have as yet been virtually no attempts to systematically replicate *specific* EMG-findings in the reviewed domain of inquiry. Also, the studies reviewed differ greatly in how the data were analysed, in terms of baselining (width of interval, subtraction or % change), in statistical testing (in a single latency range or a series, boundaries chosen, t-tests, simple condition by time ANOVA's, or growth curve analysis), in whether tests compared post-stimulus levels to the pre-stimulus baseline or to a post-stimulus control condition, and in whether raw, difference, or composite scores were entered into statistical testing. None of this is unrepresentative of current psychophysiological research, where there is often no single best way to analyse the data. However, published results obtained under conditions of many experimenter degrees of freedom probably contain a non-trivial proportion of false positives (see, e.g., 117 for the case of EEG). Therefore, as in other domains, future EMG-work on language-induced emotion should greatly benefit from preregistration and systematic replication.

A valence approach to emotion. In virtually all of the EMG-studies reviewed, emotion is framed in terms of valence, with researchers characterizing their stimuli and/or the emotional responses to those stimuli as positive or negative. In line with this framing, most studies recorded activity in the corrugator supercilii and/or the zygomaticus major, the two facial muscles broadly perceived to be the most useful ones for tracking emotional valence (see Table 1). Some valence-framed studies focussed on just one of the two muscles (e.g., 98, 99, 82, 83), and other studies sometimes also recorded from additional muscles deemed sensitive to positive or negative valence, such as the orbicularis oculi (involved in smiling), or the levator labii superioris (involved in disgust). Very few studies classified their stimuli as potentially evoking *specific* emotions and recorded from specific facial muscles to assess those emotions (e.g., the zygomaticus for Schadenfreude, or the levator labii superioris for disgust, see 86). To some extent, this may result from a dimension-oriented theoretical perspective on emotions. However, we suspect that the predominance of corrugator and zygomaticus recording mainly reflects the impact of influential early EMG research (such as 54, or 17), and the fact that there is simply less knowledge, and more debate, on how to tap into specific emotions by means of EMG (cf. 118, 38).

Rapid valence effects. Of the studies that reported onset-relevant statistics, several clearly indicate that the effects of valence can emerge in the EMG-record within only a few hundred milliseconds after critical language input. This holds for single words (e.g., 67), for words embedded in a sentence (e.g., 81, 84), and for words embedded in a discourse (e.g., 96). Several studies that provided time-course information without reporting onset statistics numerically confirm that valence-dependent EMG-

effects can emerge rapidly in the signal (e.g., see figures 2C and 3A, 3B and 3C). These observations are consistent with what we know about the speed of language processing and emotional responding, and, perhaps more interestingly, show that such rapid effects do not just emerge for depictions and sounds of concrete objects, situations, and events out there in the world, but also for arbitrary signs used to communicate about those things. It is too early to say if language- or other symbol-elicited EMG effects lag behind those of non-symbolic stimulus types (see 66 control experiments of studies 2 and 3, for first observations).

Corrugator-dominated effects. Our review also indicates that although the corrugator and the zygomaticus are the muscles most often used to assess the impact of language-driven emotion manipulations (see Table 1), the corrugator is, on average, more sensitive, at least with the particular verbal materials and tasks used here: of the 37 studies recording from *both* muscles, 92% reported emotion-related effects in the corrugator, while only 68% reported such effects in the zygomaticus (with also some unexpected effect direction reversals in the latter). The reasons for this differential sensitivity have been discussed in detail elsewhere (e.g., 17, 42). For one, different muscle types are involved: whereas the zygomaticus is a phasic muscle that is often inactive and that can in those cases only increase its activity, the corrugator is a tonic muscle that is always 'on', and that can as such easily increase as well as decrease its activity (see, e.g., Figure 3C, 35, and 66, for clear evidence). Also, whereas the evidence suggests that the corrugator tracks valence in a relatively monotonic way, with increasing activity as one moves from strongly positive via neutral stimuli to strongly negative stimuli, zygomaticus activity can be increased by both positive *and very negative* stimuli, relative to neutral stimuli (66 study 2 discourse experiment, 17, 110), presumably because very negative stimuli can lead to, for example, wry smiles, grins of embarrassment, or disgust-induced raising of the cheeks.[4] This non-monotonic (and non-linear, 65) behaviour of the zygomaticus need not be problematic when contrasting positive and neutral stimuli only, but it may well get in the way when contrasting either of those to negative stimuli.

Task effects as well as automaticity. There is some evidence that secondary tasks, imposed on participants above and beyond the primary task of reading or listening to language, can have an impact on language-driven emotional EMG-responses. This is not surprising, as such tasks can easily change the focus of participants. The more important question is whether the observation of language-driven emotional EMG-responses *critically depends* on the presence of a secondary task. As we have seen in this review, the answer is no. For example, consistent and replicable EMG-effects have been observed in studies where participants had no other task than to read (98, 99, 89: study 3), and consistent EMG-effects have also been obtained in situations where participants were supposed to deliberately use another muscle (74) or were not aware of the stimulus at all (68, 69). Such observations echo EMG-results with other types of stimuli (e.g., 25, 26), and testify to a very important property of facial EMG: the electromyographic recording of facial muscle activity does not only pick up on consciously controlled facial expressions, but *also* on involuntarily generated ones.

Reading out involuntary emotion. Although usually not made explicit, the studies reviewed share an important assumption, which is that facial EMG indexes inner emotional states that are automatically

---

[4] Related, smiles may serve a number of different functions, such as displaying enjoyment, affiliative intentions, or dominance (see 119, and references therein).

generated. For example, we found no studies that used facial EMG to study the *deliberate* generation of a facial display as a social tool used in, e.g., conversation. As such, the current language-relevant facial EMG research is closer to a basic emotions perspective on emotion (e.g., 120) than, say, to a social constructionist or 'behavioural ecology' perspective on emotion (e.g., 121). We offer this observation as a fact rather than a verdict. In the minimal social context of a laboratory study where stimuli are presented to solitary individuals for reading or listening only, with a experimenter that is trying to be as absent as possible, it is in fact not unlikely that the facial responses picked up on via EMG *are* indexing relatively involuntary inner emotional states. And since much of human behaviour is generated involuntarily, rather than under conscious control, such results can be highly relevant to understanding affective language use. At the same time, and echoing a more general 'passive comprehension' bias in psycholinguistics, language- and communication-oriented facial EMG research has yet to begin to explore emotion in socially richer arenas of language use, where both involuntary facial expressions *and* deliberate, strategic facial displays play an important role.

Tracking immediate emotion only. As might be expected from studies with a time-sensitive biosignal measure, all of the research reviewed focused on relatively immediate emotional responses, usually unfolding within half a second to a a few seconds after the relevant language materials. Understanding real-time responding is important, for theoretical as well as practical reasons, and such responses may also be correlated with later, more stable emotional evaluations (e.g., as part of attitudes). However, there is no principled reason why facial EMG recording cannot also be used to actually probe those more stable emotional results (e.g., via the delayed presentation of single 'probe' words, or phrases, that relate to an attitude object). As with real-time data, the advantage would be that our knowledge of emotional impact is not limited to what participants can report in an attitude or valence rating survey, but is assessed in a broader fashion.

Complexity in what drives emotion. The EMG-evidence reviewed suggests that language can very rapidly elicit emotion during comprehension, in at least partly automatic ways. However, the *triggers* for such emotion are complex. For convenience, we have organized our review in terms of familiar chunks of language structure: a single isolated word, a single isolated phrase or sentence, and a multi-sentence discourse. But merely concluding that all three can elicit emotion is rather superficial. After all, we know from psycholinguistics and pragmatics that language comprehension is a very complex process involving the (near-)simultaneous integration of many different features, at various levels of analysis. Also, emotional state or emotional expression descriptions (e.g., "happiness", "frowning") probably elicit emotion in a different way from how other words (e.g., "weekend", "dying", or the name of a loved one) elicit emotion. Although the various facial EMG-studies discussed all have their own local theoretical context, what is currently missing is a coherent theoretical framework that makes explicit the many fundamentally different ways in which language can give rise to emotional facial expressions during comprehension. In the next section, we provide such a theory.

4. THE FALC MODEL

The model we present is a version of the *Affective Language Comprehension* or *ALC* model (12, 13), slightly modified and extended to better conceptualize the potential sources of facial EMG effects (hence the 'f'). The *fALC* model, schematically depicted in Figure 4, combines broadly accepted

psycholinguistic and pragmatic ideas on what is needed to comprehend language (e.g., 122, 123) with knowledge of how emotion and its facial expression can be triggered, automatically or deliberately, without or with conscious awareness. In the model, we draw various distinctions that we consider to be critical to understanding language-driven facial EMG-effects. We first discuss these distinction (sections 4.1 to 4.3), and then briefly conceptualize some of the empirical EMG-findings in terms of the model (section 4.4).
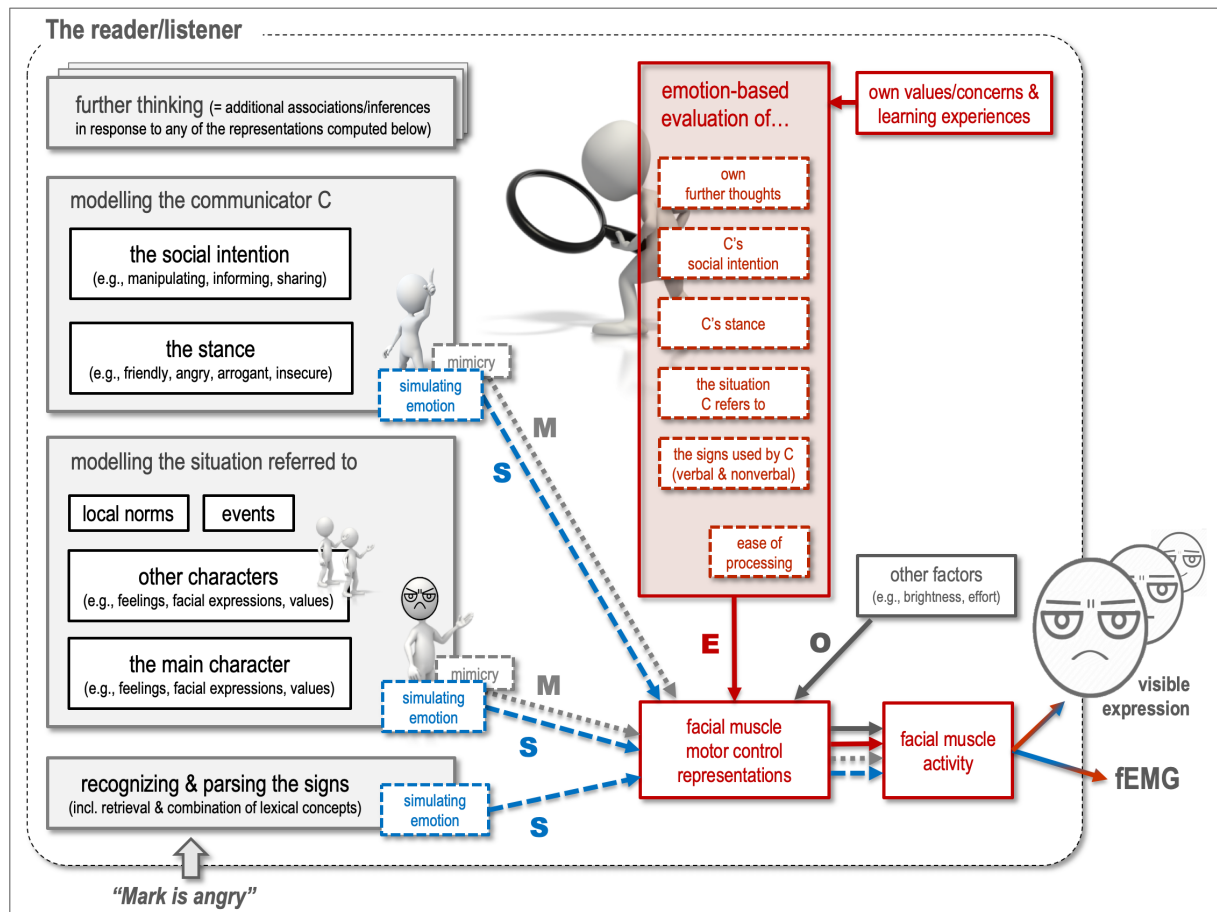

Figure 4: The fALC model, a theoretical framework for understanding and predicting facial EMG effects during affective language comprehension. The various cognitive processes drawn in the left part of the figure can influence each other, and this may also hold for various evaluations drawn on the right of them (arrows omitted for simplicity). Potential facial feedback loops are not explicitly marked. Further thoughts can be triggered rapidly by representations generated by each of the other cognitive components of language comprehension. S = impact of emotion simulation; M = impact of emotional mimicry; E = impact of emotion-based evaluation; O = impact of other factors. See text for further explanation.

4.1 Language comprehension at multiple levels

In everyday language use, understanding an utterance like "Mark is angry" requires processing at several fundamentally different levels, described briefly below (see 12, 13, for details), and illustrated in the left half of Figure 4.

(1) Recognizing and parsing the signs: To understand "Mark is angry", you'll need to retrieve relevant information stored in long-term memory for the words "Mark", "is", and "angry", and combine that information with other relevant cues (e.g., linguistic prosody, a declarative, interrogative, or imperative sentence form) in accordance with the grammar of English. The result, sometimes referred to as 'timeless sentence meaning', specifies that, in some to be determined context, time, and place, an agent exists whose name is Mark and whose current state includes anger. What this means *in the current context* is to be determined at another level.

(2) Modelling the situation referred to by the communicator: For successful comprehension, you also need to work out which specific (real or fictional) "Mark" the communicator is talking about, and somehow model *this particular person* as being in a state of anger *now*, as part of a larger model of the situation under discussion (situation model; 124). In most instances of everyday language use, a lot will already be in place in that model. For example, if "Mark is angry" is not the first utterance in a text or conversation, you may already have modelled where Mark is, who else is around and what you know about them, what has happened before, and what social norms are in place. Situation models constructed during communication are extremely rich, and individual utterances usually only add or modify bits of the model.

(3) Modelling the communicator, which involves at least two important aspects:

(3a) Inferring the communicator's stance: To understand "Mark is angry" in everyday language use, it is important to model details about the communicator too. For example, when somebody utters "Mark is angry" in a conversation, it is not just important to work out what he or she is referring to, but also what his or her stance (feeling, attitude, orientation) on the matter is. Here, facial, vocal, and other bodily cues matter a lot. For example, the affective prosody with which "Mark is angry" is produced can easily betray the speaker's stance (although not necessarily what the stance is *about*). Inferring stance can also be crucial when comprehending written language (e.g., a WhatsApp message, an internet blog, an advertisement, or a political statement), where, in the absence of facial, vocal and other bodily cues, other cues can carry the relevant information (e.g., reply speed, capital letters, exclamation marks, emoji).

(3b) Inferring the communicator's social intention: Knowing which Mark is angry and how the speaker feels about this is is usually not enough, though, as there is often a deeper question to be answered (123): what is it that the communicator wants you to do, know or feel, by producing this utterance in this particular way? Is the intention to just let you know Mark is angry, share his or her feelings over this, or persuade you to do something? For example, does the speaker want you to share in amazement over this fact and as such pull you closer, or does he or she want to tell you that you messed up? Answering these questions is not just important when conducting a spoken or texted conversation, but also in such cases like overhearing a conversation or listening to a lecture, as well as, for example, when reading an advertisement, political statement, or blog.

(4) Further thinking: Finally, there are countless things that the communicator did not intend to convey but that you will nevertheless rapidly infer from the signs, the situation model, and/or the communicator's stance and social intention, consciously or unconsciously. For example, the use of overly complex words ("Mark is antagonized") can signal professional deformation or a disregard for

the addressee, the situation referred to can reveal a misanalysis on the part of the communicator, and, say, a contemptuous tone of voice and social intention to gossip can betray other things, such as that you're talking to an arrogant person, or to one that is compulsively trying to speak badly about people. Although perhaps not strictly part of language comprehension, these further thoughts can emerge rapidly, as you are reading or listening to the utterance at hand.

4.2 Emotion-based evaluation

The second critical part of the fALC model is the assumption that *all* of these various representations retrieved or constructed during language comprehension can trigger emotion, as internal stimuli appraised as relevant to the concerns of the comprehender. For example, at the sign level, you may have an unconscious positive or negative response to the name "Mark", not because what it refers to *now*, but simply because the name itself has a negative connotation for you, for whatever other conscious or unconscious reason. At the situation model level, learning that *this* particular Mark is angry can trigger all sorts of emotional responses, depending, in part, on your relationship to him (partner, child, friend, competitor, etc.). At the stance level, hearing compassion, contempt, anger or glee in a speaker's voice may elicit all sorts of emotion, either with or without you being aware of it. At the social intention level, inferring that the speaker is saying things about Mark to get closer to you may flatter or worry you. And as for further thinking, realizing that the speaker is kind, or not such a good friend after all, can also elicit rapid emotion. The various different strong or subtle emotional responses elicited as you are evaluating the utterance at all these levels can *all* express themselves in such things as corrugator or zygomaticus activity, and presumably do so simultaneously.

In addition, and in line with research on fluency (e.g., 125), the model captures the assumption that the *ease or difficulty of processing* can elicit evaluative emotion during language comprehension, conceptually -- but not necessarily empirically -- independent of what that processing is about. Think about negative emotion to words that are hard to pronounce, to sentences that are hard to parse, or to texts that are poorly composed or hard to read or hear (e.g. because of poor typography or too much background noise).

4.3 Emotion as simulation

In the above routes from language to emotion, the comprehender's emotion systems are used for their original purpose, *evaluation*, in ways that are comparable to how directly perceived objects, situations and events, as well as the fluency of one's own actions, can elicit emotion. However, language is special because it can also *refer to* emotional states and expressions and can recruit the comprehender's emotion systems *as part of doing so*. Embodied language processing studies have indicated that reading or hearing a word can lead to a simulation of concrete experiences with what the word denotes or refers to, i.e. the neural (and sometimes also bodily) re-instantiation of relevant perceptual, motor, and other experience-induced processes and states associated with what the concept or phrasal combination of concepts *is about* (126, 127, 128, 129, 130, 124). For example, reading action words like 'kick' or 'pick' leads to activation of the motor cortex involved in actually realizing the described movements (131, 132), and reading phrases such as "he saw an eagle in the sky" leads to a perceptual

simulation of the described situation (133, 134). In line with these observations in other domains, the corrugator and zygomaticus EMG-effects induced by words such as "angry" or "I am smiling" are usually interpreted in terms of emotion *simulation*, rather than as reflecting emotion-based evaluation (see, e.g. 67, 82, 87).

According to the fALC model, emotion simulation -- the use of one's own emotion systems to construct mental representations of emotion or components thereof -- can in principle occur in at least three different components of language comprehension. First, when reading "Mark is angry", people may simulate anger as part of retrieving stored information about the word "angry" from the mental lexicon -- to the extent that such retrieval-based simulation recruits facial muscle motor control systems (along similar lines as in, e.g., the abovementioned Pülvermüller et al. study), the resulting neural activity could lead to a bit of frowning. Second, comprehenders may simulate anger as part of imagining, i.e., constructing a vivid representation of an angry Mark in their model of the situation being talked about -- to the extent that such situation model simulation recruits facial muscle motor control systems, this could again lead to a bit of frowning. Third, in cases where a communicative act contains partial or indirect cues to strong *communicator* stance, emotion simulation may also occur as part of modelling the latter. For example, when a text message from a familiar person suggests strong emotion via its 'tone' (i.e., via choice of words or typography), readers may imagine the plausibly associated facial or prosodic expressions as part of their model of the communicator's current stance. Also, when hearing a familiar person smile over the phone, listeners may use their emotion systems to model other, e.g., visual, aspects of the communicator's stance. Whether any of this actually occurs in any particular situation is an empirical issue, of course (see 67, and other embodied language processing research for relevant evidence). Critically, however, and illustrated by the fact that people can enjoy somebody else's negative emotion (as in Schadenfreude), *simulating* emotion as part of the retrieval of a lexical concept from long-term memory and/or as part of modelling the affective state of protagonists or communicators is conceptually very different from using one's emotion system to *evaluate* things. The fALC model captures this important distinction by postulating two different routes (**S** and **E** in figure 4) to facial motor systems activation, and, ultimately, EMG-recorded facial muscle activity.

4.4 Emotional mimicry and other factors

Apart from making explicit multiple levels of language comprehension and the difference between evaluation and simulation, the fALC model makes two additional assumptions. One is that when comprehenders vividly *imagine* what, e.g., an angry Mark looks like, or what the communicator's emotional expression might be when he or she is not directly seen, it is theoretically possible that they are also involuntarily 'contaminated' by the resulting mental image, in the same way in which *actually seeing* a person with a strong facial expression can cause observers to automatically mimic that expression. The idea of mimicking facial expressions that we have ourselves imagined may sound far-fetched, but may become somewhat more intuitive when we consider the impact of, say, "Trump smiled broadly", "Leonardo di Caprio looked really concerned", or similar sentences involving friends or loved ones. Importantly, the idea follows naturally from two well-established facts. First, there is considerable evidence that people partly involuntarily mimic visible emotional expressions of other people (see 135 and 136, for review; see also 42), and such visual mimicry must involve representations in the visual perception system (e.g., areas V1 and V2). The second fact is that the same visual

perception system is thought to be recruited when people *imagine*, rather than perceive, a visual scene (e.g., 137, 138). These two facts together open the door to an interesting hypothesis, which is that people may involuntarily mimic facial expressions *that they themselves have constructed* as part of making sense of language (see 87 for a mimicry-based interpretation of language-driven facial EMG effects). This self-cued facial mimicry hypothesis is not easy to test, and perhaps impossible to experimentally separate from the language-driven emotion simulation that is needed to bootstrap the process. Nevertheless, in the absence of evidence against the idea, we think it is important to include mimicry as a possible source of language-mediated facial EMG-effects in our model (**M** in figure 4).[5]

The second additional assumption is that many *non-emotional other factors* can potentially act as systematic confounds or sources of noise, such as the increased muscle tension induced by physical effort (48), facial muscle activity in the lower half of the face during covert articulation (46, 47), the selective relaxation or activation of specific facial muscles to improve auditory or visual perception, or the effort-induced steady increase in corrugator activity during an experimental session (see 42 for review). The boundary between emotional and non-emotional EMG effects will not always be clear, as in the case of increased corrugator activity associated with an error (139) -- is that part of an emotional response, or is it a conceptually separate index of orienting and effort? However, many clearly non-emotional types of facial movement exist, and marking this in the model (**O** in figure 4) is a reminder of potential confounds and sources of noise.

4.5 Using the model

The core idea of the fALC model is that language-induced facial EMG-responses can arise for a wide variety of interestingly different reasons*.* As such, the model can provide a new perspective on the studies reviewed. For example, it points to the possibility that facial EMG-effects induced by negation or person (cf. "I am not smiling", "you are smiling") need not just involve the contextual inhibition or tuning of lexical-conceptual emotion simulation (as supposed in 82, and 85), but can also involve simulation as part of situation model construction, and, in sufficiently contextualized cases, perhaps even a subtle evaluative response to the situation modelled. Situation model evaluation is clearly also a relevant possibility to consider for facial EMG effects involving whether an in- or outgroup member "got soaked by a taxi" (86), whether an in- or outgroup member "... is smiling" (88: study 3, 87), whether a good or bad Mark "... is angry" (98, 99, 89: study 3), or whether negative news concerns a bad-reputation company or a good-reputation one (106). Furthermore, to the extent that the verbally described situation is rich enough to allow people to vividly imagine the emotional expression of a

---

[5] Although regular perception-driven facial mimicry is itself also often described as a form of simulation (e.g., 119), such perceptual simulation is conceptually different from simulation involved in language-driven imagery -- the notion explored here is that the latter may give rise to the former. Also, although one can argue that emotional facial mimicry is a low-level form of emotional *evaluation* (the 'emotional contagion' or 'affective resonance' part of empathy; 140), there is some debate as to whether such mimicry is truly mediated by 'deep' emotional states or on a par with other, non-emotional behavioral mimicry (such as unconsciously adopting somebody else's sitting posture or walking rhythm). In the fALC model, therefore, we currently prefer to separate mimicry from evaluation.

protagonist (e.g., because it involves the facial expression of famous politicians, 87), we should consider the possibility that the EMG effects obtained might reflect facial mimicry as well.

Over and above situation-level representations, the model reminds us of the fact that some of the facial EMG-effects reported in the literature, such as the emoji findings reported in 100, as well as the affective prosody findings reported in 90, 76, and 92 can to an unknown extent reflect emotion that is triggered as a function of *the communicator's* inferred stance or social intention -- which also raises further questions about their specific proximal cause (emerging via evaluation, simulation, and/or, perhaps, mimicry). The model makes explicit that the facial EMG-effect reported to unexpected or incoherent materials (115, 116, 93, 94) might reflect an evaluative response to disfluent processing. And the model can for example help us be more specific about what particular secondary tasks can bring about (e.g., a "sentence likeability" rating task probably leads people to rate particular *situations*, not sentences; cf. 84).

The fALC model can help think about past results but also about future experiments. Consider the results of the two experiments with morally loaded stories (98, 99) depicted in Figure 3A, and replicated in another paradigm (89: study 3). The most interesting finding is that whereas "Mark is frustrated" increased corrugator activity relative to "Mark is happy" when Mark had displayed morally good behavior before, it did *not* increase corrugator activity when Mark had displayed morally bad behavior. By itself, this already shows that simple emotion simulation at the conceptual or situation-model level cannot account for the findings. The fALC model, however, suggests a number of alternative possible accounts. One is that the apparent non-responsiveness of readers to the emotions of a bad character reflects the simultaneous use of their emotion systems to *simulate and evaluate* the events described, with the two forces counteracting for bad characters. For example, reading about a "frustrated" bad character might increase frowning because of simulation, while simultaneously decreasing frowning because of some fairness-based evaluation (cf. Schadenfreude). A second possibility is that readers are somehow *less inclined to simulate the state of a bad character*, an idea that fits with the emerging realization that language-driven simulation is not an all-or-none concept but depends on all kinds of contextual factors (128, 141, 142, 132, 129, 130). A third possibility is that readers are *less likely to automatically mimic the simulated emotions of bad characters*, an idea that is consistent with reports that facial mimicry can be diminished by disliking or disidentifying with the other person, by the desire to disaffiliate from somebody, and, related, by classifying him or her as an outgroup member (135). And fourth, it could be that readers *do not evaluate -- i.e., care about -- what happens to bad characters at all*. Some of these hypotheses might be more plausible than others, and some are very hard to test. For now, however, the point is that the fALC model can help in systematically defining the options, and as such facilitate the search for what is actually happening in this particular situation.

5. CHALLENGES AND OPPORTUNITIES

We have reviewed facial EMG-research on affective language comprehension and proposed a model of how language can lead to changes in facial muscle activity. What are the challenges and opportunities ahead of us? *One* opportunity is obvious: facial EMG can help track conscious and unconscious emotional responses to language as it unfolds. That is good news, because facial EMG

extends the methods repertoire for tracking emotion in unique ways. For example, relative to EEG, MEG or fMRI, it can tap into somebody's emotional state without requiring lengthy electrode attachments sessions (EEG), expensive and relatively inaccessible equipment (MEG, fMRI), and the complex analyses that comes with high-dimensional data (all three). Also, whereas skin conductance provides information about undirected arousal only, with fairly low temporal resolution, facial EMG provides directional (valence) as well as intensity information, with a higher temporal resolution. And because EMG can detect facial muscle activity even when this is too weak to lead to observable skin movement (53), the measure is more sensitive than automated facial image analysis (such as Face Reader), an important property when working with language stimuli in a laboratory setting (42). Whether facial EMG should be the method of choice naturally depends on the research question: if the latter is about *feeling* only, for example, self-report is the way to go. However, in affective language comprehension research, facial EMG clearly occupies a unique and attractive niche.

We see several important challenges for facial EMG research in this domain. First, although the fALC model need not be correct in the exact distinctions made, Figure 4 does immediately foreground a big challenge to facial EMG research in psycholinguistics and other fields: we're dealing with a *very* complex situation here. When exploring single written words presented without any additional context in the lab, this complexity is still relatively restricted. However, as soon as we enrich the materials or the context, many other options open up. For example, as soon as language is spoken, stance-elicited emotion can enter the picture, even with a single word. Also, as soon as sentences really *describe* something, situation model simulation and evaluation enter the picture, and as we move to bigger chunks of discourse, such as private or professional conversations, advertisements, government messages, or blogs (to name just a few), emotions elicited by inferred social intentions enter the picture too. Although the complexity made explicit in our model is perhaps a little disheartening, it also points to exciting new questions that as yet have not been tackled. Research on those questions might confirm some of the predictions of the fALC model, but -- just as attractive -- might also eliminate some of the proposed routes from language to facially expressed emotion.

The second challenge involves using facial EMG research to assess specific emotions. Although emotion and emotional expression is part and parcel of our biological heritage, there has been much debate over how reliable the information provided by facial, vocal and other bodily cues to emotion actually is (see, e.g., 38, 118, 39). What that debate has made very clear is that, in contrast to what early basic-emotions research suggested (e.g., 143), particular emotions do not map onto particular facial, vocal, or other bodily expression in a simple one-to-one fashion, or one that is completely invariant across occasions. The various aspects of a particular emotion are *probabilistically* linked (see 144, 39), which means that particular appraisals and motivational, physiological, cognitive and behavioral responses typically *but not invariably* cohere with each other. For example, although anger tends to increase the probability of frowning, to such an extent that the cue becomes an informative cue, not *every* instance of anger does so. Because our body is used for many things besides expressing emotions, facial, vocal, and other bodily cues are often ambiguous, an ambiguity that we can only resolve by taking the context into account too (e.g., what is the situation, who is involved, what cultural constraints are in place?).

Now, emotional expressions are reliable and specific enough to do considerable work in our daily lives. We routinely pay attention to how people look, sound, and move to infer specific emotional states and

the associated intentions -- all that would not happen if facial, vocal, and other embodied emotional cues are fundamentally unreliable, or only signal valence. However, the problem is that much of the rich context that allows us to effectively disambiguate facial signals in real life is *not* present in the average laboratory experiment. One way to address this problem is to resort to high-dimensional signal measurement (38), so that the simultaneous recording of many different facial muscles, autonomous nervous system parameters, and other potentially relevant bodily cues can provide additional constraints. The other, and often more feasible, option is to design experiments in which the materials, tasks, and other details of the setting constrain interpretation to such an extent that the activity of even just one or two facial muscles becomes sufficiently unambiguous and informative.

The final challenge also relates to the multi-interpretability of facial expressions. It has been argued that emotional expressions conveyed through the face, the voice, and the rest of the body provide a more 'honest' indication of emotion than what people *say*, because such embodied multi-channel expressions often arise involuntarily, are not easy to suppress, and, as rich and complex patterns, are relatively hard to generate deliberately (145, 39, 40). At the same time, however, real-life experience shows that people *can* deliberately generate emotional expressions that we take at face value. Actors, for instance, do so routinely, and all parents of young children will recognize the utility of being able to make an emotional facial expression that is at odds with one's inner state. Moving beyond such anecdotal observations, careful research has shown, for instance, that some facial expressions are only produced when a particular audience is around (e.g., 146, 147, 148), and that, more generally, we all use facial expressions as social tools (121). Related, there is discussion as to what 'honest' really means (see, e.g., 119). All this testifies to the complexity of using facial EMG when studying language comprehension. As long as nobody else is around, and the experiment is designed such that comprehenders do not feel that making certain facial expressions is a desirable thing to do, facial EMG may predominantly tap into 'inner' emotional states, generated for one or more of the reasons laid out in the fALC model. However, all that may change when an interlocutor or other audience enters the arena, because in such more social situations, facial expressions can and often will be used *strategically*, under the expressers's full control and deliberate designed to have a particular impact on one's current interlocutor or audience (121, 146). This means that as soon as we abandon the classic solitary-comprehender paradigm to explore comprehension in a more social context, facial EMG will most certainly not just 'tap into inner emotional states', but will also pick up on strategic facial displays that, although probably often motivated by some emotion, are not themselves direct reflections of that emotion (nor part of language comprehension proper).

These are all non-trivial challenges. However, rather than just avoiding all this complexity, it is much more interesting to address it. For example, by increasing the richness of our verbal stimuli, we can use facial EMG to explore the impact of stance signals and social intentions. By designing EMG-studies that independently control emotion simulation, emotional evaluation, and perhaps mimicry, we can try to tease those factors apart. And by manipulating the social context, we can use facial EMG to explore the exact conditions under which language-induced emotional expression arises, as an involuntary response to the stimulus and its context, as a deliberate social tool, or both. Language-driven emotion is all around us, in our personal lives, and in the big world out there. Facial EMG provides a unique tool to help us understand how such emotion comes about, as well as how we express it to influence others.

Acknowledgments

References

1. Brysbaert, M. (2019). *How many words do we read per minute? A review and meta-analysis of reading rate.* Submitted for publication.
2. Levelt, W. J. M. (1989) *Speaking: From intention to articulation.* Cambridge, MA: MIT Press.
3. Hagoort (Ed.). (2019). *Human language: From genes and brains to behavior*. Cambridge, MA: MIT Press.
4. Rueschemeyer, S. & Gaskell, M. G. (Eds.). (2018). *The Oxford handbook of psycholinguistics*. Oxford: Oxford University Press.
5. de Zubicaray, G. I., & Schiller, N. O. (Eds.). (2019). *The Oxford handbook of neurolinguistics*. Oxford: Oxford University Press.
6. Bohn-Gettler, C. M. (2019). Getting a Grip: The PET Framework for Studying How Reader Emotions Influence Comprehension. *Discourse Processes*, 1-16.
7. Hinojosa, J. A., Moreno, E. M., & Ferré, P. (2019). Affective neurolinguistics: towards a framework for reconciling language and emotion. Language, Cognition and Neuroscience, 1-27.
8. Jensen, T. W. (2014). Emotion in languaging: Languaging as affective, adaptive and flexible behavior in social interaction. *Frontiers in Psychology, 5,* 720.
9. Koelsch, S., Jacobs, A. M., Menninghaus, W., Liebal, K., Klann-Delius, G., von Scheve, C., & Gebauer, G. (2015). The quartet theory of human emotions: an integrative and neurofunctional model. *Physics of life reviews*, *13*, 1-27.
10. Majid, A. (2012). Current emotion research in the language sciences. *Emotion Review, 4(4),* 432-443.
11. Peräkylä, A., & Sorjonen, M. L. (2012). *Emotion in interaction*. Oxford: Oxford University Press.
12. van Berkum, J. J. A. (2018). *Language comprehension, emotion, and sociality: Aren't we missing something?* In Rueschemeyer, S. A. & Gaskell, G. (Ed.). *Oxford Handbook of Psycholinguistics* (pp. 644-669). Oxford: Oxford University Press.
13. van Berkum, J. J. A. (2019a). *Language comprehension and emotion: Where are the interfaces, and who cares?* In G. de Zubicaray & N. O. Schiller (Eds.), *Oxford Handbook of Neurolinguistics* (pp. 736-766). Oxford: Oxford Univ.Press.
14. van Berkum, J. J. A. (2019b). *Inclusive* affective neurolinguistics. *Language, Cognition and Neuroscience*.
15. Scherer, K. R. (2005). What are emotions? And how can they be measured? *Social science information*, *44*(4), 695-729.
16. Bradley, M. M., & Lang, P. J. (1994). Measuring emotion: the self-assessment manikin and the semantic differential. Journal of behavior therapy and experimental psychiatry, 25(1), 49-59.
17. Larsen, J. T., Norris, C. J., & Cacioppo, J. T. (2003). Effects of positive and negative affect on electromyographic activity over zygomaticus major and corrugator supercilii. *Psychophysiology*, *40*(5), 776 – 785.
18. Fontaine, J. R., Scherer, K. R., & Soriano, C. (Eds.). (2013). Components of emotional meaning: A sourcebook. Oxford: Oxford University Press.
19. Nummenmaa, L., Glerean, E., Hari, R., & Hietanen, J. K. (2014). Bodily maps of emotions. Proceedings of the National Academy of Sciences, 111(2), 646-651.
20. Adolphs, R. (2017). How should neuroscience study emotions? By distinguishing emotion states, concepts, and experiences. *Social, Cognitive and Affective Neuroscience 12(1),* 24-31.

21. Carlson, J.M. (2018). Reactive emotional processes in the absence of conscious awareness. In A. S. Fox, R. C. Lapate, A. J. Shackman & R. J. Davidson (Eds.). (2018). *The nature of emotion: Fundamental questions* (pp. 312-316). Oxford: Oxford University Press.

22. Damasio, A. R. & Damasio, H. (2018). Emotions and feelings: William James then and now. In A. S. Fox, R. C. Lapate, A. J. Shackman & R. J. Davidson (Eds.). (2018). *The nature of emotion: Fundamental questions* (pp. 1-6). Oxford: Oxford University Press.

23. De Gelder, B. & Tamietto, M. (2018). What is the role of unconscious emotions and of conscious awareness in emotions? In A. S. Fox, R. C. Lapate, A. J. Shackman & R. J. Davidson (Eds.). (2018). *The nature of emotion: Fundamental questions* (pp. 316-322). Oxford: Oxford University Press.

24. Scherer, K. R., & Moors, A. (2019). The emotion process: event appraisal and component differentiation. *Annual Review of Psychology*, *70*, 719-745.

25. Dimberg, U., Thunberg, M., & Elmehed, K. (2000). Unconscious facial reactions to emotional facial expressions. *Psychological Science*, *11*(1), 86-89.

26. Tamietto, M., & De Gelder, B. (2010). Neural bases of the non-conscious perception of emotional signals. Nature Reviews Neuroscience, 11(10), 697.

27. Frijda, N. H. (2007). *The laws of emotion.* Mahwah, NJ: Erlbaum.

28. Krieglmeyer, R., Deutsch, R., De Houwer, J., & De Raedt, R. (2010). Being moved: Valence activates approach-avoidance behavior independently of evaluation and approach-avoidance intentions. Psychological Science, 21(4), 607-613.

29. Citron, F. M., Abugaber, D., & Herbert, C. (2016). Approach and withdrawal tendencies during written word processing: Effects of task, emotional valence, and emotional arousal. *Frontiers in Psychology*, *6*, 1935.

30. van Berkum, J. J. A., Holleman, B. C., Nieuwland, M., Otten, M. & Murre, J. J. M. (2009). Right or wrong? The brain's fast response to morally objectionable statements. *Psychological Science, 20,* 1092-1099.

31. Citron, F. M. (2012). Neural correlates of written emotion word processing: a review of recent electrophysiological and hemodynamic neuroimaging studies. Brain and language, 122(3), 211-226.

32. Wood, A., Martin, J. & Niedenthal, P. (2018). How and why emotions are embodied. In A. S. Fox, R. C. Lapate, A. J. Shackman & R. J. Davidson (Eds.). (2018). *The nature of emotion: Fundamental questions* (pp. 277-280). Oxford: Oxford University Press.

33. Damasio, A. R. (2003). *Looking for Spinoza: Joy, sorrow, and the feeling brain.* Houghton Mifflin Harcourt.

34. Kreibig, S. D. (2010). Autonomic nervous system activity in emotion: A review. Biological psychology, 84(3), 394-421.

35. Lucas, I., Sánchez-Adam, A., Vila, J., & Guerra, P. (2019). Positive emotional reactions to loved names. *Psychophysiology*, e13363.

36. Boren, J. P., & Veksler, A. E. (2011). A decade of research exploring biology and communication: The nervous, endocrine, cardiovascular, and immune systems. *Communication Research Trends, 30*(4), 1 – 31.

37. Francis, A. L., & Oliver, J. (2018). Psychophysiological measurement of affective responses during speech perception. *Hearing Research*, 369, 103 – 119.

38. Cowen, A., Sauter, D., Tracy, J. L., & Keltner, D. (2019). Mapping the Passions: Toward a High-Dimensional Taxonomy of Emotional Experience and Expression. *Psychological Science in the Public Interest*, *20*(1), 69-90.

39. Scarantino, A. (2017). How to do things with emotional expressions: The theory of affective pragmatics. *Psychological Inquiry*, *28*(2-3), 165-185.

40. Scarantino, A. (2018). Emotional Expressions as Speech Act Analogs. Philosophy of Science, 85(5), 1038-1053.

41. Altenmüller, E., Schmidt, S., & Zimmermann, E. (Eds.). (2013). *The evolution of emotional communication: From sounds in nonhuman mammals to speech and music in man.* Oxford: Oxford University Press.

42. van Boxtel, A. Electromyographic (EMG) responses of facial muscles during language processing. This volume

43. Hess, U. (2018). The (more or less) communication of emotions serves social problem solving. In A. S. Fox, R. C. Lapate, A. J. Shackman & R. J. Davidson (Eds.). (2018). *The nature of emotion: Fundamental questions* (pp. 250-253)*. Oxford: Oxford University Press.

44. van Boxtel, A. (2010). Facial EMG as a tool for inferring affective states. In A.J. Spink, F. Grieco, O.E. Krips, L.W.S. Loijens, L.P.J.J. Noldus, & P.H. Zimmerman (Eds.), *Proceedings of Measuring Behavior 2010.*

45. Fridlund, A. J., & Cacioppo, J. T. (1986). Guidelines for human electromyographic research. *Psychophysiology, 23(5),* 567 - 589.

46. Cacioppo, J. T., & Petty, R. E. (1981a). Electromyograms as measures of extent and affectivity of information processing. *American Psychologist*, *36*(5), 441 – 456.

47. Cacioppo, J. T., & Petty, R. E. (1981b). Electromyographic specificity during covert information processing. *Psychophysiology*, *18*(5), 518-523.

48. de Morree, H. M., & Marcora, S. M. (2012). Facial electromyography as a measure of effort during physical and mental tasks. In H. Takada (Ed.), *Electromyography: New developments, procedures and applications* (pp. 103-122). Nova Science Publishers.

49. Waterink, W. & van Boxtel, A. (1994). Facial and jaw-elevator EMG activity in relation to changes in performance level during a sustained information processing task. *Biological Psychology, 37,* 183-198.

50. Harris, K. S. (1970). Physiological measures of speech movements: EMG and fiber-optic studies. *ASHA Reports, 5,* 271-282.

51. Wohlert, A. B., & Hammen, V. L. (2000). Lip muscle activity related to speech rate and loudness. *Journal of Speech, Language, and Hearing Research, 43(5),* 1229-1239.

52. Schwartz, G. E., Fair, P. L., Salt, P., Mandel, M. R., & Klerman, G. L. (1976). Facial muscle patterning to affective imagery in depressed and nondepressed subjects. *Science*, *192*(4238), 489 – 491.

53. Rodriguez-Falces, J., Navallas, J., & Malanda, A. (2012). EMG modeling. In G.R. Naik (Ed.), *Computational Intelligence in Electromyography Analysis - A Perspective on Current Applications and Future Challenges*. IntechOpen.

54. Cacioppo, J. T., & Petty, R. E. (1979). Attitudes and cognitive response: An electrophysiological approach. *Journal of Personality and Social Psychology*, *37*(12), 2181 – 2199.

55. Tassinary, L. G., & Cacioppo, J. T. (1992). Unobservable facial actions and emotion. *Psychological Science*, *3*(1), 28 – 33.

56. Braun, N., Goudbeek, M., & Krahmer, E. (2019). Language and emotion–A foosball study: The influence of affective state on language production in a competitive setting. *PloS one, 14(5),* e0217419.

57. Andrade, C. R. F. D., Sassi, F. C., Juste, F., & Mendonça, L. I. Z. D. (2008). Persistent developmental stuttering as a cortical-subcortical dysfunction: evidence from muscle activation. *Arquivos de Neuro-Psiquiatria, 66(3B),* 659-664.

58. Walsh, B., & Smith, A. (2013). Oral electromyography activation patterns for speech are similar in preschoolers who do and do not stutter. *Journal of Speech, Language, and Hearing Research, 56(5),* 1441-1454.

59. Sukalla, F., Bilandzic, H., Bolls, P. D., & Busselle, R. W. (2015). Embodiment of narrative engagement. *Journal of Media Psychology*, *28*(4), 175 – 186.

60. Bolls, P. D., Lang, A., & Potter, R. F. (2001). The effects of message valence and listener arousal on attention, memory, and facial muscular responses to radio advertisements. *Communication Research*, *28*(5), 627-651.

61. Cacioppo, J. T., Petty, R. E., & Marshall-Goodell, B. (1984). Electromyographic specificity during simple physical and attitudinal tasks: Location and topographical features of integrated EMG responses. *Biological Psychology*, *18*, 85-121.

62. Cannon, P. R., Schnall, S., & White, M. (2011). Transgressions and expressions: Affective facial muscle activity predicts moral judgments. *Social Psychological and Personality Science*, *2*(3), 325-331.

63. Elash, C. A., Tiffany, S. T., & Vrana, S. R. (1995). Manipulation of smoking urges and affect through a brief-imagery procedure: Self-report, psychophysiological, and startle probe responses. *Experimental and Clinical Psychopharmacology*, *3*(2), 156 – 162.

64. Peasley-Miklus, C. E., & Vrana, S. R. (2000). Effect of worrisome and relaxing thinking on fearful emotional processing. *Behaviour Research and Therapy*, *38*(2), 129-144.

65. Larsen, J. T., Norris, C. J., McGraw, A. P., Hawkley, L. C., & Cacioppo, J. T. (2009) The evaluative space grid: A single-item measure of positivity and negativity. *Cognition and Emotion, 23(3),* 453-480.

66. Kunkel, A. E. (2018). *The Processing of Moral Transgressions: Investigating the Role of Affective Evaluations* (Dissertation).

67. Foroni, F., & Semin, G. R. (2009). Language that puts you in touch with your bodily feelings: The multimodal responsiveness of affective expressions. *Psychological Science*, *20*(8), 974-980.

68. Borgeat, F., Elie, R., Chaloult, L., & Chabot, R. (1984). Psychophysiological responses to masked auditory stimuli. *The Canadian Journal of Psychiatry*, *30*(1), 22 – 27.

69. Wexler, B. E., Warrenburg, S., Schwartz, G. E., & Janer, L. D. (1992). EEG and EMG responses to emotion-evoking stimuli processed without conscious awareness. *Neuropsychologia*, *30*(12), 1065 – 1079.

70. Arndt, J., Allen, J. J. B., & Greenberg, J. (2001). Traces of terror: Subliminal death primes and facial electromyographic indices of affect. *Motivation and Emotion, 23*(3), 253 – 277.

71. Niedenthal, P. M., Winkielman, P., Mondillon, L., & Vermeulen, N. (2009). Embodiment of emotion concepts. *Journal of Personality and Social Psychology*, *96*(6), 1120 – 1136.

72. Baumeister, J. C., Foroni, F., Conrad, M., Rumiati, R. I., & Winkielman, P. (2017). Embodiment and emotional memory in first vs. second language. *Frontiers in Psychology*, *8*: 394.

73. Künecke, J., Sommer, W., Schacht, A., & Palazova, M. (2015). Embodied simulation of emotional valence: Facial muscle responses to abstract and concrete words. *Psychophysiology*, *52*(12), 1590-1598.

74. Neumann, R., Hess, M., Schulz, S. M., & Alpers, G. W. (2005). Automatic behavioural responses to valence: Evidence that facial action is facilitated by evaluative processing. *Cognition and Emotion*, *19*(4), 499 – 513.

75. Zhu, Y., & Suzuki, N. (2018). The face and brain in the emotional loop: Event-related potential correlates of the first facial response to emotional words. *North American Journal of Psychology*, *20*(1), 91 – 110.

76. Hietanen, J. K., Surakka, V., & Linnankoski, I. (1998). Facial electromyographic responses to vocal affect expressions. *Psychophysiology*, *35*(5), 530-536.

77. Philip, L., Martin, J. C., & Clavel, C. (2018). Suppression of facial mimicry of negative facial expressions in an incongruent context. *Journal of Psychophysiology*, *32*(4), 160 – 171.

78. Ferdenzi, C., Joussain, P., Digard, B., Luneau, L., Djordjevic, J., & Bensafi, M. (2017). Individual differences in verbal and non-verbal affective responses to smells: influence of odor label across cultures. *Chemical Senses*, *42*(1), 37 – 46.

79. Herbert, C., & Kissler, J. (2010). Motivational priming and processing interrupt: Startle reflex modulation during shallow and deep processing of emotional words. *International Journal of Psychophysiology*, *76*(2), 64 – 71.

80. Herbert, C., Kissler, J., Junghöfer, M., Peyk, P., & Rockstroh, B. (2006). Processing of emotional adjectives: Evidence from startle EMG and ERPs. *Psychophysiology*, *43*(2), 197-206.

81. Bayer, M., Sommer, W., & Schacht, A. (2010). Reading emotional words within sentences: the impact of arousal and valence on event-related potentials. *International Journal of Psychophysiology*, *78*(3), 299 – 307.

82. Foroni, F., & Semin, G. R. (2013). Comprehension of action negation involves inhibitory simulation. *Frontiers in Human Neuroscience*, *7*, 1 – 7.

83. Foroni, F. (2015). Do we embody second language? Evidence for 'partial' simulation during processing of a second language. *Brain and Cognition*, *99*, 8-16.

84. Fino, E., Menegatti, M., Avenanti, A., & Rubini, M. (2016). Enjoying vs. smiling: Facial muscular activation in response to emotional language. *Biological Psychology*, *118*, 126-135.

85. Weis, P. P., & Herbert, C. (2017). Bodily reactions to emotional words referring to own versus other people's emotions. *Frontiers in Psychology*, *8*: 1277.

86. Cikara, M., & Fiske, S. T. (2012). Stereotypes and schadenfreude: Affective and physiological markers of pleasure at outgroup misfortunes. *Social Psychological and Personality Science*, *3*(1), 63-71.

87. Fino, E., Menegatti, M., Avenanti, A., & Rubini, M. (2019). Unfolding political attitudes through the face: facial expressions when reading emotion language of left-and right-wing political leaders. *Scientific Reports*, *9*(1), 1-10.

88. Fino, E. (2014). *The language of others mirrored in the face: The role of political affiliation in automatic facial effects of language*. Bologna, doctoral dissertation (http://amsdottorato.unibo.it/6535/1/fino_edita_tesi.pdf).

89. 't Hart, B., Struiksma, M. E., Van Boxtel, A., & Van Berkum, J. J. A. (submitted). *Reading about us and them: Moral and minimal group effects on language-induced emotion.* Submitted for publication.

90. Arias, P., Belin, P., & Aucouturier, J. J. (2018). Auditory smiles trigger unconscious facial imitation. *Current Biology*, *28*(16), R782-R783.

91. Livingstone, S. R., Thompson, W. F., & Russo, F. A. (2009). Facial expressions and emotional singing: A study of perception and production with motion capture and electromyography. *Music Perception: An Interdisciplinary Journal*, *26*(5), 475 – 488.

92. Magnée, M. J. C. M., Stekelenburg, J. J., Kemner, C., & de Gelder, B. (2007). Similar facial electromyographic responses to faces, voices, and body expressions. *Neuroreport*, *18*(4), 369 – 372.

93. Levy, N., Harmon-Jones, C., & Harmon-Jones, E. (2018). Dissonance and discomfort: Does a simple cognitive inconsistency evoke a negative affective state?. *Motivation Science*, *4*(2), 95 – 108.

94. Topolinski, S., & Strack, F. (2015). Corrugator activity confirms immediate negative affect in surprise. *Frontiers in Psychology, 6,* 134.

95. Topolinski, S., Likowski, K. U., Weyers, P., & Strack, F. (2009). The face of fluency: Semantic coherence automatically elicits a specific pattern of facial muscle reactions. *Cognition and Emotion*, *23*(2), 260 – 271.

96. Bartholow, B. D., Fabiani, M., Gratton, G., & Bettencourt, B. A. (2001). A psychophysiological examination of cognitive processing of and affective responses to social expectancy violations. *Psychological Science*, *12*(3), 197-204.

97. Krumhuber, E. G., Tsankova, E., & Kappas, A. (2016). Examining subjective and physiological responses to norm violation using text-based vignettes. *International Journal of Psychology*, *53*(1), 23 – 30.

98. 't Hart, B., Struiksma, M. E., Van Boxtel, A., & Van Berkum, J. J. A. (2018). Emotion in stories: Facial EMG evidence for both mental simulation and moral evaluation. *Frontiers in Psychology*, *9*: 613.

99. 't Hart, B., Struiksma, M. E., Van Boxtel, A., & Van Berkum, J. J. A. (2019). Tracking affective language comprehension: Simulating and evaluating character affect in morally loaded narratives. *Frontiers in Psychology*, *10*: 318.

100. Thompson, D., Mackenzie, I. G., Leuthold, H., & Filik, R. (2016). Emotional responses to irony and emoticons in written language: Evidence from EDA and facial EMG. *Psychophysiology*, *53*(7), 1054-1062.

101. Fiacconi, C. M., & Owen, A. M. (2015). Using psychophysiological measures to examine the temporal profile of verbal humor elicitation. *PloS One*, *10*(9), 1 – 16.

102. Gavaruzzi, T., Sarlo, M., Giandomenico, F., Rumiati, R., Polato, F., De Lazzari, F., & Lotto, L. (2018). Assessing emotions conveyed and elicited by patient narratives and their impact on intention to participate in colorectal cancer screening: A psychophysiological investigation. *PloS one*, *13*(6), e0199882.

103. Leshner, G., Bolls, P., Gardner, E., Moore, J., & Kreuter, M. (2018). Breast cancer survivor testimonies: Effects of narrative and emotional valence on affect and cognition. *Cogent SocialSciences*, *4*(1), 1426281.

104. Tuisku, O. A., Ilves, M. K., Lylykangas, J. K., Surakka, V. V., Ainasoja, M., Rytövuori, S. E., & Ruohonen, M. J. (2018). Emotional responses of clients to veterinarian communication style during a vaccination visit in companion animal practice. *Journal of the American Veterinary Medical Association*, *252*(9), 1120 – 1132.

105. Kätsyri, J., Ravaja, N., & Salminen, M. (2012). Aesthetic images modulate emotional responses to reading news messages on a small screen: A psychophysiological investigation. *International Journal of Human-Computer Studies*, *70*(1), 72-87.

106. Ravaja, N., Aula, P., Falco, A., Laaksonen, S., Salminen, M., & Ainamo, A. (2015). Online news and corporate reputation. *Journal of Media Psychology*, *27*(3), 118 – 133.

107. Ravaja, N., Kallinen, K., Saari, T., & Keltikangas-Jarvinen, L. (2004). Suboptimal exposure to facial expressions when viewing video messages from a small screen: Effects on emotion, attention, and memory. *Journal of Experimental Psychology: Applied*, *10*(2), 120 – 131.

108. Ravaja, N., Saari, T., Kallinen, K., & Laarni, J. (2006). The role of mood in the processing of media messages from a small screen: Effects on subjective and physiological responses. *Media Psychology*, *8*(3), 239 – 265.

109. Wise, K., Kim, H. J., & Kim, J. (2009). The effect of searching versus surfing on cognitive and emotional responses to online news. *Journal of Media Psychology*, *21*(2), 49 – 59.

110. Lee, S., & Potter, R. F. (2018). The impact of emotional words on listeners' emotional and cognitive responses in the context of advertisements. *Communication Research, 00*(0), 1 – 16.

111. Fiacconi, C. M., & Owen, A. M. (2016). Using facial electromyography to detect preserved emotional processing in disorders of consciousness: A proof-of-principle study. *Clinical Neurophysiology*, *127*(9), 3000-3006.

112. Morisseau, T., Mermillod, M., Eymond, C., Van Der Henst, J. B., & Noveck, I. A. (2017). You can laugh at everything, but not with everyone. *Interaction Studies*, *18*(1), 116-141.

113. van Leeuwen, A. R. (2017). *Right on Time: Synchronization, Overlap, and Affiliation in Conversation*. Utrecht: LOT Dissertation Series.

114. Wassiliwizky, E., Koelsch, S., Wagner, V., Jacobsen, T., & Menninghaus, W. (2017). The emotional power of poetry: Neural circuitry, psychophysiology and compositional principles. *Social Cognitive and Affective Neuroscience*, *12*(8), 1229-1240.

115. Larson, K., Hazlett, R. L., Chaparro, B. S., & Picard, R. W. (2007). Measuring the Aesthetics of Reading. In *People and Computers XX—Engage* (pp. 41-56). London: Springer.

116. Durso, F. T., Geldbach, K. M., & Corballis, P. (2012). Detecting confusion using facial electromyography. *Human Factors*, *54*(1), 60-69.

117. Luck, S. J., & Gaspelin, N. (2017). How to get statistically significant effects in any ERP experiment (and why you shouldn't). *Psychophysiology*, *54*(1), 146-157.

118. Feldman Barrett, L., Adolphs, R., Marsella, S., Martinez, A. M., & Pollak, S. D. (2019). Emotional expressions reconsidered: Challenges to inferring emotion from human facial movements. *Psychological science in the public interest*, *20*(1), 1-68.

119. Niedenthal, P. M., Mermillod, M., Maringer, M., & Hess, U. (2010). The Simulation of Smiles (SIMS) model: Embodied simulation and the meaning of facial expression. *Behavioral and Brain Sciences*, *33*(6), 417-480.

120. Ekman, P., & Cordaro, D. (2011). What is meant by calling emotions basic. *Emotion Review*, *3*(4), 364-370.

121. Fridlund, A. J. (1994). *Human facial expression: An evolutionary view.* San Diego, CA: Academic Press.

122. Jackendoff, R. (2007). A parallel architecture perspective on language processing. Brain Research, 1146, 2-22.

123. Tomasello, M. (2008). *Origins of human communication*. Cambridge, MA: MIT Press.

124. Zwaan, R. A. (2016). Situation models, mental simulations, and abstract concepts in discourse comprehension. *Psychonomic Bulletin & Review, 23(4),* 1028-1034.

125. Winkielman, P., Olszanowski, M., & Gola, M. (2015). Faces in-between: Evaluations reflect the interplay of facial features and task-dependent fluency. Emotion, 15(2), 232.

126. Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology, 59,* 617–645.

127. Glenberg, A. M. (2017). How reading comprehension is embodied and why that matters. *International Electronic Journal of Elementary Education*, *4*(1), 5 - 18.

128. Havas, D. A., & Matheson, J. (2013). The functional role of the periphery in emotional language comprehension. *Frontiers in Psychology*, *4*: 294.

129. Winkielman, P., Coulson, S., & Niedenthal, P. (2018). Dynamic grounding of emotion concepts. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *373*(1752), 20170127.

130. Zwaan, R. A. (2014). Embodiment and language comprehension: reframing the discussion. *Trends in Cognitive Sciences,* 18, 229–234.

131. Pulvermüller, F., Shtyrov, Y., & Ilmoniemi, R. (2005). Brain signatures of meaning access in action word recognition. *Journal of Cognitive Neuroscience*, *17*(6), 884-892.

132. Willems, R. M., & Casasanto, D. (2011). Flexibility in embodied language understanding. *Frontiers in Psychology*, *2*.

133. Zwaan, R. A., & Pecher, D. (2012). Revisiting mental simulation in language comprehension: six replication attempts. *PLoS One,* 7:51382.

134. Zwaan, R. A., Stanfield, R. A., & Yaxley, R. H. (2002). Language comprehenders mentally represent the shapes of objects. *Psychological Science, 13,* 168–171.

135. Hess, U., & Fischer, A. (2014). Emotional mimicry: why & when we mimic emotions. *Social and Personality Psychology Compass, 8,* 45-57.

136. Hatfield, E., Bensman, L., Thornton, P. D., & Rapson, R. L. (2014). New perspectives on emotional contagion: A review of classic and recent research on facial mimicry and contagion. *Interpersona, 8(2),* 159–179.

137. Albers, A. M., Kok, P., Toni, I., Dijkerman, H. C., & De Lange, F. P. (2013). Shared representations for working memory and mental imagery in early visual cortex. *Current Biology, 23(15),* 1427-1431.

138. Dijkstra, N., Bosch, S. E., & van Gerven, M. A. (2019). Shared neural mechanisms of visual perception and imagery. *Trends in Cognitive Sciences, 23(5*), 423-434.

139. Elkins-Brown, N., Saunders, B., & Inzlicht, M. (2016). Error-related electromyographic activity over the corrugator supercilii is associated with neural performance monitoring. *Psychophysiology*, *53*(2), 159-170.

140. Decety, J., & Cowell, J. M. (2014). Friends or foes: is empathy necessary for moral behavior? *Perspectives in Psychological Science*, 9, 525–537.

141. Pecher, D. (2018). Curb your embodiment. *Topics in Cognitive Science*, *10*(3), 501-517.

142. Pecher, D., & Zeelenberg, R. (2018). Boundaries to grounding abstract concepts. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *373*(1752), 20170132.

143. Ekman, P., & Friesen, W. V. (1971). Constants across cultures in the face and emotion. Journal of personality and social psychology, 17(2), 124.

144. Scarantino, A. (2014). The motivational theory of emotions. *Moral psychology and human agency*, 156-185.

145. Mortillaro, M., Mehu, M., & Scherer, K. R. (2013). The evolutionary origin of multimodal synchronization and emotional expression. In E. Altenmüller, S. Schmidt, & E. Zimmermann, (Eds.). *The evolution of emotional communication: From sounds in nonhuman mammals to speech and music in man* (pp. 3-25)*.* Oxford: Oxford University Press.

146. Crivelli, C., & Fridlund, A. J. (2018). Facial displays are tools for social influence. *Trends in Cognitive Sciences*, *22*(5), 388-399.

147. Kraut, R. E., & Johnston, R. E. (1979). Social and emotional messages of smiling: an ethological approach. Journal of personality and social psychology, 37(9), 1539.

148. Ruiz-Belda, M. A., Fernández-Dols, J. M., Carrera, P., & Barchard, K. (2003). Spontaneous facial expressions of happy bowlers and soccer fans. Cognition and Emotion, 17(2), 315-326.