Title: 'My face is listening to your smile': Emotional contagion to vocal smile revealed by combined pupil reactivity and motor resonance

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Abstract:

Interaction between the different components of emotional contagion (i.e. emotional state and facial motor resonance), whether during implicit or explicit appraisal of emotion remains controversial. The aim of this study was i) to separate between these components thanks to vocal smile processing and ii) to estimate how they reflect implicit processes and/or an explicit appraisal loop. Emotional contagion to discrete vocal emotions was studied in 25 adults, through motor resonance and Autonomic Nervous System (ANS) reactivity. Facial expressions (fEMG: facial electromyography) and pupil dilation were assessed during processing and judgement of artificially emotionally modified sentences. fEMG revealed that *Zygomaticus major* was reactive to perceived sounds valence while *Corrugator supercilii* activity rather reflected explicit judgement. Timing analysis of pupil dilation provided further insight into both the emotional state and the implicit and explicit processing of vocal emotion, showing an early activity for emotional stimuli compared to neutral ones, followed by variations based on sounds valence, and by a late additional increase of pupil diameter depending on judgement. This innovative combination of these electrophysiological measures shed new light on the debated central and peripherical views within the framework of emotional contagion.

1. Introduction

Emotional contagion corresponds to a tendency to infer and react to sensory, motor, physiological and affective states of others (Hatfield et al., 1993). Three invariable characteristics can be identified: it is primitive, automatic, and implicit. This process enables humans to understand and feel others emotions, thoughts and intentions (Premack & Woodruff, 1978). Emotional contagion triggers both emotional state (possibly through automatic mapping of emotions; Damasio & Blanc, 1995) and expression in the receiver, such as congruent facial expression through the motor resonance process (Carsten et al., 2019). However, the role of facial output has been subject of much debate as it could constitute both a readout of emotional state and an input for the subjective experience of emotion. Authors even proposed a primacy of facial expression on emotional experience (Izard, 1971), even if effect of facial feedback on discrete emotion remains controversial (Coles et al., 2022; Soussignan, 2004). Such hypothesis of a facial feedback supports more comprehensive theories according to which emotional state is modulated by feedback from the peripherical bodily sensations (James, 1884), as opposed to central theories that postulate that they would reflect independent components of the emotional response (Cannon, 1927). Another theoretical framework suggests that emotional state would largely be influenced by cognitive appraisal (Scherer, 2009), and thus would depend on the explicitness of tasks (Lindström et al., 2018).

Previous studies have therefore examined the facial feedback effect on subjective emotional experience, or the influence of cognitive appraisal on facial expression (through unconscious mimicry, Dimberg et al., 2000). However, there is still a gap in literature concerning the interaction between emotional state and facial motor resonance, whether during implicit or explicit appraisal of emotion. The present study proposes to fill this gap by providing objective measures of the two components of emotional response during judgement of discrete vocal emotion.

One of the most characteristic example of emotional contagion is motor resonance to visual smile. It is already present in very young infant (Simpson et al., 2014) and in several species (Burrows et al., 2006). Because smiling is an important social cue, automatic response to someone else's smile contributes to matching the feeling of the sender (Olszanowski et al., 2020; Rychlowska et al., 2017), to synchronizing of feelings (Shore & Heerey, 2011) and to social reciprocity (U. Hess & Bourgeois, 2010).

Emotions can also be communicated vocally, through modulations of several acoustic cues (pitch, timbre, speech rate) that constitutes emotional prosody. Smiling is a great example of mouth position modulations. It involves the bilateral contraction of the *Zygomaticus major* (ZM) muscles (Wood et al., 2016) which induces a retraction of the mouth, leading to vocal tract modifications changing voice: stretching lips causes a reduction of vocal tract length, and an increase of formants frequency, making voice brighter (Ohala, 1980). It has been demonstrated that auditory cues are sufficient to identify smile through voice (Aubergé & Cathiard, 2003; Tartter, 1980; Tartter & Braun, 1994). Vocal smile has a robust mental representation in adults characterized by an upward shift in frequency of formants F1 and F2, and an increase of energy in F2, F3 and F4 (Ponsot et al., 2018).

Facial motor resonance is thus possible in response to information from auditory modality, as demonstrated in several studies using highly salient stimuli such as baby cry or crowd cheer from IADS (IADS: International Affective Digitized Sounds; Bradley & Lang, 2007) sounds database (Hietanen et al., 1998; Larsen et al., 2003; Verona et al., 2004). Music also provokes a congruent emotional response with a contraction of ZM in response to 'happy' music and in contrast, a contraction of the *Corrugator supercilii* (CS) for 'sad' one (Bullack et al., 2018). A contraction of ZM in response to pleasant vocalizations, and a relaxation in response to unpleasant sounds, have also been observed (Verona et al., 2004). Hietanen et al. (1998) used vocal affect expressions (i.e. 'Sarah' pronounced with 10 different emotional expressions such as astonished and sad) which led to congruent facial motor resonance.

Motor resonance to visual emotional stimuli has been shown to be unconscious (Dimberg et al., 2002; Dimberg & Thunberg, 1998) and could reflect an implicit processing of emotion (Dimberg et al., 2000). However, it should be noted that for vocal affect, motor resonance has been elicited only under attentional condition, while participants actively rated the listened stimuli (Lindström et al., 2018), making it difficult to dissociate between implicit and explicit contribution. Arias et al.'s studies (2018, 2021) used sentences artificially modified using a smiling filter, based on the perceptual representation of vocal smile demonstrated through a previous psychophysical task (Ponsot et al., 2018). They showed a congruent facial motor resonance with an increase of ZM activity in response to smiling sentences and an increase of CS activity in response to sentences rated as unsmile in sighted adults but also in congenitally blind participants. Interestingly, in this study ZM activity increased for smiling sentences even when participants did not rate them correctly, suggesting that implicit processing of smile elicited motor resonance that would be fairly independent of explicit judgement. Conversely, CS activity was directly associated with rating, making this paradigm suitable to disentangle between implicit processes and explicit appraisal involved in emotional contagion.

In parallel to facial muscle resonance, other physiological indices rather reflect the emotional state of the receiver. As an objective (Babiker et al., 2013) and face located index of the Autonomic Nervous System (ANS), pupil reactivity reflects the activation of the locus coeruleus-norepinephrine system (Aston-Jones & Cohen, 2005) and sympathetic activity related to emotional processing (Bradley et al., 2008; Aguillon-Hernandez et al., 2020; Babiker et al., 2015; Beatty, 1982; E. H. Hess & Polt, 1964). Prochazkova defined a model of Neurological Mechanisms of Emotional Contagion in which the emotional state of the 'sender' is reflected by the ANS of the 'receiver' to converge in a common physiological (i.e. with pupil dilation and motor contagion) and cognitive state (Prochazkova & Kret, 2017).

Pupil reactivity in response to emotion has been widely studied through visual modality (Aguillon-Hernandez et al., 2020; Bradley et al., 2001, 2008; Geangu et al., 2011). A larger automatic pupil dilation has thus been demonstrated in response to emotional compared to neutral facial expressions modulated by the ecological character of a stimulus: the more natural (i.e. dynamic vs static) the stimulus, the more the pupil dilates (Aguillon-Hernandez et al., 2020). Also, emotion nature impacts pupil reactivity. For example, happy faces induced a larger pupil dilation in comparison to sad faces (Burley & Daughters, 2020), or conversely (Aguillon-Hernandez et al., 2020). In the visual modality, face-to-face interaction generally leads to a synchronization of pupil size. Whether this synchronization is purely related to pupil mimicry (Aktar et al., 2020) or reflects an autonomic response to salient socio-emotional stimulus is still unknown. One way to disentangle these two processes is to study pupil reactivity to non-visual stimuli.

Pupil also reacts to pure tones (Legris et al., 2022) but also to emotional sounds such as vocalizations or voices that also induced dilation (Cherng et al., 2020; Zekveld et al., 2018), that is modulated, as for visual stimuli, by authenticity (Cosme et al., 2021). Strong auditory emotions through vocalizations, whether positive (baby laughing) or negative (a couple fighting), induce pupil dilation (Jin et al., 2015; Partala & Surakka, 2003), with a larger effect for negative compared to positive stimuli (Babiker et al., 2015). In the context of emotional prosody, a difference between negative and positive emotions has been observed with negative sentences inducing a stronger pupil dilation than positive emotions, in a protocol using very salient emotions from the IADS database (Jürgens et al., 2018). However, the study of pupil reactivity to emotional sounds is still in its infancy, and remains to be developed for ambiguous or discrete emotions.

The main objective of the current study was twofold:

i) To separate between the different components of emotional contagion (i.e. motor resonance and emotional state) and inform on their interplay.

ii) To estimate how these components reflect implicit processes and/or a potential explicit appraisal loop that would reinforce vocal emotional contagion.

For this purpose, we investigated facial motor resonance and autonomic reactivity (pupil dilation) to vocal smile. The combination of these indices was used to identify the various components of emotional contagion. To unravel implicit and explicit motor resonance to vocal smile respectively, facial muscle activity (ZM and CS) was measured reflecting participants listening (processing phase) and rating (judgment phase) standardized sentences containing discrete emotions. Using such discrete emotions would allow to prevent from saliency effect and to estimate the implicit processing thanks to poorly-recognized trials.

2. Materials and Method

2.1. Population

Twenty-five young adults aged from 20 to 30 years (mean 24.0 ± 2.5 years) participated in the study (12 females); all were native French speakers. To be included in this study, participants should not present (or having history of) neurological, psychiatric, metabolic disorder, or be under medication at the time of the study. Each participant signed an informed consent form, and the protocol received approval from Ethic Committee (PROSCEA2017/23; ID RCB: 2017-A00756-47). Each participants completed the Empathy Quotient questionnaire (EQ) (Baron-Cohen & Wheelwright, 2004) to estimate empathic abilities.

2.2.Stimuli and experimental design

2.2.1. Stimuli and sequence of stimulation

The same corpus as in Arias et al's studies (2018, 2021) has been used (see supplementary materials for a detailed description). To modify emotional prosody of used sentences, an algorithm was applied which modified sentences with a Smiling or an Unsmiling filter, according to the model of vocal smile demonstrated by Ponsot et al. (2018). A validation of the vocal smile model in this sample was a prerequisite when it came to the validity of modified emotional sentences. To confirm that participants in the current study used the same acoustic cues to characterized vocal smile, the same reverse correlation task has been performed (Ponsot et al., 2018). This validation revealed that the vocal smile model was the same in this new group of participants. The smiling effect is characterized by an increase and a shift of energy of F1 and F2, and an increase of F3 and F4 energy. A more detailed analysis of the reverse correlation results is presented in supplementary materials (Figure S1).

2.2.2. Procedure

Because the research question was focused on sounds effect, the displayed image, a rating scale (Figure 1B), was the same during all the experiment; successive stages were indicated with tones. Showing the same image all along the sequence allowed to keep a constant luminance (around 20 lux) and ensure that the observed effects on pupil were the consequence of the auditory task. Two tones, each one with a specific frequency, were created using Praat (Boersma, 2002) with a duration of 300ms each, normalized in energy and faded on in- and output. A first tone (440Hz) indicated the beginning of a new trial. The sentence was played 1000ms later, followed by a silent period of 2000ms, and then the second tone (275Hz) indicated the rating and the return to baseline (lasting 5000ms). The time course of each trial is represented in Figure 1A.

The participants were comfortably sitting 70cm away from the screen (1980x1080 px) and the speakers, with no chinrest. The intensity of sounds was controlled for sentences and was maintained between 58- and 62-dB SPL.

The following instruction was given to participants: ‘You will hear sentences, and you will have to rate how joyful or not the sentence was pronounced. You should not judge the content of the sentence but the way it was pronounced’. For the behavioral data associated to facial EMG and pupil recording, judgement was recorded through a 4-key response pad. The display image corresponds to the rating scale: the 2 right keys for 2 intensity levels of smile, the 2 left keys for 2 intensity levels of unsmile.

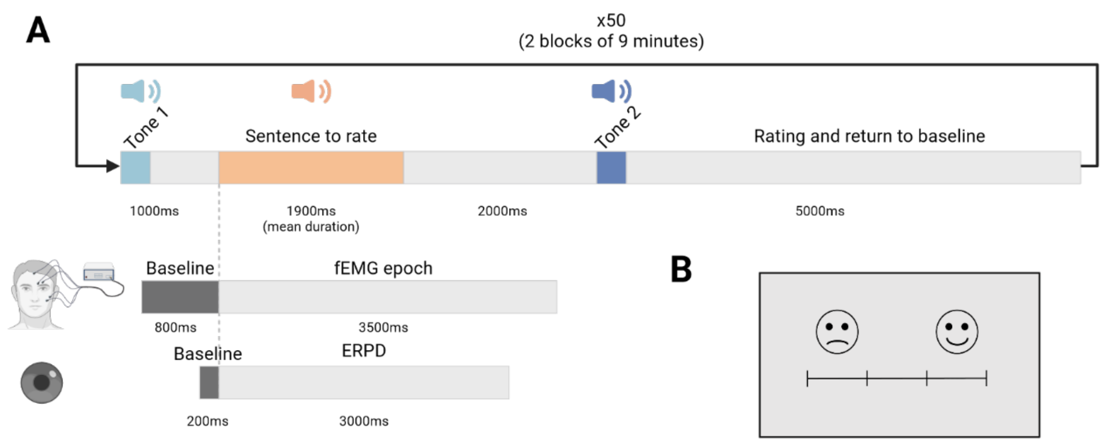

Figure 1: A: Timeline of a trial in the experimental sequence. Tone 1 indicated the beginning of a new trial, tone 2 indicated that the subject should rate the sentence at this timepoint. B: Rating scale displayed on screen during all the task; ERPD: Event Related Pupil Dilation; fEMG: facial ElectroMyoGraphy.

2.3.Measurements

2.3.1. Facial EMG (fEMG) - Recording

Facial EMG (fEMG) was recorded with 4-mm Ag-AgCl electrodes EL254 and EL254S, the BIOPAC MP36 system (BIOPAC® Systems Inc. Goleta, CA) and AcqKnowledge® 4.1 software. In order to measure the activity of two facial muscles, *Zygomaticus major* (ZM) and *Corrugator supercilii*(CS), electrodes were placed on the participant’s left face after scrubbing with an abrasive paste to eliminate traces of moisturizer, makeup or transpiration according to standard Fridlund and Cacioppo's guidelines (1986). Data were recorded with a sampling rate of 1024Hz. For each muscle, two electrodes, separated by approximately 1cm, were used to measure the potential difference between anode and cathode, placed in the same position on every participant's face. One reference electrode was added in the middle forehead at the hairline.

2.3.2. Pupillometry - Recording

Pupil data were recorded using a SMI RED 500® system, synchronized with BIOPAC MP36®, at a 500Hz sampling rate using an infrared light (λ = 870nm) to detect and measure pupil diameter. Data were recorded only after a correct 5-points calibration with a deviation degree inferior to 1° (mean: 0.59°/0.58°).

2.4. Data analysis

2.4.1. Behavioral data analysis

In the following parts, the acoustical modification of the sentences is referred as Filter (Smiling vs Unsmiling) and the rating of the smiliness of the sentences is referred as Choice (Smile vs Unsmile). The congruence between Filter and Choice is referred as the Response, Correct (Smiling rated as Smile and Unsmiling rated as Unsmile) and Incorrect (Smiling rated as Unsmile and Unsmiling rated as Smile).

The Accuracy was calculated as the number of Correct responses divided by the sum of all Smiling and Unsmiling sentences (80 for each participant), to reflect the good rating of both filters (Equation 1). The Accuracy was compared to chance level (50%) to evaluate the recognition of emotional prosodic modulation.

$$Accuracy = \frac{nSmiling_{smile} + nUnsmiling_{unsmile}}{nSmiling + nUnsmiling}$$

Equation 1: Accuracy formula; $nFilter_{Choice}$: number of trials for a specific Filter and Choice; nFilter: total of trials for a specific Filter.

2.4.2. fEMG – Processing

Analysis and pre-processing of fEMG data were performed with MNE-toolbox on Python 3.9.4 (Gramfort et al., 2014). Data were filtered with a 50Hz IIR high-pass filter and a 250Hz low-pass filter. Then massive muscular activity considered as artefacts was manually removed after a visual inspection of all the recording. This step was followed by a segmentation in epochs with a 800ms pre-stimulus baseline and a duration of 3500ms. The beginning of the sentence marked the start of an epoch. The absolute value of the muscular activity was smoothed and averaged with a 300ms sliding window before a z-score normalization according to the baseline of the current trial was calculated. A mean of 20 ± 11% (mean ± sd) of trials was removed for each participant due to excessive movement artefacts. One participant was excluded from the fEMG group analysis because of excessive noise in signal, but data from this participant were kept in pupil and behavioral analysis.

2.4.3. Pupillometry – Processing

Raw pupil data pre-processing and processing was done on MATLAB® (R2015b; MathWorks) with in-house scripts. The first step of pupil data pre-processing was to detect and interpolate artifacts due to blinks and short losses of signal. Detection of blinks was done thanks to a velocity-based algorithm (Kret & Sjak-Shie, 2019; Nyström & Holmqvist, 2010) and manual detection. Then interpolation of the losing value was done with a cubic interpolation with the median value. For each trial, a 200ms baseline before the beginning of a sentence playing was extracted. The ERPD (Event-Related Pupil Dilation) was calculated as pupil diameter variation in response to stimuli presentation and choice compared to the baseline of the trial. Pupillary response was measured during 3000ms after the beginning of the sentence.

Finally, a visual inspection of each trial was done and 34 ± 22% (mean ± sd) of trials was removed for each participant due to excessive artifacts.

2.4.4. Statistical analysis

Statistical analyses were conducted with Rstudio 4.2.2 (R Core Team, 2022; Team, 2020) with the packages ggplot2 (Wickham, 2016), ez (Lawrence, 2016), tidyverse (Wickham et al., 2019) and dplyr (Wickham et al., 2021).

For each physiological measurement (i.e., muscle activity and pupil diameter) effects of different factors (Filter, Choice, Response) were estimated through mean amplitude of electrophysiological measures in selected time windows. In order to assess differences between conditions in a psychophysiologically relevant time window, randomizations (n = 10,000) were realized between conditions (Smiling vs Unsmiling and Smile vs Unsmile) (Voeten, 2022) with a Guthrie-Buchwald correction (Guthrie & Buchwald, 1991). For the fEMG data randomizations, a down-sampling to 512Hz was applied on the signal using MNE.

Within the randomizations a common 500ms window was selected, in the significant time period, in which average amplitude was measured for the different conditions in each physiological measure. To specify the significant effect in the selected time window, a repeated-measures ANOVA (Filter x Choice) was performed on mean muscular activity or ERPD amplitude. To assess the effect of the Response and interaction with Choice, a repeated-measures ANOVA of the mean amplitude of muscle activity and ERPD was performed with post-hoc pairwise comparisons with Bonferroni correction to further specify significant interaction effects within Correct and Incorrect Response.

Beside the mean amplitude analysis, in order to evaluate the kinetic of pupil dilation in response to Emotion, Filter and Choice according to Timing, an analysis of slopes was performed. A linear mixed model was applied with Emotion, Filter and/or Choice and Timing as fixed factors and with subjects as random factor with the lmer R library (Kuznetsova et al., 2017). This analysis was performed in different time windows after signal visual inspection: 700 to 1200ms for Emotion, 1200 to 1700 ms for Filter and 1700 to 2100 ms for Choice effect.

Finally, to link all measures, a Pearson correlation matrix was calculated between physiological measures, rating responses and EQ scores. A Bonferroni correction was applied for multiple comparisons. These results are presented in supplementary materials (Figure S5)

3. Results

3.1. Accuracy

In the present study, artificial prosodic modifications were correctly recognized by participants (Smiling and Unsmiling Filters) with an accuracy of 61 ± 5% (mean ± sd), above 50% ($t(24) = 11.55$, $p < .001$).

3.2. Motor resonance

Considering that the aim of this work was to contrast the muscular activity to Filter, Choice and Response, neutral sentences were removed from the analysis.

Considering that the two muscles display distinct activity, two separate analyses were performed (see Supplementary materials, Figure S2).

The permutations test revealed that significant differences were observed between 3000 and 3400ms for the Filter condition on *Zygomaticus major* (ZM) activity and between 1500 and 3500ms for the Choice condition on *Corrugator supercilii* (CS) activity. To standardize the analyses, amplitude measurements were performed on a common 500ms time window (2900-3400ms) for each muscle and condition.

3.2.1. *Zygomaticus major* (ZM) activity

A repeated-measures ANOVA was performed to analyze the effects of Filter (Smiling vs. Unsmiling), Choice (Smile vs Unsmile) and the interaction between these two factors on mean muscular activity of ZM in the 2900-3400ms time window. Main effect analysis revealed a significant effect of Filter ($F(1,23) = 4.73$, $p < .05$, $\eta^2 = .06$) (Table 1) (Figure 2A upper part and Figure 2C). A Smiling sentence induced a higher activity of ZM than an Unsmiling one (Figure 2C). Meanwhile, there was no main effect of Choice ($F(1,23) = .66$, $p > .05$, $\eta^2 = .007$) (Table 1) (Figure 2A lower part and Figure 2D) and no interaction between Filter and Choice ($F(1,23) = .28$, $p > .05$, $\eta^2 = .002$). A repeated-measures ANOVA considering the effects of Choice (Smile vs Unsmile) and Response (Correct vs Incorrect) did not provide any different results (see supplementary materials, Figure S3).

	Filter		Choice	
Condition	**Smiling**	**Unsmiling**	**Smile**	**Unsmile**
ZM	-14.7 ± 7	-44.6 ± 11	-24.7 ± 9	-34.5 ± 8
CS	18.7 ± 10	5.8 ± 13	-8.1 ± 13	32.5 ± 11

Table 1: Mean muscular activity amplitude in the 2900-3400ms window in response to smiling and unsmiling filtered sentences (a.u.) (mean ± standard error of the mean), ZM: Zygomaticus major, CS: Corrugator supercilii.

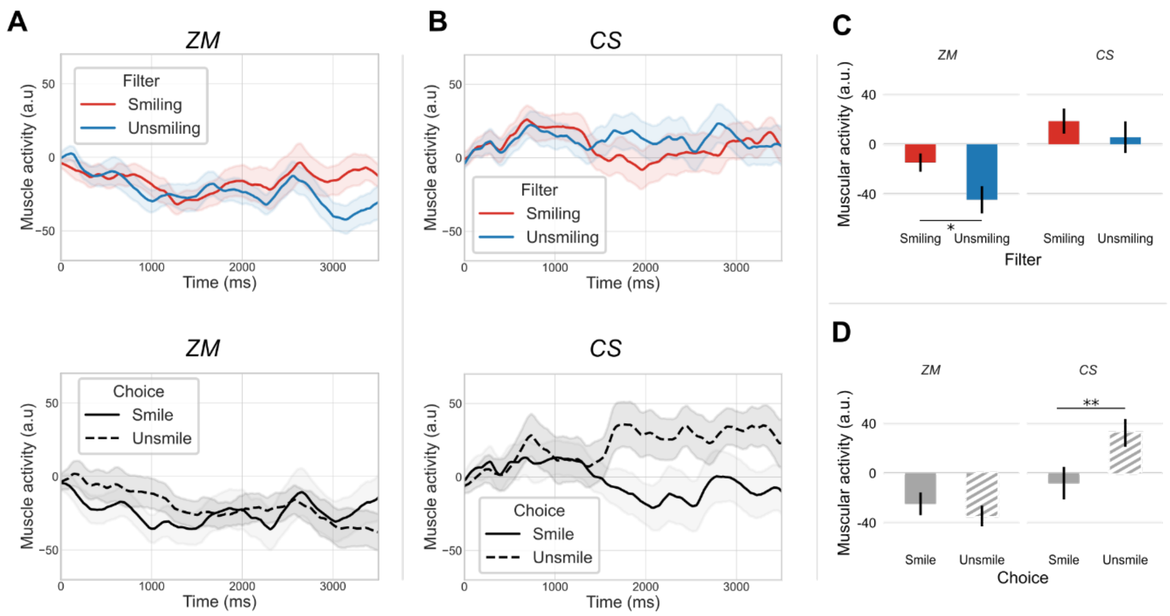

*Figure 2: Zygomaticus major (ZM) and Corrugator supercilii (CS) activity. A: Effect of filter (upper panel) and choice (lower panel) on ZM; B: Effect of filter (upper panel) and choice (lower panel) on CS; Effect of filter (C) and of the given choice (D) on CS and ZM -mean response amplitude in the window 2900-3400ms. Shaded areas represent standard error of the mean. * p<.05; ** p<.01*

3.2.2. *Corrugator Supercilii* (CS) activity

The same analysis was performed on CS activity with a repeated-measures ANOVA to analyze the effects of Filter (Smiling vs. Unsmiling), Choice (Smile vs. Unsmile) and the interaction between these two factors on mean muscular activity of CS in the 2900-3400ms time window. There was no main effect of Filter on mean amplitude activity of CS ($F(1,23) = 1.88$, $p > .05$, $\eta^2 = .01$) (Table 1) (Figure 2B upper part and Figure 2C) and no interaction between Filter and Choice ($F(1,23) = 3.33$, $p > .05$, $\eta^2 = .01$). Meanwhile, main effect analysis showed that Choice ($F(1,23) = 10.18$, $p<.01$, $\eta^2 = .09$) had a significant effect on mean amplitude activity of CS (Table 1). An Unsmile rated sentence (regardless of the filter) induced a higher activity of CS muscle than a Smile rated sentence (Figure 2B lower part and Figure 2D) (Table 1). A repeated-measures ANOVA considering the effects of Choice (Smile vs Unsmile) and Response (Correct vs Incorrect) did not show any effect of Response nor interaction with Choice (see supplementary materials, Figure S4).

3.3. Pupil emotional reactivity

Randomizations tests revealed that differences on pupil diameter were observed between emotional and neutral conditions between 2100 and 2600ms. To standardize the analyses, the same time window was used to test each condition.

3.3.1. Emotional content

A repeated-measures ANOVA was performed to analyze the effects of emotional content (Emotional, including both Smiling and Unsmiling, vs. Neutral) on mean pupil diameter in the 2100-2600ms window. Analysis showed that emotional content had a significant main effect ($F(1,24) = 6.61$, $p <.05$, $\eta^2 = .06$) on mean pupil diameter. Pupil diameter was larger when listening to emotional sentences compared to neutral sentences (Table 2) (Figure 3A).

	Filter			Choice			
	Neutral	**Emotional**		**Smile**		**Unsmile**	
Pupil diameter	0.14 ± 0.03	0.21 ± 0.02		0.17 ± 0.02		0.20 ± 0.02	
		Filter		**Filter** *Response*		**Filter** *Response*	
	/	**Smiling**	**Unsmiling**	**Smiling** *Correct*	**Unsmiling** *Incorrect*	**Smiling** *Incorrect*	**Unsmiling** *Correct*
Pupil diameter	/	0.18 ± 0.02	0.22 ± 0.02	0.17 ± 0.03	0.20 ± 0.03	0.19 ± 0.02	0.25 ± 0.02

Table 2: Mean pupil diameter in the 2100-2600ms window in response to neutral and emotional sentences, according to the applied Filter, Choice and Response (mm) (mean ± standard error of the mean).

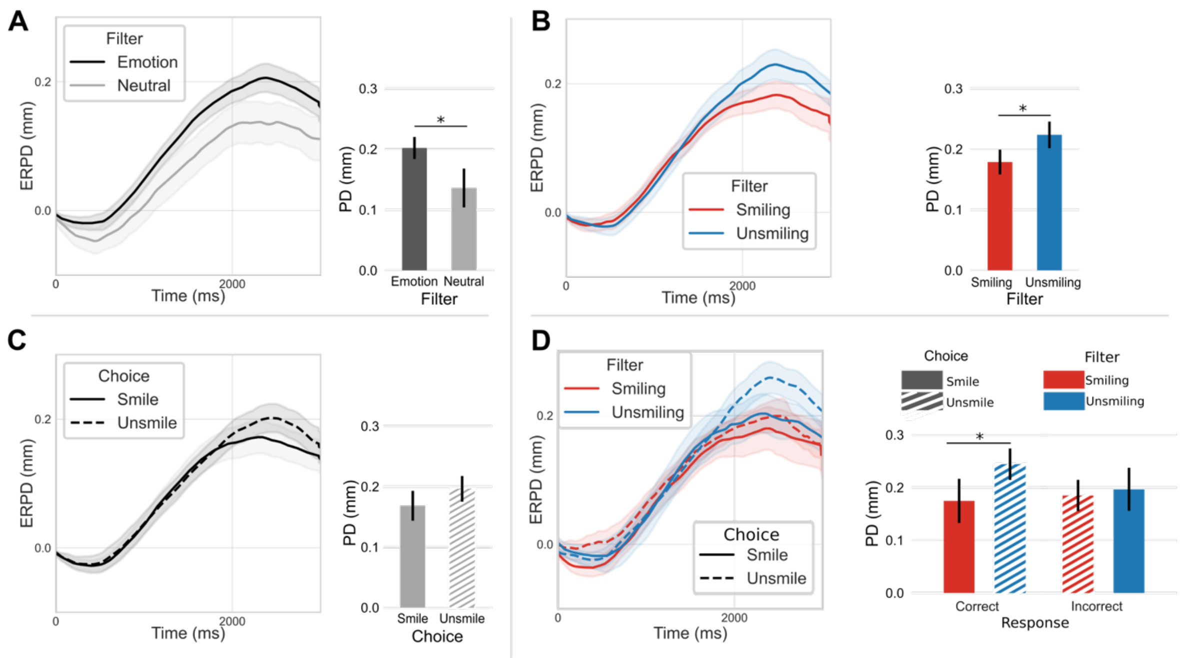

Figure 3: Effect of Filter and Choice on pupil activity. A: Effect of emotional content on pupil diameter B: Effect of Filter on pupil diameter C: Effect of Choice on pupil diameter (without neutral sentences); D: Effect of Filter, Choice and Response on pupil diameter (without neutral sentences). Shaded areas represent standard error of the mean. Barplots represent mean pupil diameter in the window 2100-2600ms (mean ± standard error of the mean). ERPD: Event-Related Pupil Dilation, PD: Pupil Dilation p<.05*

3.3.2. Filter and Choice

A repeated-measures ANOVA was performed to analyze the effects of Filter (Smiling vs Unsmiling), Choice (Smile vs Unsmile) and the interaction between these two factors on mean pupil diameter in the same time window (2100-2600ms). Main effect analysis showed that Filter had a significant effect ($F(1,24) = 4.30$, $p<.05$, $\eta^2 = .02$) on mean pupil diameter, Smiling sentences induced smaller pupil dilation than Unsmiling sentences (Figure 3B) (Table 2).

No main effect of Choice ($F(1,24) = 1.93$, $p > .05$, $\eta^2 = .02$) was revealed (Table 2) (Figure 3C) and no interaction between Filter and Choice ($F(1,24) = .48$, $p > .05$, $\eta^2 = .004$) on mean pupil diameter (Figure 3D) (Table 2).

A repeated-measures ANOVA was performed to analyze the effects of Choice (Smile vs Unsmile), Response (Correct vs Incorrect) and the interaction between these two factors on mean pupil diameter in the same time window (2100-2600ms). No main effects were observed either for Response ($F(1,24) = .48$, $p > .1$, $\eta^2 = .004$) and Choice ($F(1,24) = 1.93$, $p > .1$, $\eta^2 = .02$). A significant interaction between these two factors was however revealed ($F(1,24) = 4.30$, $p < .01$, $\eta^2 = .02$). In order to inspect relevant effects, only comparisons within Correct and Incorrect were performed with a Bonferroni correction. This analysis revealed a significant difference between Correct responses according to the Choice ($t(24) = 2.45$, $p_{corr} < .05$) (Figure 3D). No difference was observed between Incorrect responses ($t(24) = .097$, $p_{corr} > .05$).

3.3.3. Slopes analysis

First, in the 700-1200ms window a difference between Emotional (combined Smiling and Unsmiling) and Neutral sound was observed ($\beta = -2.8e^{-5}$ with Emotional as the reference level; $SE = 7.5e^{-6}$; $p < .001$), with the pupil dilation slope being sharper for Emotional than for Neutral sounds (Figure 4B-1). Note that in this early time window no difference between the slope of Smiling and Unsmiling Filter was revealed. Then, in the next time window (1200-1700ms) a difference in slope according to Filter was shown ($\beta = 3.4e^{-6}$ with Smiling as the reference level ; $SE = 6.8e^{-6}$; $p < .0001$) with a sharper pupil dilation for Unsmiling than Smiling sounds (Figure 4B-2). Finally, in the last time window (1700-2100ms), an effect of Choice on pupil dilation slope was observed ($\beta = 6.3e^{-6}$ with Smile as the reference level; $SE = 7.7e^{-6}$; $p < .0001$) with a curve continuing to increase for Unsmile but not for Smile rated sounds (Figure 4B-3).

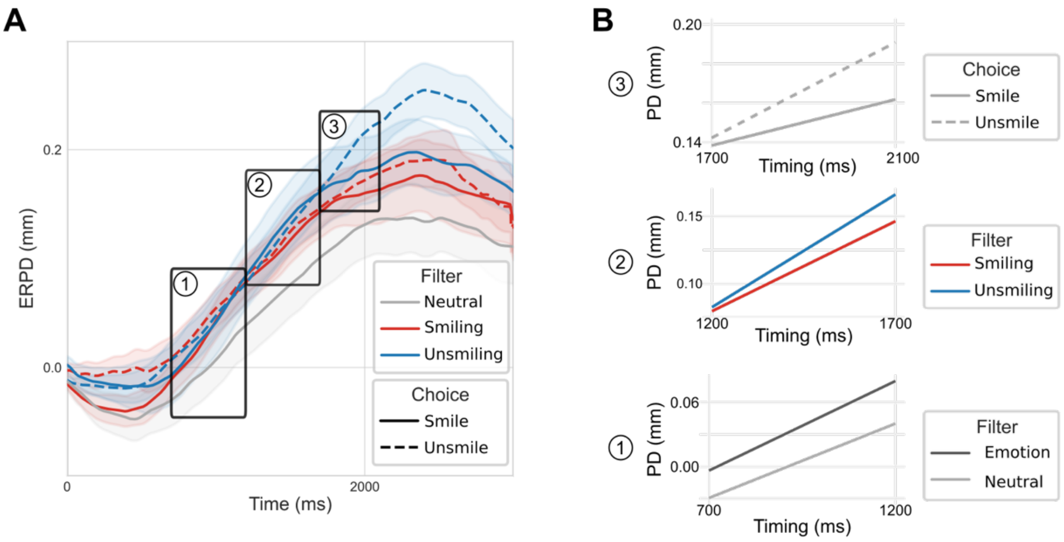

Figure 4: Effect of Filter and Choice on pupil dilation kinetic. A: Effect of Filter and Choice on pupil diameter with Neutral sentences (no matter the judgement for them) with time windows chosen for slopes analysis; ERPD : Event Related Pupil dilation. B: 1- Effect of emotional content; 2- Effect of Filter; 3- Effect of Choice . PD: Pupil Dilation.

4. Discussion

This study was the first, to our knowledge, to combine, in the same participants, facial EMG (fEMG) and pupillometry in response to vocal smile. The combination of these physiological measures assessed automatic motor resonance/reactivity at different processing stages through different systems (ANS and facial muscular activity) in response to artificially prosodically modified sentences. Combined analysis of these indices revealed that the emotional state is triggered early and thus occurs independently of facial motor contagion. Indeed, autonomic reactivity was sharper to emotional than to neutral stimuli and preceded facial muscular reactivity. Our paradigm also allows examining more stringently the facilitating influence of explicit judgement on both the muscular and autonomic nervous system activity, suggesting an appraisal and a reinforcement of the already implicitly processed and automatically expressed emotion.

Indeed, as in Arias et al. (2018), our results on facial muscular activity allowed to distinguish implicit and explicit motor resonance to vocal smile. *Zygomaticus major* (ZM) reactivity to smile took place even in the absence of congruent choice, reflecting only implicit integration of prosody, whereas *Corrugator supercilii* (CS) activity reflected explicit judgement. The positive correlation between muscular activities suggests that perception and identification of vocal smile induced congruent implicit and explicit motor resonance. However, even if CS activity reflects judgement of vocal emotion, no correlation was observed with accuracy or correct/incorrect responses: a correct recognition of emotional prosody was not related to a larger explicit motor resonance. It has been shown that even if expressing facial emotion can help to categorize other's emotions (Lewis, 2018), it is not mandatory to recognize them. Patients with Moebius syndrome, characterized by congenital facial paralysis, showed the same results as a control group in a facial expression recognition task (Bate et al., 2013; Calder et al., 2000; Rives Bogart & Matsumoto, 2010).

Analysis of autonomic reactivity allowed to go further in emotional contagion investigation. Pupil automatic reactivity would reflect the modulation of emotional state following vocal smile perception. Firstly, pupil reactivity was observed for both emotional and neutral sentences. This systematic dilation reflected cognitive load, low sensory level processing and rating of sentences (Ferencova et al., 2021; Oliva & Anikin, 2018; van der Wel & van Steenbergen, 2018; Zekveld et al., 2014). Secondly, the application of artificial filters to sentences made them emotional enough to induce a larger dilation compared to unmodified neutral sounds in an early time window, similar to the effect observed with natural emotion (Burley & Daughters, 2020; Kuchinke et al., 2011). Thirdly, in the next time window, sounds valence influenced pupil reactivity with a larger dilation for negative than positive sentences. This result has been replicated several times in response to sounds (Babiker et al., 2015; Oliva & Anikin, 2018; Partala & Surakka, 2003), but only with very salient emotional stimuli. Indeed, in these previous studies the stimuli were highly attention-grabbing, which might lead to cofounding effects and prevent from exploring purely emotional aspects. Our results extend these observations to more discrete stimuli: the sentences used exhibited subtle emotions allowing a finer recognition of acoustic cues and therefore an effect closer to that observed during a real communication situation. Altogether, our findings point towards the existence of emotional contagion to subtle vocal smile. In the last time window pupil dilation continues for recognized Unsmiling sentences, meaning that explicit appraisal modulates pupil reactivity for negative emotion. This increasingly detailed analysis of the emotional content reflected in the pupil makes it a valuable insight into the emotional integration processes at the ANS level.

A recent study has demonstrated that ZM muscle innervation is at 10% composed by ANS fibers (vs 3.9% for CS) (Tereshenko et al., 2023). Thus, in our study, implicit ANS response to sounds emotional content could also be reflected in ZM reactivity. These findings are consistent with Prochazkova's model, the Neurological Mechanisms of Emotional Contagion (NMEC): in response to visual emotion, a contagion of ‘sender's’ emotion is observed via the ANS on ‘receiver’ (Prochazkova & Kret, 2017). This model could thus be generalized to auditory emotion.

The present study time course contributes to enrich theories of emotions regarding the feedback loop between perception of emotions, facial expressions, and their experience. This emotional loop raises several questions referring to the historic debate about emotion between the peripheralist (James, 1884) and the central theories (Cannon, 1927). Damasio also studied the effect of emotional somatic markers on decision-making (Damasio & Blanc, 1995; Soussignan, 2002). With regard to the latter, emotional motor resonance and pupil reactivity could possibly act as reinforced among each other. This idea could be strengthened by the correlation between muscles activities reflecting a reinforcement between facial muscles. Activation of one of the effectors triggers a congruent global facial response.

The current study offered the rare opportunity to jointly observe emotional motor resonance and emotional state modulation with different electrophysiological measures. To go deeper in studying these two phenomena, questioning participants about their subjective feelings towards used filters could provide a confirmation of emotional contagion. The addition of other ANS measures such as heart rate, would inform about emotion valence, and in particular the prosocial valence of smiling voices, in regards of the polyvagal theory (Porges, 2009; Sorinas et al., 2020). Finally, to confirm that implicit effects were the consequence of prosodic modulations rather than artificial characteristics, natural smiling and unsmiling sentences could be added.

5. Conclusion

This suitable paradigm allows to control intensity and acoustic characteristics of emotional prosody content demonstrating emotional contagion through two different physiological indices.

Emotional contagion is the last process of the perception – representation – action loop, (Chartrand & Bargh, 1999) where congruent response to visual smile associated with mimicry has already been widely studied in the visual domain. This study disentangles emotional states and motor resonance, together with implicit and explicit aspects of emotional contagion thanks to auditory emotional stimuli and combination of autonomic and facial motor responses. Mimicry is altered in some disorders such as autism for emotion like laughing and smiling (Beall et al., 2008; McIntosh et al., 2006). The present paradigm, including measures of motor and autonomic reactivity to emotional vocal sounds, could be used to investigate clinical populations. In particular, the artificial modification of sounds with a smiling filter could be pushed one step further, through the utilization of individual models of vocal smile. This method offers the possibility to measure emotional contagion in response to one's own vocal smile model, and the individual variability could be a signature of some disorders.

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Ethics Statement

The protocol received approval from Ethics Committee (PROSCEA2017/23; ID RCB: 2017-A00756-47). Each participant signed an informed consent form.

Author Contributions

Annabelle Merchie, Nadia Aguillon-Hernandez, Claire Wardak, Jean-Julien Aucouturier and Marie Gomot designed the study. Annabelle Merchie and Zoé Ranty performed data acquisition. Annabelle Merchie, Zoé Ranty, Claire Wardak, Jean-Julien Aucouturier and Marie Gomot were responsible for data and statistical analyses. Annabelle Merchie, Zoé Ranty, Claire Wardak and Marie Gomot wrote the first version of the manuscript. All authors were involved in preparing and reviewing the manuscript.

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Conflict of interest

All authors declare that they have no conflicts of interest.

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Availability of data and material

Please contact the corresponding author for data and experimental stimuli requests.