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► **To cite this version:**

Ladislav Nalborczyk, Marcela Perrone-Bertolotti, Céline Baeyens, Romain Grandchamp, Mircea Polosan, et al.. Orofacial electromyographic correlates of induced verbal ruminations.. *Biological Psychology*, 2017, 127, pp.53-63. 10.1016/j.biopsycho.2017.04.013 . hal-01569420

**HAL Id: hal-01569420**

**<https://hal.science/hal-01569420v1>**

Submitted on 22 Oct 2024

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# Orofacial electromyographic correlates of induced verbal rumination

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Rumination is predominantly experienced in the form of repetitive verbal thoughts. Verbal rumination is a particular case of inner speech. According to the Motor Simulation view, inner speech is a kind of motor action, recruiting the speech motor system. In this framework, we predicted an increase in speech muscle activity during rumination as compared to rest. We also predicted increased forehead activity, associated with anxiety during rumination. We measured electromyographic activity over the *orbicularis oris superior and inferior*, *frontalis* and *flexor carpi radialis* muscles. Results showed increased lip and forehead activity after rumination induction compared to an initial relaxed state, together with increased self-reported levels of rumination. Moreover, our data suggest that orofacial relaxation is more effective in reducing rumination than non-orofacial relaxation. Altogether, these results support the hypothesis that verbal rumination involves the speech motor system, and provide a promising psychophysiological index to assess the presence of verbal rumination.

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25 *Keywords:* rumination; inner speech; electromyography; orbicularis oris; frontalis; relaxation  
26

## 27 1. Introduction

28 As humans, we spend a considerable amount of time reflecting upon ourselves, thinking  
29 about our own feelings, thoughts and behaviors. Self-reflection enables us to create and clarify  
30 the meaning of past and present experiences (Boyd & Fales, 1983; Nolen-Hoeksema, Wisco, &  
31 Lyubomirsky, 2008). However, this process can lead to unconstructive consequences when self-  
32 referent thoughts become repetitive, abstract, evaluative, and self-critical (Watkins, 2008).

33 Indeed, rumination is most often defined as a repetitive and recursive mode of responding  
34 to negative affect (Rippere, 1977) or life situations (Robinson & Alloy, 2003). Although  
35 rumination is a common process that can be observed in the general population (Watkins, 2008),  
36 it has been most extensively studied in depression and anxiety. Depressive rumination has been  
37 thoroughly studied by Susan Nolen-Hoeksema, who developed the Response Style Theory (RST;  
38 Nolen-Hoeksema, 1991). According to the RST, depressive rumination is characterized by an  
39 evaluative style of processing that involves recurrent thinking about the causes, meanings, and  
40 implications of depressive symptoms. Even though rumination can involve several modalities  
41 (i.e., visual, sensory), it is a predominantly verbal process (Goldwin & Behar, 2012; McLaughlin,  
42 Borkovec, & Sibrava, 2007). In this study, we focus on verbal rumination, which can be  
43 conceived of as a particularly significant form of inner speech.

44 Inner speech or covert speech can be defined as silent verbal production in one's mind or  
45 the activity of silently talking to oneself (Zivin, 1979). The nature of inner speech is still a matter  
46 of theoretical debate (see Perrone-Bertolotti, Rapin, Lachaux, Baciú, & Løevenbruck, 2014 for a  
47 review). Two opposing views have been proposed in the literature: the *Abstraction view* and the  
48 *Motor Simulation view*. The *Abstraction view* describes inner speech as unconcerned with  
49 articulatory or auditory simulations and as operating on an amodal level. It has been described as  
50 "condensed, abbreviated, disconnected, fragmented, and incomprehensible to others" (Vygotsky,  
51 1987). It has been argued that important words or grammatical affixes may be dropped in inner

52 speech (Vygotsky, 1987) or even that the phonological form or representation of inner words may  
53 be incomplete (Sokolov, 1972; Dell & Repka, 1992). MacKay (1992) stated that inner speech is  
54 nonarticulatory and nonauditory and that “Even the lowest level units for inner speech are highly  
55 abstract” (p.122).

56 In contrast with this *Abstraction view*, the physicalist or embodied view considers inner  
57 speech production as mental simulation of overt speech production. As such, it can be viewed as  
58 similar to overt speech production, except that the motor execution process is blocked and no  
59 sound is produced (Grèzes & Decety, 2001; Postma & Noordanus, 1996). Under this *Motor*  
60 *Simulation view*, a continuum exists between overt and covert speech, in line with the continuum  
61 drawn by Decety and Jeannerod (1996) between imagined and actual actions. This hypothesis has  
62 led certain authors to claim that inner speech by essence should share features with speech motor  
63 actions (Feinberg, 1978; Jones & Fernyhough, 2007). The *Motor Simulation view* is supported by  
64 several findings. Firstly, covert and overt speech have comparable physiological correlates: for  
65 instance, measurements of speaking rate (Landauer, 1962; Netsell, Ashley, & Bakker, 2010) and  
66 respiratory rate (Conrad & Schönle, 1979) are similar in both. A prediction of the *Motor*  
67 *Simulation view* is that the speech motor system should be recruited during inner speech. Subtle  
68 muscle activity has been detected in the speech musculature using electromyography (EMG)  
69 during verbal mental imagery, silent reading, silent recitation (Jacobson, 1931; Sokolov, 1972;  
70 Livesay, Liebke, Samaras, & Stanley, 1996; McGuigan & Dollins, 1989), and during auditory  
71 verbal hallucination in patients with schizophrenia (Rapin, Dohen, Polosan, Perrier, &  
72 Lœvenbruck, 2013). Secondly, it has been shown that covert speech production involves a similar  
73 cerebral network as that of overt speech production. Covert and overt speech both recruit  
74 essential language areas in the left hemisphere (for a review, see Perrone-Bertolotti et al., 2014).  
75 However, there are differences. Consistent with the *Motor Simulation view* and the notion of a  
76 continuum between covert and overt speech, overt speech is associated with more activity in

77 motor and premotor areas than inner speech (e.g., Palmer et al., 2001). This can be related to the  
78 absence of articulatory movements during inner verbal production. In a reciprocal way, inner  
79 speech involves cerebral areas that are not activated during overt speech (Basho, Palmer, Rubio,  
80 Wulfeck, & Müller, 2007). Some of these activations (cingulate gyrus and superior rostral frontal  
81 cortex) can be attributed to the inhibition of overt responses.

82         These findings suggest that the processes involved in overt speech include those required  
83 for inner speech (except for inhibition). Several aphasia patient studies support this view: overt  
84 speech loss can either be associated with an impairment in inner speech (e.g., Levine, Calvanio,  
85 & Popovics, 1982; Martin & Caramazza, 1982) or with intact inner speech: only the later phases  
86 of speech production (execution) being affected by the lesion (Baddeley & Wilson, 1985;  
87 Marshall, Rappaport, & Garcia-Bunuel, 1985; Vallar & Cappa, 1987). Geva, Bennett, Warburton,  
88 & Patterson (2011) have reported a dissociation that goes against this view, however. In three  
89 patients with chronic post-stroke aphasia (out of 27 patients), poorer homophone and rhyme  
90 judgement performance was in fact observed in covert mode compared with overt mode. A  
91 limitation of this study, though, was that the task was to detect rhymes in written words, which  
92 could have been too difficult for the patients. To overcome this limitation, Langland-Hassan,  
93 Faries, Richardson, & Dietz (2015) have tested aphasia patients with a similar task, using images  
94 rather than written words. They also found that most patients performed better in the overt than in  
95 the covert mode. They inferred from these results that inner speech might be more demanding in  
96 terms of cognitive and linguistic load, and that inner speech may be a distinct ability, with its own  
97 neural substrates. We suggest an alternative interpretation to this dissociation. According to our  
98 view, rhyme and homophone judgements rely on auditory representations of the stimuli (see e.g.,  
99 Paulesu, Frith, & Frackowiak, 1993). Overt speech provides a strong acoustic output that is fed  
100 back to the auditory cortex and can create an auditory trace, which can be used to monitor speech.  
101 In the covert mode, the auditory output is only mentally simulated, and its saliency in the

102 auditory system is lesser than in the overt mode. This is in accordance with the finding that inner  
103 speech is associated with reduced sensory cortex activation compared with overt speech (Shuster  
104 & Lemieux, 2005). In patients with aphasia, the weakened saliency of covert auditory signals  
105 may be accentuated for two reasons: first, because of impairment in the motor-to-auditory  
106 transformation that produces the auditory simulation, and second, because of associated auditory  
107 deficits. Therefore, according to our view, the reduced performance observed in rhyme and  
108 homophone judgment tasks in the covert compared with the overt mode in brain-injured patients,  
109 simply indicates a lower saliency of the auditory sensations evoked during inner speech  
110 compared with the actual auditory sensations fed back during overt speech production. In  
111 summary, these findings suggest that overt and covert speech share common subjective,  
112 physiological and neural correlates, supporting the claim that inner speech is a motor simulation  
113 of overt speech.

114         However, the *Motor Simulation view* has been challenged by several experimental results.  
115 Examining the properties of errors during the production of tongue twisters, Oppenheim and Dell  
116 (2010) showed that speech errors display a lexical bias in both overt and inner speech. According  
117 to these researchers, errors also display a phonemic similarity effect (or articulatory bias), a  
118 tendency to exchange phonemes with common articulatory features, but this second effect is only  
119 observed with overt speech or with inner speech accompanied with mouthing. This has led  
120 Oppenheim and Dell (2010) to claim that inner speech is fully specified at the lexical level, but  
121 that it is impoverished at lower featural (articulatory) levels. This claim, related to the  
122 *Abstraction view*, is still debated however, as a phonemic similarity effect has been found by  
123 Corley, Brocklehurst and Moat (2011). Their findings suggest that inner speech is in fact  
124 specified at the articulatory level, even when there is no intention to articulate words overtly.  
125 Other findings however, may still challenge the *Motor Simulation view*. Netsell et al. (2010) have  
126 examined covert and overt speech in persons who stutter (PWS) and typical speakers. They have

127 found that PWS were faster in covert than in overt speech while typical speakers presented  
128 similar overt and covert speech rates. This can be interpreted in favour of the *Abstraction view*, in  
129 which inner representations are not fully specified at the articulatory level, which would explain  
130 why they are not disrupted in PWS speech. Altogether, these results suggest that full articulatory  
131 specification may not always be necessary for inner speech to be produced.

132         The aim of this study is to examine the physiological correlates of verbal rumination in an  
133 attempt to provide new data in the debate between motor simulation and abstraction. A prediction  
134 of the *Motor Simulation view* is that verbal rumination, as a kind of inner speech, should be  
135 accompanied with activity in speech-related facial muscles, as well as in negative emotion or  
136 anxiety-related facial muscles, but should not involve non-facial muscles (such as arm muscles).  
137 Alternatively, the *Abstraction view* predicts that verbal rumination should be associated with an  
138 increase in emotion-related facial activity, without activity in speech-related muscles and non-  
139 facial muscles.

140         There is strong interest in the examination of physiological correlates of rumination as  
141 traditional assessment of rumination essentially consists of self-reported measures. The  
142 measurement of rumination as conceptualized by Nolen-Hoeksema (1991) was operationalized  
143 by the development of the *Ruminative Response Scale* (RRS), which is a subscale of the response  
144 style questionnaire (Nolen-Hoeksema & Morrow, 1991). The RRS consists of 22 items that  
145 describe responses to dysphoric mood that are self-focused, symptom-focused, and focused on  
146 the causes and consequences of one's mood. Based on this scale, Treynor, Gonzalez & Nolen-  
147 Hoeksema (2003) have offered a detailed description of rumination styles and more recently;  
148 Watkins (2004, 2008) have further characterized different modes of rumination. The validity of  
149 these descriptions is nevertheless based on the hypothesis that individuals have direct and reliable  
150 access to their internal states. However, self-reports increase reconstruction biases (e.g., Brewer,



151 1986; Conway, 1990) and it is well known that participants have a very low level of awareness of  
152 the cognitive processes that underlie and modulate complex behaviors (Nisbett & Wilson, 1977).

153 In order to overcome these difficulties, some authors have attempted to quantify state  
154 rumination and trait rumination more objectively, by recording physiological or neuroanatomical  
155 correlates of rumination (for a review, see Siegle & Thayer, 2003). Peripheral physiological  
156 manifestations (e.g., pupil dilation, blood pressure, cardiac rhythm, cardiac variability) have been  
157 examined during induced or chronic rumination. Vickers and Vogeltanz-Holm (2003) have  
158 observed an increase in systolic blood pressure after rumination induction, suggesting the  
159 involvement of the autonomic nervous system in rumination. Moreover, galvanic skin response  
160 has shown to be increased after a rumination induction, in highly anxious women (Sigmon,  
161 Dorhofer, Rohan, & Boulard, 2000). According to Siegle and Thayer (2003), disrupted  
162 autonomic activity could provide a reliable physiological correlate of rumination. In this line,  
163 Key, Campbell, Bacon, and Gerin (2008) have observed a diminution of the high-frequency  
164 component of heart rate variability (HF-HRV) after rumination induction in people with a low  
165 tendency to ruminate (see also Woody, McGeary, & Gibb, 2014). A consistent link between  
166 perseverative cognition and decreased HRV was also found in a meta-analysis conducted by  
167 Ottaviani et al. (2015). Based on these positive results and on suggestions that labial EMG  
168 activity may accompany inner speech and therefore rumination, our aim was to examine facial  
169 EMG as a potential correlate of rumination and HRV as an index to examine concurrent validity.

170 In addition to labial muscular activity, we also recorded forehead muscular activity (i.e.,  
171 *frontalis* muscle) because of its implication in prototypical expression of sadness (e.g., Ekman,  
172 2003; Kohler et al., 2004), reactions to unpleasant stimuli (Jäncke, Vogt, Musial, Lutz, &  
173 Kalveram, 1996), and anxiety or negative emotional state (Conrad & Roth, 2007)<sup>1</sup>. Our

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<sup>1</sup> The *corrugator supercilii* was another potential site, as it is sensitive to negative emotions. However, it has been claimed to be mostly activated for strong emotions such as fear/terror, anger/rage and sadness/grief (Ekman & Friesen, 1978; Sumitsuji, Matsumoto, Tanaka, Kashiwagi, & Kaneko, 1967). The

174 hypothesis was that *frontalis* activity could be an accurate electromyographic correlate of induced  
175 rumination, as a negatively valenced mental process.

176 In this study, we were also interested in the effects of relaxation on induced rumination.  
177 Using a relaxation procedure targeted on muscles involved in speech production is a further way  
178 to test the reciprocity of the link between inner speech (verbal rumination) and orofacial muscle  
179 activity. If verbal rumination is a kind of action, then its production should be modulated in  
180 return by the effects of relaxation on speech effectors. This idea is supported by the results of  
181 (among others) Cefidekhanie, Savariaux, Sato and Schwartz (2014), who have observed  
182 substantial perturbations of inner speech production while participants had to realize forced  
183 movements of the articulators.

184 In summary, the current study aimed at evaluating the *Motor Simulation view* and the  
185 *Abstraction view* by using objective and subjective measures of verbal rumination. To test the  
186 involvement of the orofacial motor system in verbal rumination, we used two basic approaches.  
187 In the first approach, we induced verbal rumination and examined concurrent changes in facial  
188 muscle activity (Experiment 1). In the second approach, we examined whether orofacial  
189 relaxation would reduce verbal rumination levels (Experiment 2). More specifically, in  
190 Experiment 1, we aimed to provide an objective assessment of verbal rumination using  
191 quantitative physiological measures. Thus, we used EMG recordings of muscle activity during  
192 rumination, focusing on the comparison of speech-related (i.e., two lip muscles – *orbicularis oris*  
193 *superior* and *orbicularis oris inferior*) and speech-unrelated (i.e., forehead –*frontalis*- and  
194 forearm - *flexor carpi radialis*) muscles. Under the *Motor Simulation view*, an increase in lip and  
195 forehead EMG activity should be observed after rumination induction, with no change in forearm

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rumination induction used in this study was designed to have participants self-reflect and brood over their failure at the IQ-test. It was not meant to induce such strong emotions. Several studies have reported increased activity in the *frontalis* muscle at rest in anxious or generalized anxiety disorder patients (for a review see Conrad & Roth, 2007). We expected the type of emotional state induced by rumination to be closer to anxiety or worry than to strong emotions like fear, anger or grief. It was therefore more appropriate to record non-speech facial activity in the *frontalis* rather than in the *corrugator*.

196 EMG activity, associated with an increase in self-reported rumination. Alternatively, under the  
197 *Abstraction view*, an increase in forehead activity should be observed, associated with an increase  
198 in self-reported rumination, and no changes in either lip or forearm activity should be noted.

199 In Experiment 2, in order to assess the reciprocity of the rumination and orofacial motor  
200 activity relationship, we evaluated the effects of orofacial relaxation on rumination. More  
201 specifically, we compared three kinds of relaxation: i) Orofacial Relaxation (i.e., lip muscles), ii)  
202 Arm Relaxation (i.e., to differentiate effects specific to speech-related muscle relaxation) and iii)  
203 Story Relaxation (i.e., to differentiate effects specific to attentional distraction). If the *Motor*  
204 *simulation view* is correct, we predicted a larger decrease of lip and forehead muscle activity after  
205 an Orofacial Relaxation than after an Arm Relaxation (associated with a larger decrease in self-  
206 reported rumination), which should also be larger than after listening to a story. We also  
207 predicted that forearm activity should remain stable across the three conditions (i.e., should not  
208 decrease after relaxation). Alternatively, if the *Abstraction view* is correct, we predicted that none  
209 of the relaxation conditions should have an effect on lip or arm activity, because none of these  
210 should have increased after induction. However, we expected to observe a decrease in forehead  
211 activity and self-reported rumination after Orofacial or Arm relaxation, this decrease being larger  
212 than after listening to a Story. Importantly, we predicted that, under the *Abstraction View* no  
213 superiority of the Orofacial relaxation should be observed over the Arm relaxation.

214

## 215 2. Method

### 216 2.1. Participants

217 Because of the higher prevalence of rumination in women than in men (see Johnson &  
218 Whisman, 2013; for a recent meta-analysis), we chose to include female participants only.  
219 Seventy-two female undergraduate students from Université Grenoble Alpes, native French  
220 speaking, participated in our study. One participant presenting aberrant data (probably due to

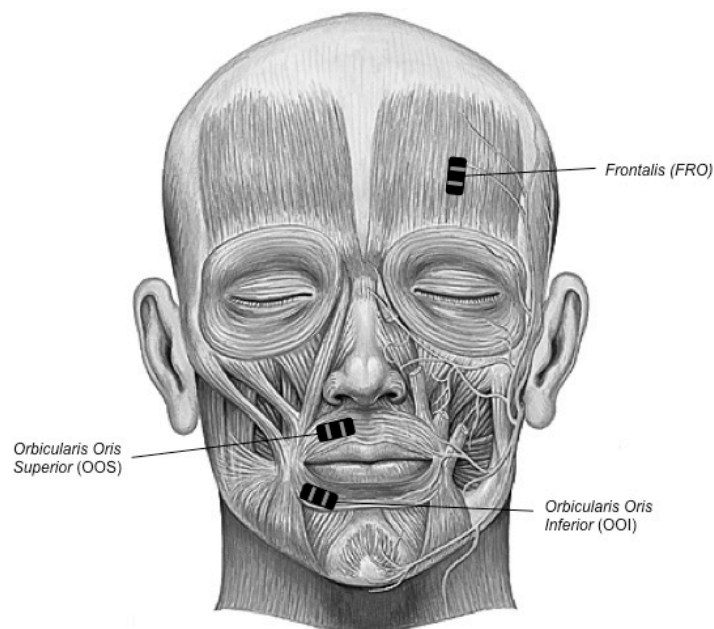
221 inadequate sensor sticking) was removed from analyses. Final sample consisted of seventy-one  
222 undergraduate female students ( $M_{\text{age}} = 20.58$ ,  $SD_{\text{age}} = 4.99$ ). They were recruited by e-mail  
223 diffusion lists and participated in the experiment for course credits. They did not know the goals  
224 of the study. The cover story presented the research as aiming at validating a new I.Q. test, more  
225 sensitive to personality profiles. Participants reported having no neurologic or psychiatric  
226 medical history, no language disorder, no hearing deficit, and taking no medication. Each  
227 participant gave written consent and this study has been approved by the local ethical committee  
228 (CERNI, N° 2015-03-03-61).

229

## 230 **2.2. Material**

231 EMG signals were detected with Trigno<sup>TM</sup> Mini sensors (Delsys Inc.) at a sampling rate  
232 of 1926 samples/s with a band pass of 20 Hz (12 dB/oct) to 450 Hz (24 dB/oct) and were  
233 amplified by a Trigno<sup>TM</sup> 16-channel wireless EMG system (Delsys Inc.). The sensors consisted of  
234 two 5 mm long, 1 mm wide parallel bars, spaced by 10 mm, which were attached to the skin  
235 using double-sided adhesive interfaces. The skin was cleaned by gently scrubbing it with 70%  
236 isopropynol alcohol. EMG signals were then synchronized using the PowerLab 16/35  
237 (ADInstrument, PL3516). Raw data from the EMG sensors were then resampled at a rate of 1  
238 kHz and stored in digital format using Labchart 8 software (ADInstrument, MLU60/8). As shown  
239 in Figure 1, bipolar surface EMG recordings were obtained from two speech-related labial  
240 muscles: *orbicularis oris superior* (OOS) and *orbicularis oris inferior* (OOI), as well as from one  
241 non speech-related but negative-affect-related facial muscle: *frontalis* (FRO) and from one non-  
242 facial and non speech-related muscle: *flexor carpi radialis* (FCR) on the non-dominant forearm.  
243 The latter pair of electrodes was used to check whether the rumination induction would cause any  
244 muscle contraction, outside of the facial muscles. The same sensor layout was used for all  
245 participants. Asymmetrical movements of the face have been shown in speech and emotional

246 expression. As reviewed in Everdell, Marsh, Yurick, Munhall, & Paré (2007), the dominant side  
247 of the face displays larger movements than the left during speech production, whereas the non-  
248 dominant side is more emotionally expressive. To optimise the capture of speech-related activity,  
249 the OOS and OOI sensors were therefore positioned on the dominant side of the body (i.e. the  
250 right side for right-handed participants). To optimise the capture of emotion-related activity, the  
251 FRO sensor was positioned on the non-dominant side. To minimise the presence of involuntary  
252 manual gestures during the recording, the FCR sensor was positioned on the non-dominant side.  
253 Each pair of electrodes was placed parallel with the direction of the muscle fibers, at a position  
254 distant from the innervation zones and the muscle tendon interface, following the  
255 recommendations of DeLuca (1997). The experiment was video-monitored using a Sony HDR-  
256 CX240E video camera to track any visible facial movements. A microphone was placed 20 to 30  
257 cm away from the participant's lips to record any faint vocal production during rumination.  
258 Stimuli were displayed with E-prime 2.0 (<http://www.psnet.com>) on a 19-inch color monitor.  
259



260

261

Figure 1. (Single column)

262

### 263 **2.3.Procedure**

264 This study consisted of two parts. The first part was carried out a week before the EMG  
265 experiment and consisted in checking the inclusion criteria. We checked that participants did not  
266 exceed a threshold on a depressive symptoms scale. This was assessed using the French version  
267 of the *Center for Epidemiologic Studies Depression* scale (CES-D; Fuhrer & Rouillon, 1989),  
268 which evaluates the level of depressive symptom in subclinical population. We also collected  
269 information about any potential speech, neurologic, neuromuscular or cardiac disorders and about  
270 academic curriculum. Finally, the tendency to ruminate (i.e., trait rumination) in daily life was  
271 evaluated using the French version of the Mini-CERTS (Cambridge-Exeter Repetitive Thought  
272 Scale; Douilliez, Philippot, Heeren, Watkins, & Barnard, 2014). The second part included two  
273 EMG interdependent experiments related to *Rumination Induction* and *Rumination Reduction by*  
274 *Muscle Relaxation*. Specifically, Experiment 1 consisted of acquiring physiological EMG data  
275 during rest and induced rumination and Experiment 2 consisted of acquiring physiological EMG  
276 data after different kinds of relaxation (see below).

277 During both Experiment 1 and Experiment 2, momentary rumination was assessed using  
278 four different Visual Analogue Scales (VAS, the first two being adapted and translated to French  
279 from Huffziger, Ebner-Priemer, Koudela, Reinhard, & Kuehner, 2012) rated from 0 to 100: i) “At  
280 this moment, I am thinking about my feelings” (referred to as VAS “*Feelings*”), ii) “At this  
281 moment, I am thinking about my problems” (referred to as VAS “*Problems*”), iii) “At this  
282 moment, I am brooding about negative things” (referred to as VAS “*Brooding*”) and iv) “At this  
283 moment, I am focused on myself” (referred to as VAS “*Focused*”).

284

#### 285 **2.3.1. Experiment 1: Rumination Induction**

286 Participants were seated in front of a computer screen in a comfortable and quiet room.  
287 EMG sensors were positioned as explained above (see Figure 1). Before the rumination  
288 induction, each participant underwent a non-specific relaxation session (i.e., without targeting  
289 specific muscles) in order to minimize inter-individual initial thymic variability (approximate  
290 duration ~ 330 seconds). Immediately after, participants were instructed to remain silent and not  
291 to move for one minute to carry out EMG “baseline” measurements. Then, participants’ initial  
292 level of rumination was assessed using the four VASs.

293 Subsequently, participants were invited to perform a 15-minute I.Q. test, which was  
294 presented on the computer screen facing them. They were instructed to correctly respond to three  
295 types of I.Q. questions (logical, mathematical and spatial-reasoning questions) in a very short  
296 time (30 seconds). Most of the questions were very difficult, if not impossible, to correctly  
297 answer in 30 seconds. We included ten different questions for each of the three types of IQ  
298 question: ten logical questions (e.g., finding the next number of a Fibonacci sequence), ten  
299 mathematical questions (e.g., “What is the result of the following calculus:  $(30 / 165) - (70 / 66)$ ”)  
300 and ten spatial-reasoning questions (e.g., finding the next figure of a series). Forced-failure tasks  
301 have extensively been employed in the literature to induce a slightly negative mood, ideal for  
302 subsequent rumination induction (e.g., LeMoult & Joormann, 2014; Van Randenborgh,  
303 Hüffmeier, LeMoult, & Joormann, 2010).

304 After the I.Q. test, participants were invited to reflect upon the causes and consequences  
305 of their feelings, during five minutes (rumination induction). This method is based on the  
306 induction paradigm developed by Nolen-Hoeksema and Morrow (1993). The classical paradigm  
307 uses a series of prompts. In order to avoid the potential confound in muscle activity induced by  
308 silent reading, we did not use the full paradigm. We simply summarised the series of prompts by  
309 one typical induction sentence. During this period, participants were asked to remain silent and  
310 not to move, while EMG recordings were carried out (i.e., EMG Post-induction measures). EMG

311 signals of rumination were collected during the last minute of this period. Finally, participants  
312 were instructed to self-report momentary rumination on the four VASs.

313

### 314 **2.3.2. Experiment 2: Rumination Reduction by Relaxation**

315 After Experiment 1, participants were randomly allocated to one of three groups. In the  
316 first group, participants listened to a pre-recorded relaxation session that was focused on orofacial  
317 speech-related muscles (“Orofacial Relaxation” condition). In the second group, relaxation was  
318 focused on the arm muscles (“Arm Relaxation” condition). In the third group, participants simply  
319 listened to a story, read by the same person, for an equivalent duration (“Story” condition,  
320 detailed content of the story can be found in the Supplementary Materials, in French). In  
321 summary, the first condition allowed us to evaluate the effects of targeted speech muscle  
322 relaxation on rumination. The second condition allowed evaluating the effects of a non-orofacial  
323 relaxation (i.e., speech-unrelated muscles) while the third condition allowed controlling for  
324 effects of attentional distraction during relaxation listening.

325 The speeches associated with the three conditions, relaxation sessions and story listening  
326 session, were delivered to the participants through loudspeakers. They were recorded by a  
327 professional sophrology therapist in an anechoic room at GIPSA-lab (Grenoble, France) and were  
328 approximately of the same duration (around 330 seconds).

329 After the relaxation/distraction session, participants were asked to remain silent and not to  
330 move during one minute, during which EMG measurements were collected (EMG Post-  
331 relaxation measures). Finally, participants were instructed to self-report rumination on the four  
332 VASs.

333

## 334 **2.4. Data processing and analysis**

### 335 **2.4.1. EMG data processing**



336 EMG signal pre-processing was carried out using Labchart 8. The EMG data were high-  
337 pass filtered using a Finite Impulse Response (FIR) filter at a cut-off of 20 Hz, using the Kaiser  
338 window method with  $\beta = 6$ . Then, output of this first filter was to a low-pass filtered at a cut-off  
339 of 450 Hz (with the same parameters), in order to focus on the 20 – 450 Hz frequency band,  
340 following current recommendations for facial EMG studies (DeLuca, 1997; DeLuca, Gilmore,  
341 Kuznetsov, & Roy, 2010; Van Boxtel, 2001).

342 Although we specifically asked participants to remain silent and not to move during EMG  
343 data collection, tiny facial movements (such as biting one's lips) or vocal productions sometimes  
344 occurred. Periods with such facial movement or vocal production were excluded from the  
345 analysis. To do this, visual inspection of audio, video, and EMG signal was performed.  
346 Specifically, for the EMG signals, we compared two methods of signal selection. The first one  
347 consisted of setting a threshold on the absolute value of the EMG signal and portions of signals  
348 above this threshold were removed. This threshold was empirically chosen using visual  
349 inspection of a few samples and set to the mean EMG value plus 6 SDs. The second method  
350 consisted of manually removing periods of time that included visually obvious bursts of EMG  
351 activity, corresponding to overt contraction (as in Rapin *et al.*, 2013). Based on samples from a  
352 few participants, the comparisons between these two methods showed that the automatic  
353 threshold method was somewhat less sensitive to overt movements. Therefore, the second  
354 method was used, as it was more conservative and less prone to leave data related to irrelevant  
355 overt movements.

356 After pre-processing, EMG data were exported from Labchart software to Matlab r2014a  
357 (Version 8.3.0.532, [www.mathworks.fr](http://www.mathworks.fr)). For each EMG signal, mean values were computed  
358 under Matlab, using 200 ms sliding windows. The average of these mean values were calculated  
359 for each recording session (baseline, after induction and after relaxation/induction). This provided

360 a score for each muscle of interest (OOS, OOI, FCR, FRO) in each Session (Baseline, Post-  
361 Induction, Post-Relaxation) for each participant.<sup>2</sup>

362

#### 363 **2.4.2. Statistical analyses**

364 Absolute EMG values are not meaningful as muscle activation is never null, even in  
365 resting conditions, due in part to physiological noise (Tassinari, Cacioppo, & Vanman, 2007). In  
366 addition, there are inter-individual variations in the amount of EMG activity in the baseline. To  
367 normalise for baseline activity across participants, we used a differential measure and expressed  
368 EMG amplitude as a percentage of baseline level (Experiment 1) or of post-induction level  
369 (Experiment 2).

370 To model EMG amplitude variations in response to the rumination induction (Experiment  
371 1) and relaxation (Experiment 2), we used a bayesian multivariate regression model with the  
372 natural logarithm of the EMG amplitude (expressed in % of baseline level) as an outcome, in an  
373 intercept-only model (in Experiment 1), and using Condition (Orofacial, Arm or Story) as a  
374 categorical predictor in Experiment 2. We used the same strategy (two multivariate models) to  
375 analyse VAS scores (expressed in relative changes) along the two experiments.

376 These analyses were conducted using RStudio (RStudio Team, 2015) and the *brms*  
377 package (Bürkner, in press), an R implementation of Bayesian multilevel models that employs  
378 the probabilistic programming language, *Stan* (Carpenter et al., 2016). *Stan* implements gradient-  
379 based Markov Chain Monte Carlo (MCMC) algorithms (e.g., Hamiltonian Monte-Carlo), which  
380 allow yielding posterior distributions that are straightforward to use for interval estimation  
381 around all parameters. Two MCMC simulations (or “chains”) were run for each model, including

---

<sup>2</sup> Because of constraints attributable to the design of our experiment, we were not able to perform conventional control measures (e.g., time of the day, food consumption, sport activity, smoking habits, etc.). Moreover, in our study, periods of signal recording had to be shorter than usual HRV analysis time periods (cf. methodology section). Although recent studies suggest that “ultrashort term” HRV analysis seems to correlate quite well with HRV analysis performed on longer periods of time (Brisinda et al., 2013; Salahuddin, Cho, Gi Jeong, & Kim, 2007), we cannot exclude that our measurements might be unreliable. For these reasons, we chose not to present HRV results in this report and to focus on EMG results as well as subjective reports of rumination.

382 100,000 iterations, a warmup of 10,000 iterations, and a thinning interval of 10. Posterior  
383 convergence was assessed examining autocorrelation and trace plots, as well as the Gelman-  
384 Rubin statistic. Fixed effects were estimated via the posterior mean and 95% highest density  
385 intervals (HDIs), where an HDI interval is the Bayesian analogue of a classical confidence  
386 interval.<sup>3</sup>

387 This strategy allowed us to examine posterior probability distribution on each parameter  
388 of interest (i.e., effects of session and condition on each response variable). When applicable, we  
389 also report evidence ratios (ERs), computed using the *hypothesis* function of the *brms* package  
390 (Bürkner, in press). These evidence ratios are simply the posterior probability under a hypothesis  
391 against its alternative (Bürkner, in press). We also report summary statistics (mean and HDI) of  
392 Cohen's d effect sizes, computed from the posterior samples.

393

### 394 3. Results

#### 395 3.1. Experiment 1: Rumination Induction

396 The evolution of VAS scores (for the four assessed scales: Feelings, Problems, Brooding,  
397 and Focused) and EMG (for the four muscles: OOS, OOI, FCR and FRO) activity from baseline  
398 to post-induction were examined.

399

##### 400 3.1.1. Self-reported rumination measures: VAS scores

401

402 Results for VAS relative changes based on the multivariate models described earlier are  
403 shown in the right panel of Figure 2. Thereafter,  $\alpha$  represents the mean of the posterior

---

<sup>3</sup> While not suffering from the misunderstandings associated with frequentist confidence intervals (for more details, see for instance Morey, Hoekstra, Rouder, Lee & Wagenmakers, 2016).

404 distribution of the intercept. Raw pre- and post-induction scores are provided in Supplementary  
405 Materials.

406 Mean VAS score on the Feelings scale was slightly lower after induction ( $\alpha = -5.55$ , 95%  
407 HDI [-10.89, -0.24],  $d = -0.23$ , 95% HDI [-0.46, -0.01]), while Problems score was slightly  
408 higher ( $\alpha = 3.99$ , 95% HDI [-2.04, 9.83],  $d = 0.15$ , 95% HDI [-0.08, 0.37]). We observed a strong  
409 increase of the score on the Brooding scale ( $\alpha = 14.45$ , 95% HDI [8.07, 20.72],  $d = 0.50$ , 95%  
410 HDI [0.26, 0.74]), and a strong decrease on the Focused scale ( $\alpha = -11.63$ , 95% HDI [-17, -6.07],  
411  $d = -0.48$ , 95% HDI [-0.72, -0.24]). As we examined the fit of the intercept-only model, these  
412 estimates represent the posterior mean for each muscle.

413 In the following, we report the mean (indicated by the Greek symbol  $\rho$ ) and the 95% HDI  
414 of the posterior distribution on the correlation coefficient ( $\rho$ ). Examination of the correlation  
415 matrix estimated by the multivariate model revealed no apparent correlation neither between  
416 Feelings and Problems scales ( $\rho = -.01$ , 95% HDI [-.23, .22]), nor between Feelings and  
417 Brooding ( $\rho = .08$ , 95% HDI [-.15, .30]). However, we observed a strong positive correlation  
418 between Problems and Brooding VASs ( $\rho = .64$ , 95% HDI [.49, .76]), a positive correlation  
419 between Feelings and Focused ( $\rho = .30$ , 95% HDI [.08, .50]), and a negative correlation between  
420 Problems and Focused ( $\rho = -.30$ , 95% HDI [-.49, -.08]), as well as between Brooding and  
421 Focused ( $\rho = -.18$ , 95% HDI [-.39, .05]).

422

### 423 **3.1.2. EMG**

424

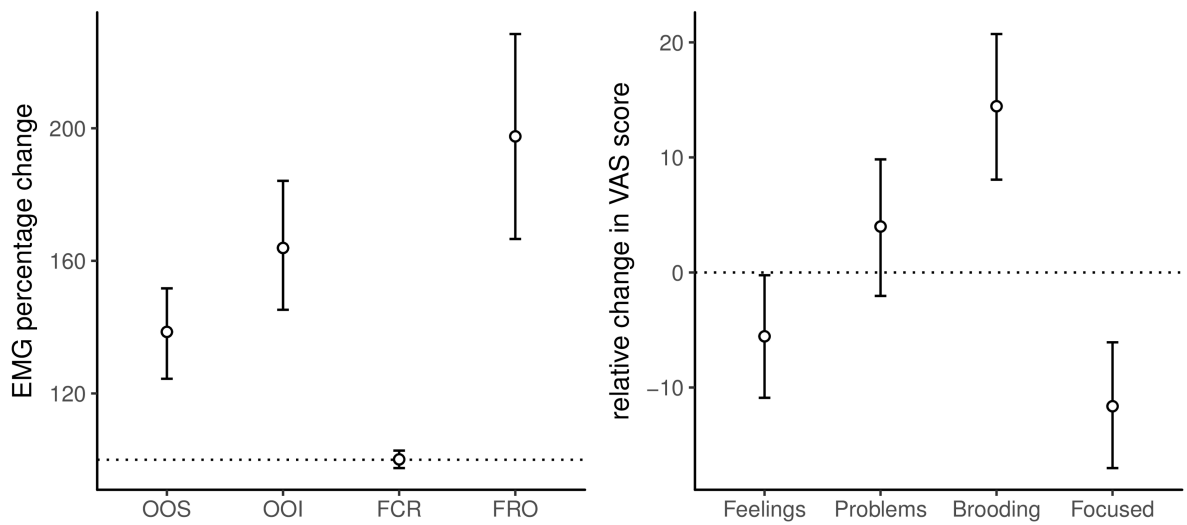
425 Results for EMG data based on the multivariate model described earlier are shown in the  
426 left panel of Figure 2. Summary statistics were computed on posterior samples transformed back  
427 from log scale.

428 Mean EMG amplitude for OOS was higher after induction ( $\alpha = 138.57$ , 95% HDI  
429 [124.43, 151.71],  $d = 0.66$ , 95% HDI [0.49, 0.84]) as well as for OOI ( $\alpha = 163.89$ , 95% HDI  
430 [145.24, 184.14],  $d = 0.77$ , 95% HDI [0.61, 0.94]), and FRO ( $\alpha = 197.55$ , 95% HDI [166.59,  
431 228.42],  $d = 0.74$ , 95% HDI [0.59, 0.89]). Effects on the FCR were approximately null ( $\alpha =$   
432 100.10, 95% HDI [97.48, 102.76],  $d = 0.01$ , 95% HDI [-0.24, 0.23]).

433 Examination of the correlation matrix estimated by the bayesian multivariate model  
434 revealed a positive correlation between OOS and OOI EMG amplitudes ( $\rho = .44$ , 95% HDI [.24,  
435 .61]), while no apparent correlations neither between OOS and FCR ( $\rho = .09$ , 95% HDI [-.14,  
436 .31]), OOS and FRO ( $\rho = .12$ , 95% HDI [-.11, .35]), OOI and FCR ( $\rho = .02$ , 95% HDI [-.21,  
437 .25]), FRO and FCR ( $\rho = -.06$ , 95% HDI [-.28, .17]), nor OOI and FRO ( $\rho = .07$ , 95% HDI [-.16,  
438 .29]). Scatterplots, marginal posterior distributions and posterior distributions on correlation  
439 coefficients are available in Supplementary Materials.

440  
441 In order to check whether the propensity to ruminate could predict the effects of the  
442 rumination induction on EMG amplitude, we compared the multivariate model described above,  
443 with a similar model but with the score on the abstract dimension of the Mini-CERTS as an  
444 additional predictor. We compared these models using the widely applicable information  
445 criterion (WAIC; Watanabe, 2010), via the *WAIC* function of the *brms* package (Bürkner, in  
446 press). Results showed that the intercept-only model had a lower WAIC (WAIC = 177.39) than  
447 the more complex model (WAIC = 182.01), indicating that there is no predictive benefit in  
448 adding the Mini-CERTS score as a predictor.

449



450

451

Figure 2. (Two columns)

452

453

### 3.1.3 Correlations between EMG amplitudes and VAS scores

454 Correlations between EMG amplitudes and VAS scores were examined using the

455 *BayesianFirstAid* package (Bååth, 2013), using 15,000 iterations for each correlation coefficient.

456 Both estimated correlation coefficients ( $\rho$ s) and 95% HDIs are reported in Table 1.

457

VAS / Muscle	OOS	OOI	FCR	FRO
Feelings	-0.07	0.01	-0.20	-0.05
	[-0.32, 0.18]	[-0.24, 0.25]	[-0.43, 0.04]	[-0.29, 0.19]
Problems	0.11	-0.01	-0.09	<b>0.26</b>
	[-0.14, 0.34]	[-0.25, 0.23]	[-0.33, 0.15]	<b>[0.02, 0.50]</b>
Brooding	-0.03	0.11	<b>-0.26</b>	0.11
	[-0.27, 0.20]	[-0.12, 0.34]	<b>[-0.47, -0.03]</b>	[-0.13, 0.36]
Focused	-0.18	<b>-0.26</b>	-0.07	0.01
	[-0.41, 0.06]	<b>[-0.47, -0.03]</b>	[-0.31, 0.18]	[-0.24, 0.26]

458

Table 1. (Single column)

459

460

### 3.2. Experiment 2: Rumination Reduction by Relaxation

461 In the second experiment, we aimed at comparing the evolution in EMG activity and VAS  
 462 scores from post-induction to post-relaxation in three different conditions: Orofacial relaxation,  
 463 Arm relaxation, and listening to a Story.

464

### 465 3.2.1. *Self-reported rumination measures: VAS scores*

466 Posterior means and 95% HDIs of the VAS scores in each condition of experiment 2 are  
 467 represented in Figure 3 and Table 1.

468

VAS	Condition	$\beta$ [95% HDI]	$d$ [95% HDI]
Feelings	Orofacial	7.84 [-0.34, 16.05]	0.38 [-0.02, 0.80]
	Arm	4.60 [-3.78, 13]	0.22 [-0.21, 0.62]
	Story	-5.33 [-13.41, 2.89]	-0.26 [-0.68, 0.12]
Problems	<b>Orofacial</b>	<b>-15.24 [-23.89, -6.50]</b>	<b>-0.70 [-1.11, -0.28]</b>
	Arm	-4.23 [-13.15, 4.69]	-0.19 [-0.59, 0.22]
	Story	-9.19 [-17.90, -0.39]	-0.42 [-0.83, -0.02]
Brooding	<b>Orofacial</b>	<b>-20.40 [-28.78, -11.97]</b>	<b>-0.97 [-1.41, -0.55]</b>
	<b>Arm</b>	<b>-10.42 [-18.87, -1.93]</b>	<b>-0.50 [-0.90, -0.07]</b>
	<b>Story</b>	<b>-15.16 [-23.48, -6.83]</b>	<b>-0.72 [-1.12, -0.30]</b>
Focused	<b>Orofacial</b>	<b>17.03 [7.37, 20.67]</b>	<b>0.72 [0.29, 1.14]</b>
	<b>Arm</b>	<b>11.19 [1.56, 20.89]</b>	<b>0.48 [0.05, 0.88]</b>
	<b>Story</b>	<b>-14.94 [-24.64, -5.32]</b>	<b>-0.64 [-1.05, -0.22]</b>

469 Table 2. (Single column)

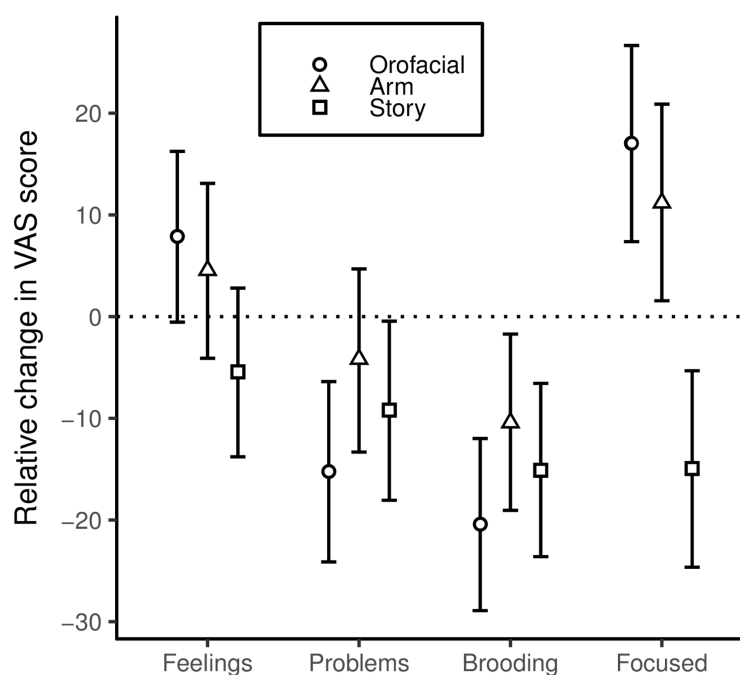
470

471 In order to compare the effects of the two kind of relaxation on the VAS scores, we then  
 472 used the *hypothesis* function of the *brms* package that allows deriving evidence ratios (ER).  
 473 These evidence ratios are simply the posterior probability under a hypothesis (e.g., the hypothesis  
 474 that the Orofacial relaxation session would be more effective in reducing self-reported rumination  
 475 than the Arm relaxation session) against its alternative (Bürkner, in press).

476 Since the Problems and the Brooding scales seemed to be sensitive markers of rumination  
 477 (as their scores increased after induction in Experiment 1), our analyses were focused on these  
 478 two scales.

479 Concerning the Problems VAS, the decrease observed in the Orofacial condition was  
 480 more pronounced than in the Arm condition (Est = -11.06, SE = 6.35, ER<sub>10</sub> = 22.65), and slightly  
 481 more pronounced compared to the Story condition (Est = -6.05, SE = 6.31, ER<sub>10</sub> = 4.98). The  
 482 observed on the Brooding VAS score in the Orofacial condition was larger than in the Arm  
 483 condition (Est = -9.98, SE = 6.07, ER<sub>10</sub> = 18.85), and slightly more important compared to the  
 484 Story condition (Est = -5.23, SE = 6.01, ER<sub>10</sub> = 4.27).

485



486

487

Figure 3. (Single column)

488

489

### 3.2.2. EMG

490



491 Posterior means and 95% HDIs of the EMG amplitude in each condition of experiment 2  
 492 are represented in Figure 4 and reported in Table 3.

493

Muscle	Condition	$\beta$ [95% HDI]	$d$ [95% HDI]
OOS	<b>Orofacial</b>	<b>69.80 [56.96, 83.62]</b>	<b>-0.92 [-1.54, -0.32]</b>
	Arm	98 [79.83, 117.71]	-0.07 [-0.48, 0.32]
	Story	109.54 [89.05, 130.74]	0.16 [-0.21, 0.49]
OOI	<b>Orofacial</b>	<b>71.05 [52.67, 90.71]</b>	<b>-0.62 [-1.24, -0.08]</b>
	Arm	100.43 [74.05, 128.68]	-0.03 [-0.42, 0.34]
	Story	89.94 [66.54, 114]	-0.19 [-0.63, 0.22]
FCR	Orofacial	97.01 [93.12, 100.89]	-0.32 [-0.75, 0.10]
	Arm	98.46 [94.51, 102.48]	-0.16 [-0.58, 0.25]
	Story	99.24 [95.26, 103.18]	-0.08 [-0.48, 0.32]
FRO	<b>Orofacial</b>	<b>59.22 [48.18, 70.93]</b>	<b>-1.44 [-2.20, -0.70]</b>
	<b>Arm</b>	<b>61.31 [49.69, 73.82]</b>	<b>-1.32 [-2.08, -0.61]</b>
	Story	98.31 [80.19, 117.29]	-0.06 [-0.46, 0.32]

494

Table 3. (Single column)

495

496 We used the same strategy as before to compare the effects of the two kinds of relaxation  
 497 on the EMG amplitudes.

498 Concerning the OOS, the observed decrease in the Orofacial condition was more  
 499 pronounced than in the Arm condition (Est =  $-0.34$ , SE = 0.14, ER<sub>10</sub> = 140.73), as well as  
 500 concerning the OOI (Est =  $-0.35$ , SE = 0.19, ER<sub>10</sub> = 29.46), while we observed no noticeable  
 501 differences between the two kinds of relaxation concerning the EMG amplitude of the FRO (Est  
 502 =  $-0.04$ , SE = 0.14, ER<sub>10</sub> = 1.53).

503

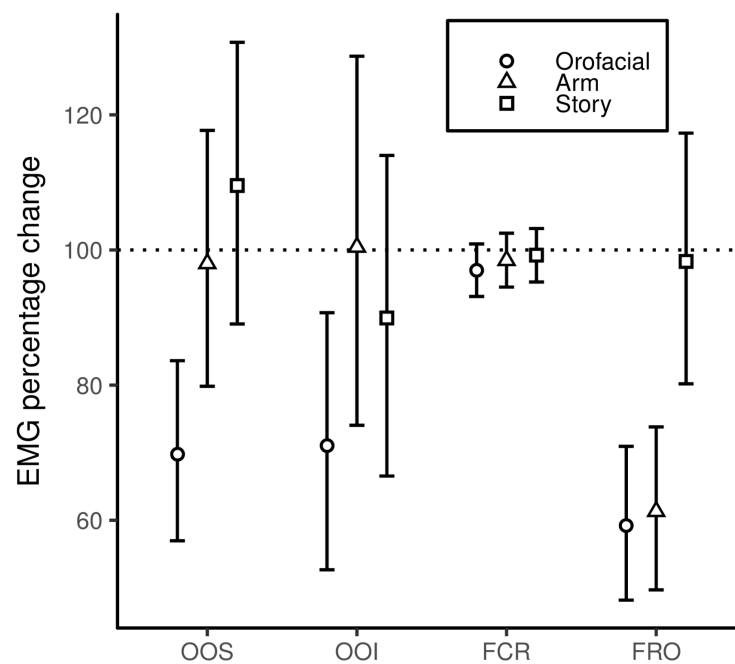


Figure 4. (Single column)

## 4. Discussion

### 4.1. Experiment 1

In the first experiment, we examined electromyographic correlates of induced rumination in healthy individuals. According to the *Motor Simulation view*, we predicted an increase in the activity of all facial muscles after the rumination induction, associated with an increase in self-reported rumination. Alternatively, the *Abstraction view* predicted an increase in self-reported rumination associated with an increase in forehead activity with no changes in either lip or forearm activity.

To test the predictions of these two theoretical views, we compared EMG measures and VAS scores after induction to their values before induction. EMG activity was examined in four muscles: OOS and OOI, two muscles involved in speech production, FRO, a facial negative-affect-related but not speech-related muscle, and FCR, a non-facial control muscle on the non-dominant forearm.

519 As predicted by the *Motor Simulation view*, we observed an increase in the activity of the  
520 two speech-related muscles (OOS & OOI) as well as in the negative-affect-related muscle (FRO)  
521 and no change in FCR activity. The increase in facial EMG together with the increase in the  
522 subjective reports of rumination suggests that facial EMG increase is a correlate of verbal  
523 rumination. As supported by several studies results, the forehead muscle activity has been  
524 associated with unpleasant emotions (Jäncke et al., 1996) or anxiety (Conrad & Roth, 2007). The  
525 increase in FRO activity observed here is consistent with the increase in negative emotions  
526 induced by our negatively valenced induction procedure. *Orbicularis oris* lip muscles are  
527 associated with speech production. The increase in lip activity observed here suggests that the  
528 speech motor system was involved during the ruminative phase. The fact that the FCR remained  
529 stable after rumination induction suggests that the observed facial activity increase was not due to  
530 general body tension induced by a negative mental state. These facial EMG results therefore  
531 support the hypothesis that rumination is an instance of articulatory-specified inner speech.

532 After the rumination induction, a larger increase in OOI activity was observed compared  
533 to the increase in OOS activity. This finding is consistent with previous findings of higher EMG  
534 amplitude in the lower lip during speech and inner speech (e.g., Barlow & Netsell, 1986; Regalo  
535 et al., 2005; Sokolov, 1972) or auditory verbal hallucinations (Rapin et al., 2013). Rapin *et al.*  
536 (2013) have explained the difference between the activities of the two lip muscles by muscle  
537 anatomy. The proximity of the OOI muscle with other speech muscles (such as the *depressor*  
538 *angular* muscle or the *mentalis*) could increase the surface EMG signal captured on the lower lip  
539 (OOI), as compared to the upper lip (OOS) during speech. An even larger increase in FRO  
540 activity was observed compared to the increase in lip muscle activity. As EMG amplitude is  
541 known to vary with muscle length (Babault, Pousson, Michaut, & Van Hoecke, 2003), the greater  
542 increase in *frontalis* activity could be explained by its anatomical properties.

543           However, although a functional distinction can be drawn between the forehead and the lip  
544 muscles, one should acknowledge the fact that these two sets of muscles can be commonly  
545 activated during some behaviours. For instance, Van Boxtel & Jessurun (1993) have shown that  
546 *orbicularis oris inferior* and *frontalis* were both activated during a two-choice serial reaction task  
547 in which nonverbal auditory or visual signals were presented. Moreover, there was a gradual  
548 increase in EMG activity in these muscles during the task, either when the task was prolonged or  
549 when the task was made more difficult. They interpreted this increase in EMG activity as  
550 associated with a growing compensatory effort to keep performance at an adequate level. An  
551 alternative interpretation is that the increase in task difficulty was dealt with by inner  
552 verbalization. Covertly rehearsing the instructions or covertly qualifying the stimuli might have  
553 helped the participants to perform adequately. Therefore, the increase in *orbicularis oris* activity  
554 might have been related to an increase in covert verbalization, whereas the increase in *frontalis*  
555 activity might have been related to increased anxiety or tension. The fact that the EMG increase  
556 was muscle specific, and that some facial muscles (*orbicularis oculi*, *zygomaticus major*,  
557 *temporalis*) did not show an increase in activity unless the task became too difficult, supports this  
558 interpretation. It cannot be ruled out, however, that *orbicularis oris* activity may in some cases be  
559 related to mental effort without mental verbalisation. Nevertheless, although the IQ test itself was  
560 designed to induce mental effort, no cognitively demanding task was asked to the participant  
561 during the period of EMG recording (i.e., approximately four minutes after the end of the test).  
562 Although we cannot absolutely exclude that rumination in itself could require cognitive effort, it  
563 seems unlikely that mental effort was the main factor of variation.

564           Scores on the VAS need to be discussed in further detail. We examined which VAS scales  
565 were most suitable to capture changes in state rumination to allow focused analyses. Due to the  
566 “pre-baseline” relaxation session, during which participants were asked to concentrate on their  
567 body and breathing cycles, participants reported a high level of attentional self-focus at baseline

568 (“Feelings” and “Focused” VAS). Because of the high level of self-focused attention at baseline,  
569 it is likely that the scores on the “Feelings” and “Focused” VAS did not show the expected  
570 increase after rumination induction (ceiling effect). The scores on the scales “Problems” and  
571 “Brooding”, which are more representative of maladaptive rumination, did increase after our  
572 rumination induction paradigm, however. Interestingly, the “Brooding” VAS corresponded to a  
573 larger increase and seemed to be more sensitive to rumination induction than the “Problems”  
574 VAS. Given this greater sensibility and the strong positive correlation between the “Brooding”  
575 and the “Problems” VAS, it thus make sense to consider the “Brooding” VAS as a better estimate  
576 of ruminative state, at least within our paradigm. We will therefore only use this scale to assess  
577 rumination in the following.

578         The fact that we did not observe any association between the propensity to ruminate (as  
579 measured by the Mini-CERTS questionnaire) and the effects of the induction is consistent with  
580 the results of Rood, Roelofs, Bögels, and Arntz (2012) who found that the level of trait  
581 rumination did not moderate the effects of a rumination induction.

582

#### 583         **4.2. Experiment 2**

584         In the second experiment, we studied the effects of two muscle-specific relaxation  
585 sessions: Orofacial relaxation and Arm relaxation. We compared their effects to a third control  
586 condition (Story), which did not involve the deliberate relaxation of any specific muscle. Our  
587 predictions were that a decrease in facial EMG activity should be observed in each condition. If  
588 the *Motor Simulation view* is correct, we expected a larger decrease in the activity of all facial  
589 muscles in the “Orofacial relaxation” condition than in the “Arm relaxation” condition,  
590 associated with a larger decrease in self-reported rumination. Additionally, we expected a more  
591 pronounced decrease in the two relaxation conditions (orofacial and arm relaxation conditions)

592 than in the control (“Story”) condition. We also expected no difference between relaxation  
593 conditions regarding the change in the forearm muscle activity.

594 The data indicated a decrease in self-reported rumination (“Brooding” VAS) in each  
595 condition. The “Orofacial” relaxation condition elicited a slightly larger decrease than the “Arm  
596 relaxation” or the “Story” condition. However, there was extensive individual variation in  
597 response to these conditions. As concerns EMG results, we observed a decrease in OOS and OOI  
598 activities in all three conditions but this decrease was more pronounced in the orofacial condition  
599 than in the other two conditions. The *frontalis* activity did not show the same pattern. A similar  
600 FRO activity decrease was observed in both the orofacial and the non-orofacial relaxation  
601 conditions. Therefore, in Experiment 2, the lip muscles and the forehead muscle follow  
602 differential evolutions. A dissociation was observed: whereas both orofacial and arm relaxations  
603 resulted in a decrease in forehead activity, only orofacial relaxation was successful at reducing lip  
604 activity.

605 Considering both VAS results and the dissociation in EMG patterns, several  
606 interpretations are possible. The first interpretation is that verbal production associated with  
607 rumination was more reduced by orofacial muscular relaxation than by non-orofacial relaxation.  
608 This interpretation is consistent with the fact that the “Brooding” VAS was slightly more  
609 decreased in this condition compared to the other two. The larger decrease in OOS and OOI  
610 amplitude after orofacial relaxation would thus reflect this reduction in verbal production, as  
611 hypothesised by the *Motor Simulation view*. The fact that FRO activity displayed a similar  
612 decrease in both orofacial and non-orofacial relaxation conditions could suggest that any means  
613 of body relaxation (be it orofacial or not) is appropriate to reduce negative affect and can  
614 therefore reduce forehead contraction. This suggests that the FRO activity increase presumably  
615 reflected negative affect and tension (such as observed in EMG studies on generalised anxiety  
616 disorder patients, see Conrad & Roth, 2007 for a review).

617           Alternatively, one could also argue that the larger decrease in lip muscle activity after  
618 orofacial relaxation finds a more trivial explanation in that it seems obvious to expect that  
619 orofacial relaxation will be more efficient to reduce lip muscle contraction than non-orofacial  
620 relaxation. Thus, the different impacts of the two relaxation sessions on the lip muscles would not  
621 be related to reduced rumination *per se* but simply to a more anatomically targeted relaxation.  
622 However, several observations argue against such an interpretation. The larger decrease in the  
623 “Brooding” VAS in the orofacial relaxation condition compared with the other conditions  
624 suggests that the reduction in lip muscle activity is indeed related to the reduction in rumination.  
625 Moreover, an interpretation solely based on anatomical links does not explain why FRO activity  
626 displayed the same amount of reduction in both relaxation sessions. If reduction in muscle  
627 activity was merely related to the effect of facial muscle relaxation, then the decrease in FRO  
628 activity should have also been higher in the orofacial relaxation condition than in the other  
629 relaxation condition, which was not the case. Therefore the dissociation between forehead and lip  
630 patterns of activity, together with the differential effects of the two types of relaxation on  
631 subjective rumination reports strongly suggest that different processes underlie the activity of  
632 these two sets of muscles. We therefore consider that the first interpretation is more plausible:  
633 *frontalis* activity seems related to overall facial tension due to negative affect whereas lip activity  
634 seems to be related to the specific involvement of the speech musculature in rumination. These  
635 results thus seem to confirm the interpretation of decreased OOS and OOI activities in the  
636 orofacial relaxation condition as markers of rumination reduction.

637           Interestingly, we observed no changes of forearm EMG activity in any of the three  
638 conditions of experiment 2. The fact that the relaxation session focused on the forearm was not  
639 associated with a decrease in FCR activity has a simple explanation: FCR activity had not  
640 increased after rumination induction and had remained at floor level. The forearm was thus  
641 already relaxed and the Arm relaxation session did not modify FCR activity. Another interesting

642 conclusion related to this absence of modification of forearm activity is that relaxation does not  
643 spuriously decrease muscle activity below its resting level. One possible interpretation of the  
644 increase in lip EMG after rumination induction could have been that baseline relaxation  
645 artificially decreased baseline activity under its resting level. The facts that forearm activity did  
646 not decrease after arm-focused relaxation contradicts this interpretation.

647 Finally, the “Story” condition was also associated with a decrease in OOI and FRO  
648 activities. This could mean that listening to a story reduced rumination to the same extent as  
649 relaxation did. However, the discrepancy observed in “Focused” VAS between the two relaxation  
650 conditions on the one hand and the control condition on the other hand, suggests that the EMG  
651 decrease observed in the “Story” condition might be attributable to a different cause than that  
652 observed in the two relaxation conditions. Listening to a story could help reducing rumination by  
653 shifting attention away from ruminative thoughts. Relaxation sessions could help reducing  
654 rumination by shifting attention to the body in a beneficial way.

655

### 656 ***4.3. General discussion***

657 We set out two experiments to examine whether rumination involves motor simulation or  
658 is better described as linguistically abstract and articulatory impoverished. We used labial, facial,  
659 and arm EMG measures to assess potential articulatory correlates of rumination. The patterns of  
660 results of our study seem to be in favour of the motor nature of verbal rumination. In Experiment  
661 1, rumination induction was associated with a higher score on the scale “I am brooding about  
662 negative things” which is representative of abstract-analytical rumination, considered as verbal  
663 rumination. This maladaptive rumination state was associated with an increase in the activity of  
664 two speech-related muscles, without modification of the arm muscle activity, which indicates that  
665 rumination involves activity in speech articulatory muscles, specifically. The concurrent increase  
666 in forehead muscle activity could be explained by an increase in negative emotions induced by



667 our negatively valenced induction procedure. The results of Experiment 1 therefore show the  
668 involvement of the speech musculature during rumination. This is in line with the *Motor*  
669 *simulation view*, according to which inner speech is fully specified at the articulatory level, not  
670 just the lexical level.

671 In Experiment 2, guided relaxation resulted in a decrease in speech muscle activity. In the  
672 lip muscles, the activity decrease was stronger after orofacial relaxation than after arm-focused  
673 relaxation. In the forehead muscle, however the effect was the same for both types of relaxation.  
674 This decrease in speech muscle activity was associated with a decrease in self-reports of  
675 rumination and was most pronounced after orofacial relaxation. These findings suggest that a  
676 reduction in speech muscle activity could hinder articulatory simulation and thus limit inner  
677 speech production and therefore reduce rumination. This interpretation is consistent with the  
678 *Motor Simulation view* of inner speech. Brooding-type rumination was also diminished after the  
679 arm-focused relaxation as well as after listening to a story, although less than in the orofacial  
680 relaxation. This suggests that general relaxation or distraction are also likely to reduce negative  
681 rumination. To summarize, experiments 1 and 2 are consistent with the *Motor Simulation view* of  
682 inner speech, according to which speech muscle activity is inherent to inner speech production.  
683 Experiment 1 shows the involvement of the lip musculature during brooding-type rumination.  
684 Experiment 2 suggests that brooding-type rumination could be reduced by blocking or relaxing  
685 speech muscles.

686 These data support the utility of labial EMG as a tool to objectively assess inner speech in  
687 a variety of normal and pathological forms. We suggest that this method could be used as a  
688 complement to self-report measures, in order to overcome limitation of these measures.

689 Our results should be interpreted with some limitations in mind. Firstly, our sample  
690 consisted exclusively of women. Although this methodological choice makes sense considering  
691 the more frequent occurrence of rumination in women, further studies should be conducted to

692 ascertain that our results may generalize to men. Secondly, in Experiment 1, no between-subject  
693 control condition was used to compare with the group of participants who underwent rumination  
694 induction. Thus, we cannot rule out that other processes occurred between baseline and  
695 rumination induction, influencing responding. Thirdly, substantial inter-individual differences  
696 were observed concerning the size of the effect of rumination induction on facial EMG activity.  
697 The results of Jäncke (Jäncke, 1996; Jäncke et al., 1996) can shed light on this last result. Jäncke  
698 used a similar procedure (i.e., negative mood induction using a false I.Q. test and facial EMG  
699 measurements to assess emotions), except that the experimenter was not in the room while  
700 participants performed the test and acknowledged their results. The experimenter then came back  
701 to the room and analysed participants' behaviours. Jäncke observed an increase in facial muscular  
702 activity (assessed when participants were reading their results) only in participants who were  
703 prone to express their distress when the experimenter came back, while more introverted  
704 participants did not show any increased facial activity when reading their results. Jäncke  
705 interpreted these results in the framework of an ecological theory of facial expression, suggesting  
706 that facial expressions would not only be guided by underlying emotions, but also by their  
707 communicative properties. Considering these results, it seems likely that the proneness of  
708 participants to communicate their emotions could have mediated effects of the induction on their  
709 facial EMG activity. This could partially explain the observed inter-individual variability in facial  
710 EMG activity associated with rumination. Moreover, even though rumination is a predominantly  
711 verbal process, one cannot exclude that some of our participants experienced rumination in  
712 another modality (e.g., imagery-based rumination), which would explain their lower than average  
713 lip activity.

714         Thus, a logical next step is to examine qualitative factors that mediate the link between  
715 rumination and facial muscular activity. These factors (among others) could be proneness to  
716 communicate emotion or proneness to verbalize affects. Additionally, recent studies suggest a

717 link between verbal aptitudes and propensity to ruminate. Uttl, Morin and Hamper (2011) have  
718 observed a weak but consistent correlation between the tendency to ruminate and scores on a  
719 verbal intelligence test. Penney, Miedema and Mazmanian (2015) have observed that verbal  
720 intelligence constitutes a unique predictor of rumination severity in chronic anxious patients. To  
721 our knowledge, the link between verbal intelligence and induced rumination has never been  
722 studied. It would be interesting to examine whether the effects of a rumination induction could be  
723 mediated by verbal intelligence, and to what extent this could influence related facial EMG  
724 activity.

725           In conclusion, this study provides new evidence for the facial embodiment of rumination,  
726 considered as a particular instance of inner speech. Even if more data are needed to confirm these  
727 preliminary conclusions, our results seem to support the *Motor Simulation view* of inner speech  
728 production, manifested as verbal rumination. In addition, facial EMG activity provides a useful  
729 means to objectively quantify the presence of verbal rumination.

730

## 731 **Supplementary materials**

732           Supplementary materials, data, reproducible code and figures are available at:  
733 [https://osf.io/882te/?view\\_only=c4c24a38bbbb43c0aa5c49ea4478786c](https://osf.io/882te/?view_only=c4c24a38bbbb43c0aa5c49ea4478786c). This link is a “view-  
734 only” link, heading toward a private project, provided at the reviewing stage. The final link will  
735 head toward a public project.

736

## 737 **Acknowledgements**

738           This project was funded by the ANR project INNERSPEECH [grant number ANR-13-  
739 BSH2-0003-01]. The first author of the manuscript is funded by a fellowship from Université  
740 Grenoble Alpes and a grant from the *Pôle Grenoble Cognition*. We thank Nathalie Vallet for  
741 recording the relaxation and distraction sessions. We thank our colleagues from GIPSA-lab:  
742 Marion Dohen for her help in the recording of the audio stimuli in the anechoic room at GIPSA-  
743 lab, as well as Christophe Savariaux and Coriandre Vilain for their advice in the audio setup  
744 associated with the EMG measures. We are also grateful to Rafael Laboissière and Adeline  
745 Leclercq Samson for their advice concerning data analysis. We sincerely thank two anonymous  
746 reviewers for their critical reading of our manuscript and their many insightful comments and  
747 suggestions. Access to the facility of the MSH-Alpes SCREEN platform for conducting research  
748 is gratefully acknowledged.

749

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