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Defended by

Ladislas Nalborczyk

Supervised by **Pr. Elsa Spinelli & Pr. Ernst Koster**
Co-supervised by **Dr. Hélène Lœvenbruck & Dr. Marcela Perrone-Bertolotti**

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Psychophysiological characteristics of verbal rumination

Basic and clinical aspects

Publicly defended on **November XX 2019**,
in front of the following committee :

XXXX
..., President
XXXX
..., Rapporteur
XXXX
..., Rapporteur
XXXX
..., Examinatrice
XXXX
..., Examinatrice
Elsa Spinelli
..., Thesis supervisor
Ernst Koster
..., Co-encadrant de these

Contents

List of Tables

List of Figures

Acknowledgments

Acknowledgemnents are not yet available.

Abstract

...

Chapter 1

Theoretical framework

1.1 Overt and imagined actions

Blah blah (Koster et al., 2013)...

Wittgenstein's (1953) famous query: "When I raise my arm, what is left after subtracting the fact that my arm raised?". We posit that what is left is an internal model (a representation) of what should happen if and when my arm goes up (Jeannerod, 1999)...

1.1.1 Motor imagery

Considerable experimental evidence has accumulated to suggest that movement execution and MI share substantial overlap of active brain regions (for review, see Guillot et al., 2012). Such apparent functional equivalence supports the hypothesis that MI draws on the similar neural networks that are used in actual perception and motor control (Jeannerod, 1994; Grezes and Decety, 2001; Holmes and Collins, 2001)...

See introduction of O'Shea (2017) phd thesis introduction...

See Stinear's chapter in Guillot's book for intracortical and spinal mechanisms involved during motor imagery (p.55-57).

1.1.1.1 Simulation theories

...

For Jeannerod (1995), motor imagery is necessarily first-perspective. Third perspective imagery is imagery, but not MOTOR imagery... Motor representations are conceived here as 'internal models' of the goal of an action.

1.1.1.2 Emulation theories

...

1.1.1.3 Action representation and internal models

Voir Jeannerod (2004), Wolpert el al. (1995), Wolpert & Gharamani (2000)...

1.1.2 Inner speech

...

The inner voice as the sensory consequence (prediction, see Loevenbruck et al., 2018) of imagined speech. Analogy with raising the arm: what we perceive when we imagine raising our arm are the sensory consequences (e.g., visual) of what would happen if we actually raised our arm, these are then kind of predictions. The same thing happens during inner speech production: the inner voice is the predicted auditory consequence of actual speech, except that it's predicted. The two actions might seem very different, partly because of differences in the degree of automaticity. Imagining raising our arm might need a voluntary/deliberate/conscious (choose a word) intention (i.e., I want to raise my arm > I raise my arm) while speech imagery (i.e., inner speech) seems more automatic: we do not expression consciously the intention to speak, we just speak...

1.1.2.1 MVTV Cohen (1986)

...

1.1.2.2 Predictive models

Learning how to internalise speech might be similar to learning how to internalise playing an instrument... Let's consider the analogy between speaking and playing an instrument (e.g., the piano). Playing piano results from the learning of an infinitely complex coordination of fine motor sequences, that in turn produce sensory (kinestheatic, auditory, visual, etc) feedback to the producer of the action (the agent). It seems that (from a certain level of analysis), the act of speech can be paralleled with the act of playing an instrument in that its consists in the coordination of infinitely complex movements that result in some modifications in the environment that in turn generate sensory feedbacks for the agent. Thus, pursuing the analogy, we argue that imagining playing pian and imagining speaking (i.e., producing inner speech) might rest on similar mechanisms... see O'Shea & Moran (2018) on expert pianists...

1.2 Rumination as simulated speech

As suggested by **?**, rumination and other forms of spontaneous thoughts can be considered in a common conceptual space (see Figure 1). This space is built upon two dimensions: *deliberate constraints* and *automatic constraints*. These dimensions represent two general mechanisms that allow to constrain the contents of these related mental states and the transitions between them. The first contrain correspond to a deliberate processus and is implemented through **cognitive control** (**?**). The second constrain is referring to more automatic constrains like sensory afferences. In this framework, rumination is characterized by the highest level of automatic constraints and spread all along the *deliberate constraints* dimension.

...

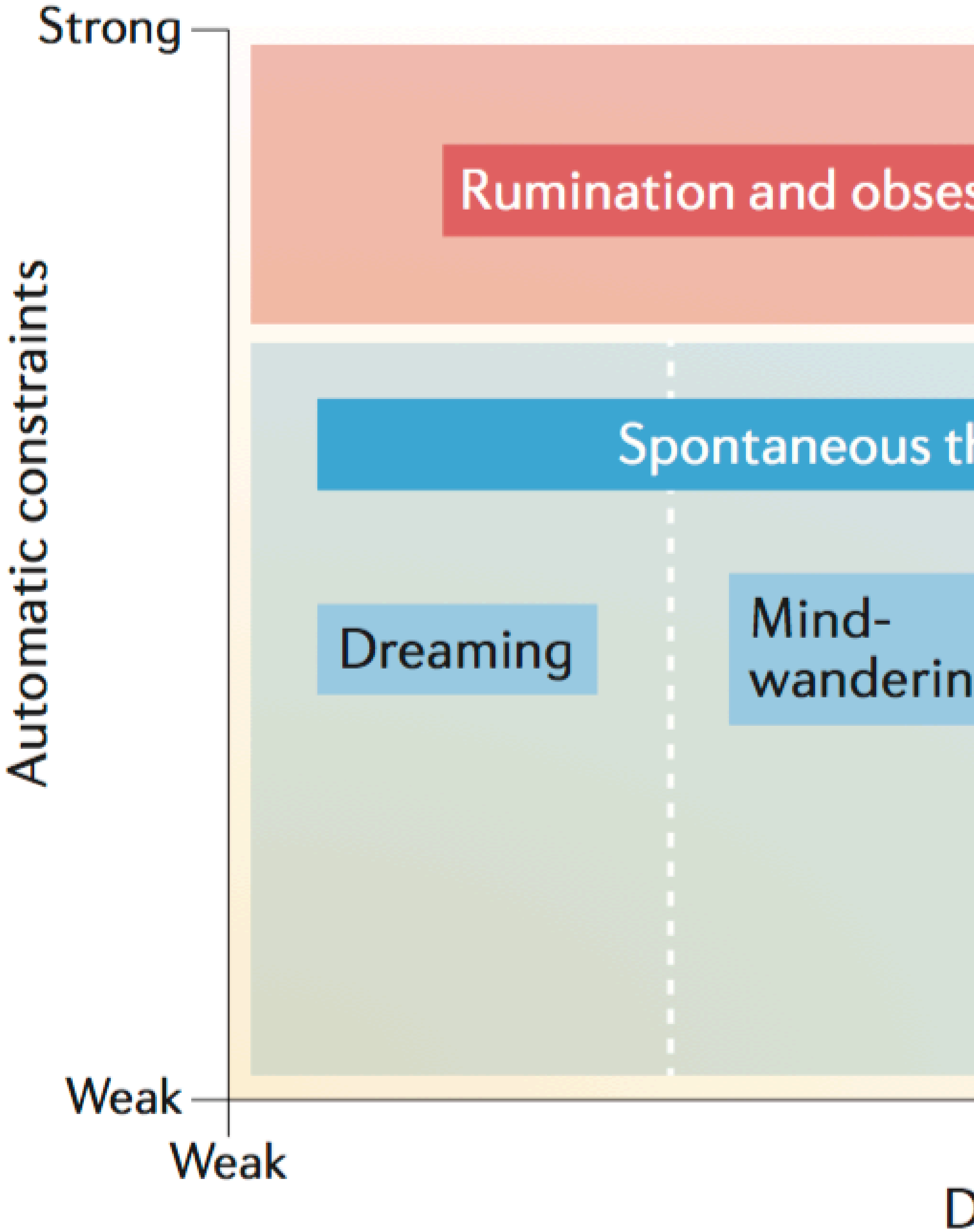

Figure 1.1: Conceptual space of different types of thought (Christoff et al., 2016)

Chapter 2

Theoretical propositions and methodological developments

2.1 Electromyographic correlates of speech production

...

2.1.1 Speech production mechanisms

...

2.1.2 Speech production muscles

...

2.1.3 Muscular physiology

...

2.1.4 EMG signal

2.2 EMG signal measures

Muscular activity can be studied at different levels. At the cellular level, using electrophysiological measures like micro-electrods implanted in the cell, that allow direct measures of **action potential**. At the segmental level, biomechanis study muscular activity using surface sensors, positionned on the skin...intermediate levels...

2.2.1 Motor unit action potential

The **motor unit action potential** (MUAP) is the electric field resulting from the sum of the electric fiels emitted by each fiber of the motor unit. This train of action potentials will generate a *train* of MUAP, call **motor unit action potential trains** (MUAPT). The electric potential generated by this field is highly dependent of parameters such as the number of fibers, their length, speed of conduction and position of the neuromuscular junction...

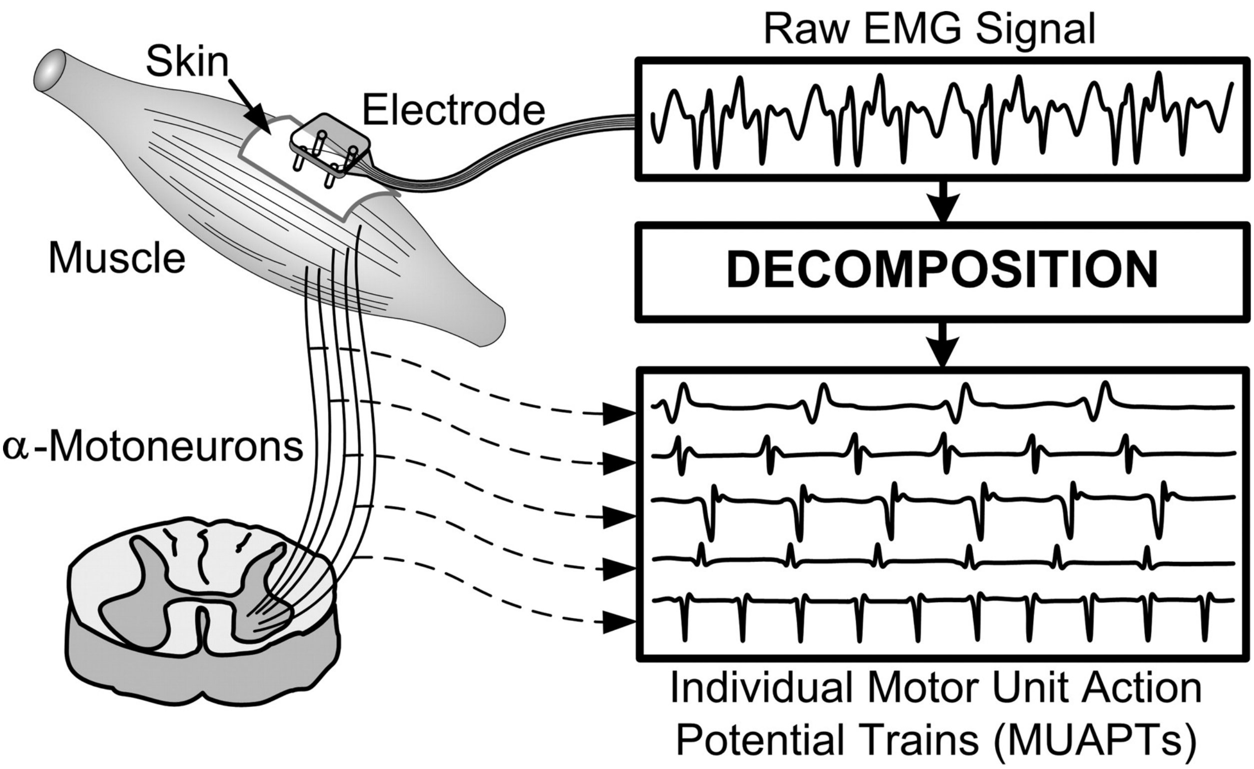

Figure 2.1: Motor unit action potential representation.

To sum up, the EMG signal results from a mixture of recruited motor units...

2.2.2 Surface EMG

...*crosstalk* phenomenon (De Luca, 1997). In reason of the important... of facial muscles, the EMG activity of one recorded muscle generally does not represent the activity of a single muscle but rather a mixture of... **?**...

2.2.3 Basic signal processing

...the EMG signal is a stochastic signal... In order to illustrate what EMG signal looks like, we simulated EMG signal based on a standard algorithm implemented in the `biosignalEMG` package (Guerrero and Macias-Diaz, 2018).

```
library(biosignalEMG)
library(tidyverse)

emg <- syntheticemg(
  off.sd = 1, on.sd = 2, on.mode.pos = 0.1, samplingrate = 1e3, units = "mV"
  )$values

ts.plot(
  emg, xlab = "Time (samples)", ylab = "Raw EMG signal (mV)",
  col = "steelblue"
  )
```

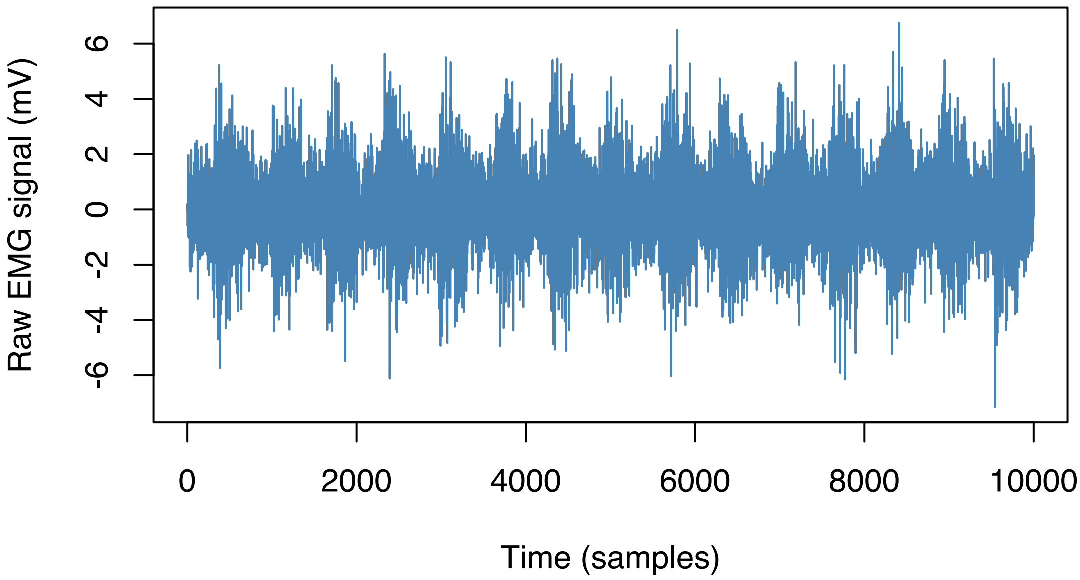

Figure 2.2: Simulated EMG signal.

We usually rectify the EMG signal by taking its absolute value and substracting the mean in order to correct for any offset (bias) present in the raw data.

```
> emg <- abs(emg - mean(emg) )
>
> ts.plot(
+   emg, xlab = "Time (samples)", ylab = "Rectified EMG signal",
+   col = "steelblue"
+   )
```

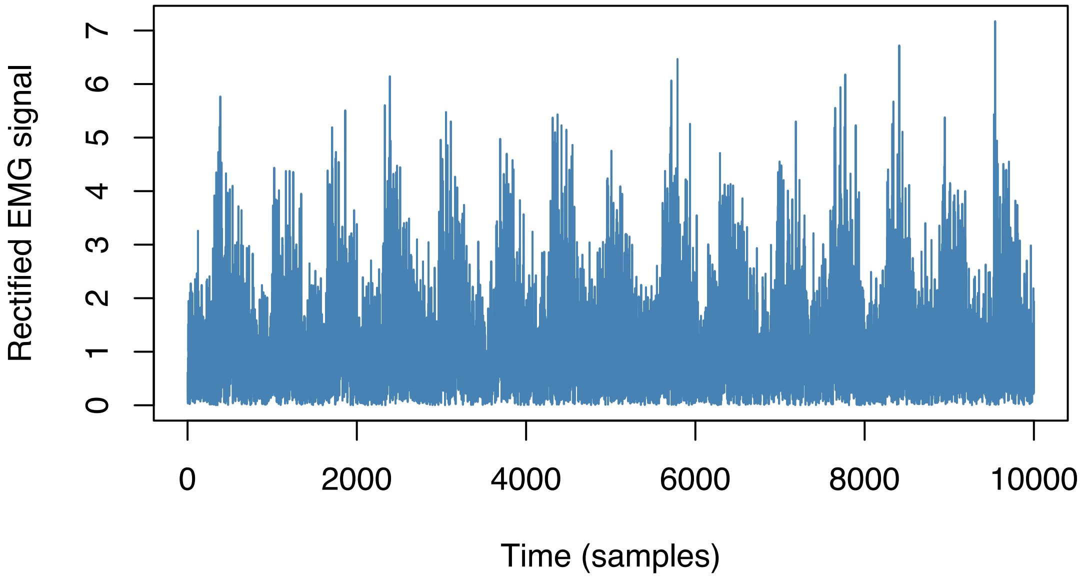

Figure 2.3: Rectified EMG signal.

From there, two main measures can be used to represent the magnitude of muscle activity[1]. The first one is the **mean absolute value** (MAV):

$$MAV = \frac{1}{N}\sum_{n=1}^{N}|x_n|$$

which is computed over a specific interval and where $|x_n|$ is the absolute value of a datum of EMG in the data window. The unit of measurement is mV or μV, and the MAV calculation is generally similar to the numerical formula for integration (Kamen and Gabriel, 2010). The second one is the **root-mean-square** (RMS) amplitude:

$$RMS = \sqrt{\frac{1}{N}\sum_{n=1}^{N}|x_n^2|}$$

where $|x_n^2|$ is the squared value of each EMG datum and has both physical and physiological meanings...

2.3 Overview of the experimental chapters

...

[1] But see Phinyomark et al. (2012) for other features that can be extracted from the surface EMG signals.

Chapter 3

Orofacial electromyographic correlates of induced verbal rumination

Summary of the research…[1]

3.1 Introduction

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

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

[1] This experimental chapter is a published paper reformatted for the need of this thesis. Source: Nalborczyk, L., Perrone-Bertolotti, M., Baeyens, C., Grandchamp, R., Polosan, M., Spinelli, E., … Lœvenbruck, H. (2017). Orofacial Electromyographic Correlates of Induced Verbal Rumination. *Biological Psychology, 127*, 53-63. http://dx.doi.org/10.1016/j.biopsycho.2017.04.013.

Inner speech or covert speech can be defined as silent verbal production in one's mind or the activity of silently talking to oneself (Zivin, 1979). The nature of inner speech is still a matter of theoretical debate (see Perrone-Bertolotti, Rapin, Lachaux, Baciu, & L & venbruck, 2014 for a review). Two opposing views have been proposed in the literature: the Abstraction view and the Motor Simulation view. The Abstraction view describes inner speech as unconcerned with articula- tory or auditory simulations and as operating on an amodal level. It has been described as "condensed, abbreviated, disconnected, fragmented, and incomprehensible to others" (Vygotsky, 1987). It has been argued that important words or grammatical affixes may be dropped in inner speech (Vygotsky, 1987) or even that the phonological form or representation of inner words may be incomplete (Sokolov, 1972; Dell & Repka, 1992). MacKay (1992) stated that inner speech is nonarticulatory and nonauditory and that "Even the lowest level units for inner speech are highly abstract" (p.122).

In contrast with this Abstraction view, the physicalist or embodied view considers inner speech production as mental simulation of overt speech production. As such, it can be viewed as similar to overt speech production, except that the motor execution process is blocked and no sound is produced (Grèzes & Decety, 2001; Postma & Noordanus, 1996). Under this Motor Simulation view, a continuum exists between overt and covert speech, in line with the continuum drawn by Decety and Jeannerod (1996) between imagined and actual actions. This hypoth- esis has led certain authors to claim that inner speech by essence should share features with speech motor actions (Feinberg, 1978; Jones & Fernyhough, 2007). The Motor Simulation view is supported by several findings. Firstly, covert and overt speech have comparable physiological correlates: for instance, measurements of speaking rate (Landauer, 1962; Netsell, Ashley, & Bakker, 2010) and respiratory rate (Conrad & Schönle, 1979) are similar in both. A prediction of the Motor Simulation view is that the speech motor system should be recruited during inner speech. Subtle muscle activity has been detected in the speech musculature using electromyography (EMG) during verbal mental imagery, silent reading, silent recitation (Jacobson, 1931; Sokolov, 1972; Livesay, Liebke, Samaras, & Stanley, 1996; McGuigan & Dollins, 1989), and during auditory verbal hallucination in patients with schizophrenia (Rapin, Dohen, Polosan, Perrier, & L & venbruck, 2013). Secondly, it has been shown that covert speech production involves a similar cerebral network as that of overt speech production. Covert and overt speech both recruit essential language areas in the left hemisphere (for a review, see Perrone- Bertolotti et al., 2014). However, there are differences. Consistent with the Motor Simulation view and the notion of a continuum between covert and overt speech, overt speech is associated with more activity in motor and premotor areas than inner speech (e.g., Palmer et al., 2001). This can be related to the absence of articulatory movements during inner verbal production. In a reciprocal way, inner speech involves cerebral areas that are not activated during overt speech (Basho, Palmer, Rubio, Wulfeck, & Müller, 2007). Some of these activations (cingulate gyrus and superior rostral frontal cortex) can be attributed to the inhibition of overt responses.

These findings suggest that the processes involved in overt speech include those required for inner speech (except for inhibition). Several studies in patients with aphasia support this view: overt speech loss can either be associated with an impairment in inner speech (e.g., Levine, Calvanio, & Popovics, 1982; Martin & Caramazza, 1982) or with intact inner speech: only the later phases of speech production (execution) being affected by the lesion

(Baddeley & Wilson, 1985; Marshall et al., 1985; Vallar & Cappa, 1987). Geva, Bennett, Warburton, and Patterson (2011) have reported a dissociation that goes against this view, however. In three patients with chronic post-stroke aphasia (out of 27 patients), poorer homophone and rhyme judgement performance was in fact observed in covert mode compared with overt mode. A limitation of this study, though, was that the task was to detect rhymes in written words, which could have been too difficult for the patients. To overcome this limitation, Langland-Hassan, Faries, Richardson, and Dietz (2015) have tested aphasia patients with a similar task, using images rather than written words. They also found that most patients performed better in the overt than in the covert mode. They inferred from these results that inner speech might be more demanding in terms of cognitive and linguistic load, and that inner speech may be a distinct ability, with its own neural substrates. We suggest an alternative interpretation to this dissociation. According to our view, rhyme and homophone judgements rely on auditory representations of the stimuli (see e.g., Paulesu, Frith, & Frackowiak, 1993). Overt speech provides a strong acoustic output that is fed back to the auditory cortex and can create an auditory trace, which can be used to monitor speech. In the covert mode, the auditory output is only mentally simulated, and its saliency in the auditory system is lesser than in the overt mode. This is in accordance with the finding that inner speech is associated with reduced sensory cortex activation compared with overt speech (Shuster & Lemieux, 2005). In patients with aphasia, the weakened saliency of covert auditory signals may be accentuated for two reasons: first, because of impairment in the motor-to-auditory transformation that produces the auditory simulation, and second, because of asso- ciated auditory deficits. Therefore, according to our view, the reduced performance observed in rhyme and homophone judgement tasks in the covert compared with the overt mode in brain-injured patients, simply indicates a lower saliency of the auditory sensations evoked during inner speech compared with the actual auditory sensations fed back during overt speech production. In summary, these findings suggest that overt and covert speech share common subjective, physiological and neural correlates, supporting the claim that inner speech is a motor simulation of overt speech.

However, the Motor Simulation view has been challenged by several experimental results. Examining the properties of errors during the production of tongue twisters, Oppenheim and Dell (2010) showed that speech errors display a lexical bias in both overt and inner speech. According to these researchers, errors also display a phonemic similar- ity effect (or articulatory bias), a tendency to exchange phonemes with common articulatory features, but this second effect is only observed with overt speech or with inner speech accompanied with mouthing. This has led Oppenheim and Dell (2010) to claim that inner speech is fully specified at the lexical level, but that it is impoverished at lower featural (articulatory) levels. This claim, related to the Abstraction view, is still debated however, as a phonemic similarity effect has been found by Corley, Brocklehurst and Moat (2011). Their findings suggest that inner speech is in fact specified at the articulatory level, even when there is no intention to articulate words overtly. Other findings however, may still challenge the Motor Simulation view. Netsell et al. (2010) have examined covert and overt speech in persons who stutter (PWS) and typical speakers. They have found that PWS were faster in covert than in overt speech while typical speakers presented similar overt and covert speech rates. This can be interpreted in favour of the Abstraction view, in which inner representations are not fully specified at the articulatory level, which would explain why they are not disrupted in PWS speech. Altogether, these results suggest that full articulatory specification may not always be necessary for inner speech to be produced.

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

There is strong interest in the examination of physiological correlates of rumination as traditional assessment of rumination essentially consists of self-reported measures. The measurement of rumination as conceptualized by Nolen-Hoeksema (1991) was operationalized by the development of the Ruminative Response Scale (RRS), which is a subscale of the response style questionnaire (Nolen-Hoeksema & Morrow, 1991). The RRS consists of 22 items that describe responses to dysphoric mood that are self-focused, symptom-focused, and focused on the causes and consequences of one's mood. Based on this scale, Treynor, Gonzalez and Nolen-Hoeksema (2003) have offered a detailed description of rumina- tion styles and more recently, Watkins (2004, 2008) has further characterized different modes of rumination. The validity of these descriptions is nevertheless based on the hypothesis that individuals have direct and reliable access to their internal states. However, self- reports increase reconstruction biases (e.g., Brewer, 1986; Conway, 1990) and it is well known that participants have a very low level of awareness of the cognitive processes that underlie and modulate complex behaviors (Nisbett & Wilson, 1977).

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

In addition to labial muscular activity, we also recorded forehead muscular activity (i.e., frontalis muscle) because of its implication in prototypical expression of sadness (e.g., Ekman, 2003; Kohler et al., 2004), reactions to unpleasant stimuli (Jäncke, Vogt, Musial, Lutz, & Kalveram, 1996), and anxiety or negative emotional state (Conrad & Roth, 2007)[2]. Our hypothesis was that frontalis activity could be an accurate electromyographic correlate of induced rumination, as a negatively valenced mental process.

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

In summary, the current study aimed at evaluating the Motor Simulation view and the Abstraction view by using objective and subjective measures of verbal rumination. To test the involvement of the orofacial motor system in verbal rumination, we used two basic approaches. In the first approach, we induced verbal rumination and examined concurrent changes in facial muscle activity (Experiment 1). In the second approach, we examined whether orofacial relaxation would reduce verbal rumination levels (Experiment 2). More specifi- cally, in Experiment 1, we aimed to provide an objective assessment of verbal rumination using quantitative physiological measures. Thus, we used EMG recordings of muscle activity during rumination, focusing on the comparison of speech-related (i.e., two lip muscles − orbicularis oris superior and orbicularis oris inferior) and speech-unrelated (i.e., forehead −frontalis- and forearm − flexor carpi radialis) muscles. Under the Motor Simulation view, an increase in lip and forehead EMG activity should be observed after rumination induction, with no change in forearm EMG activity, associated with an increase in self-reported rumination. Alternatively, under the Abstraction view, an increase in forehead activity should be observed, associated with an increase in self-reported rumination, and no changes in either lip or forearm activity should be noted.

In Experiment 2, in order to assess the reciprocity of the rumination and orofacial motor activity relationship, we evaluated the effects of orofacial relaxation on rumination. More specifically, we compared three kinds of relaxation: i) Orofacial Relaxation (i.e., lip muscles), ii) Arm Relaxation (i.e., to differentiate effects specific to speech-related muscle relaxation) and iii) Story Relaxation (i.e., to differentiate effects specific to attentional distraction). If

[2]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 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.

the Motor simulation view is correct, we predicted a larger decrease of lip and forehead muscle activity after an Orofacial Relaxation than after an Arm Relaxation (associated with a larger decrease in self-reported rumination), which should also be larger than after listening to a story. We also predicted that forearm activity should remain stable across the three conditions (i.e., should not decrease after relaxation). Alternatively, if the Abstraction view is correct, we predicted that none of the relaxation conditions should have an effect on lip or arm activity, because none of these should have increased after induction. However, we expected to observe a decrease in forehead activity and self-reported rumination after Orofacial or Arm relaxation, this decrease being larger than after listening to a Story. Importantly, we predicted that, under the Abstraction View no superiority of the Orofacial relaxation should be observed over the Arm relaxation.

3.2 Methods

3.2.1 Participants

Because of the higher prevalence of rumination in women than in men (see Johnson & Whisman, 2013; for a recent meta-analysis), we chose to include female participants only. Seventy-two female under- graduate students from Université Grenoble Alpes, native French speaking, participated in our study. One participant presenting aberrant data (probably due to inadequate sensor sticking) was removed from analyses. Final sample consisted of seventy-one undergraduate female students (Mage = 20.58, SDage = 4.99). They were recruited by e-mail diffusion lists and participated in the experiment for course credits. They did not know the goals of the study. The cover story presented the research as aiming at validating a new I.Q. test, more sensitive to personality profiles. Participants reported having no neurologic or psychiatric medical history, no language disorder, no hearing deficit, and taking no medication. Each participant gave written consent and this study has been approved by the local ethical committee (CERNI, N° 2015-03-03-61).

3.2.2 Material

...

EMG signals were detected with TrignoTM Mini sensors (Delsys Inc.) at a sampling rate of 1926 samples/s with a band pass of 20 Hz (12 dB/ oct) to 450 Hz (24 dB/oct) and were amplified by a TrignoTM 16-channel wireless EMG system (Delsys Inc.). The sensors consisted of two 5 mm long, 1 mm wide parallel bars, spaced by 10 mm, which were attached to the skin using double-sided adhesive interfaces. The skin was cleaned by gently scrubbing it with 70% isopropynol alcohol. EMG signals were then synchronized using the PowerLab 16/35 (ADInstrument, PL3516). Raw data from the EMG sensors were then resampled at a rate of 1 kHz and stored in digital format using Labchart 8 software (ADInstrument, MLU60/8). As shown in Fig. 1, bipolar surface EMG recordings were obtained from two speech-related labial muscles: orbicularis oris superior (OOS) and orbicularis oris inferior (OOI), as well as from one non speech- related but negative-affect-related facial muscle: frontalis (FRO) and from one non-facial and non speech-related muscle: flexor carpi radialis (FCR) on the non-dominant forearm. The latter pair of electrodes was used to check whether the rumination induction would cause any muscle contraction, outside of the facial muscles. The same sensor layout was used for all participants. Asymmetrical movements of the face have been shown in speech and emotional expression. As reviewed in Everdell, Marsh, Yurick, Munhall, and Paré (2007), the dominant side of the face displays larger movements than the left during speech production, whereas the non-dominant side is more emotionally expressive. To optimise the capture of speech-related activity, the OOS and OOI sensors were therefore positioned on the dominant side of the body (i.e. the right side for right-handed participants). To optimise the capture of emotion-related activity, the FRO sensor was positioned on the non-dominant side. To minimise the presence of involuntary manual gestures during the recording, the FCR sensor was positioned on the non-dominant side. Each pair of electrodes was placed parallel with the direction of the muscle fibers, at a position distant from the innervation zones and the muscle tendon interface, following the recommendations of DeLuca (1997). The experiment was video-monitored using a Sony HDR-CX240E video camera to track any visible facial movements. A microphone was placed 20–30 cm away from the participant's lips to record any faint vocal production during rumination. Stimuli were displayed with E-prime 2.0 (http://www. pstnet.com) on a 19-inch color monitor.

3.2.3 Procedure

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

During both Experiment 1 and Experiment 2, momentary rumination was assessed using four different Visual Analogue Scales (VAS, the first two being adapted and translated to French from Huffziger, Ebner- Priemer, Koudela, Reinhard, & Kuehner, 2012) rated from 0 to 100: i) "At this moment, I am thinking about my feelings" (referred to as VAS "Feelings"), ii) "At this moment, I am thinking about my problems" (referred to as VAS "Problems"), iii) "At this moment, I am brooding about negative things" (referred to as VAS "Brooding")

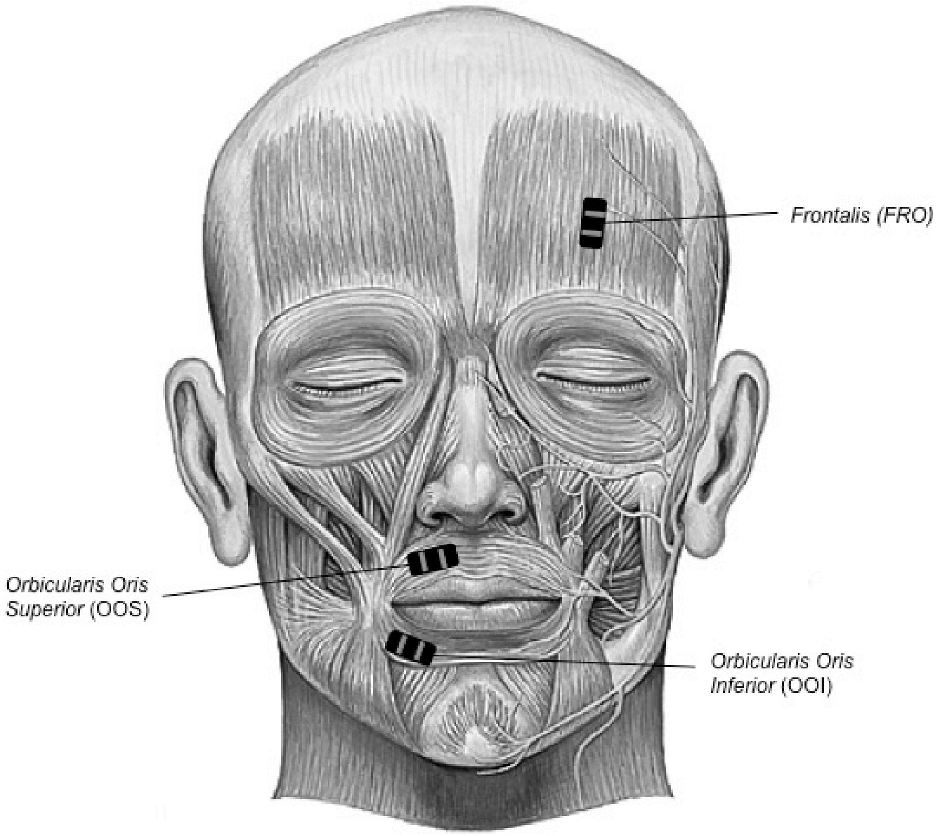

Figure 3.1: Facial muscles of interest. Two speech-related labial muscles: orbicularis oris superior (OOS) and orbicularis oris inferior (OOI); as well as one non speech-related but sadness-related facial muscle: frontalis (Front).

and iv) “At this moment, I am focused on myself” (referred to as VAS “Focused”).

3.2.3.1 Experiment 1: rumination induction

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

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

After the I.Q. test, participants were invited to reflect upon the causes and consequences of their feelings, during five minutes (rumina- tion induction). This method is based on the induction paradigm developed by Nolen-Hoeksema and Morrow (1993). The classical paradigm uses a series of prompts. In order to avoid the potential confound in muscle activity induced by silent reading, we did not use the full paradigm. We simply summarised the series of prompts by one typical induction sentence. During this period, participants were asked to remain silent and not to move, while EMG recordings were carried out (i.e., EMG Post-induction measures). EMG signals of rumination were collected during the last minute of this period. Finally, partici- pants were instructed to self-report momentary rumination on the four VASs.

3.2.3.2 Experiment 2: rumination reduction by relaxation

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

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

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

3.2.4 Data processing and analysis

3.2.4.1 EMG data processing

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

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

After pre-processing, EMG data were exported from Labchart soft- ware to Matlab r2014a (Version 8.3.0.532, www.mathworks.fr). For each EMG signal, mean values were computed under Matlab, using 200 ms sliding windows. The average of these mean values were calculated for each recording session (baseline, after induction and after relaxation/induction). This provided a score for each muscle of interest (OOS, OOI, FCR, FRO) in each Session (Baseline, Post- Induction, Post-Relaxation) for each participant[3].

3.2.4.2 Statistical analyses

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

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

These analyses were conducted using RStudio (RStudio Team, 2015) and the brms package (Bürkner, in press), an R implementation of Bayesian multilevel models that employs the probabilistic program- ming language, Stan (Carpenter et al., 2016). Stan implements gradient- based Markov Chain Monte Carlo (MCMC) algorithms (e.g., Hamilto- nian Monte-Carlo), which allow yielding posterior distributions that are straightforward to use for interval estimation around all parameters. Two MCMC simulations (or "chains") were run for each model, including 100,000 iterations, a warmup of 10,000 iterations, and a thinning interval of 10. Posterior convergence was assessed examining autocorrelation and trace plots, as well as the Gelman-Rubin statistic. Fixed effects were estimated via the posterior mean and 95% highest density intervals (HDIs), where an HDI interval is the Bayesian analogue of a classical confidence interval[4].

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

[3]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.

[4]While not suffering from the misunderstandings associated with frequentist confidence intervals (for more details, see for instance Morey, Hoekstra, Rouder, Lee & Wagenmakers, 2015).

3.3 Results

3.3.1 Experiment 1: rumination induction

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

3.3.1.1 Self-reported rumination measures: VAS scores

Results for VAS relative changes based on the multivariate models described earlier are shown in the right panel of Fig. 2. Thereafter, α represents the mean of the posterior distribution of the intercept. Raw pre- and post-induction scores are provided in Supplementary Materials.

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

In the following, we report the mean (indicated by the Greek symbol) and the 95% HDI of the posterior distribution on the correlation coefficient (ρ). Examination of the correlation matrix estimated by the multivariate model revealed no apparent correlation neither between Feelings and Problems scales ($\rho = -0.01$, 95% HDI [-0.23, 0.22]), nor between Feelings and Brooding ($\rho = 0.08$, 95% HDI [-0.15, 0.30]). However, we observed a strong positive correlation between Problems and Brooding VASs ($\rho = 0.64$, 95% HDI [.49, 0.76]), a positive correlation between Feelings and Focused ($\rho = 0.30$, 95% HDI [.08, 0.50]), and a negative correlation between Problems and Focused ($\rho = -0.30$, 95% HDI [-0.49, -0.08]), as well as between Brooding and Focused ($\rho = -0.18$, 95% HDI [-0.39, 0.05]).

3.3.1.2 EMG

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

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

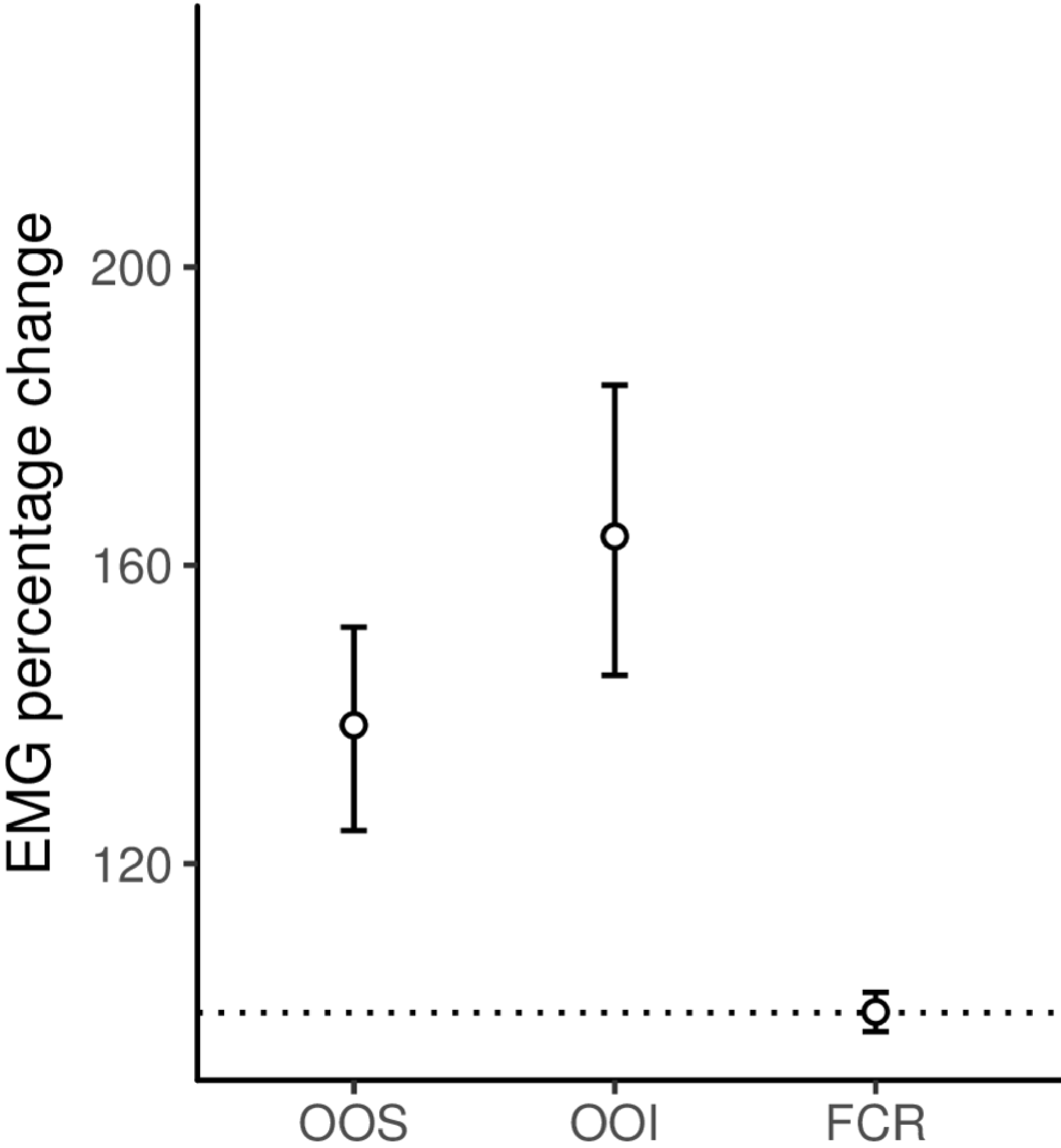

Figure 3.2: Posterior mean (white dots) and 95% credible intervals for the EMG amplitude (expressed in percentage of baseline level, left panel), and the VAS score (expressed in relative change from baseline, right panel). N = 71 (for each muscle and each VAS). Dashed line represents the null value (i.e., 100).

Examination of the correlation matrix estimated by the bayesian multivariate model revealed a positive correlation between OOS and OOI EMG amplitudes ($\rho = 0.44$, 95% HDI [.24, 0.61]), while no apparent correlations neither between OOS and FCR ($\rho = 0.09$, 95% HDI [-0.14, 0.31]), OOS and FRO ($\rho = 0.12$, 95% HDI [-0.11, 0.35]), OOI and FCR ($\rho = 0.02$, 95% HDI [-0.21, 0.25]), FRO and FCR ($\rho = -0.06$, 95% HDI [-0.28, 0.17]), nor OOI and FRO ($\rho = 0.07$, 95% HDI [-0.16, 0.29]). Scatterplots, marginal posterior distributions and posterior distributions on correlation coefficients are available in Supplementary Materials (Supplementary materials, data, reproducible code and figures are available at: https://osf.io/882te/).

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

3.3.1.3 Correlations between EMG amplitudes and VAS scores

Correlations between EMG amplitudes and VAS scores were exam- ined using the BayesianFirstAid package (Bååth, 2013), using 15,000 iterations for each correlation coefficient. Both estimated correlation coefficients (ρs) and 95% HDIs are reported in Table 1.

3.3.2 Experiment 2: rumination reduction by relaxation

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

3.3.2.1 Self-reported rumination measures: VAS scores

Posterior means and 95% HDIs of the VAS scores in each condition of experiment 2 are represented in Fig. 3 and Table 1 (Table 2).

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

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

Concerning the Problems VAS, the decrease observed in the Orofacial condition was more pronounced than in the Arm condition (Est = −11.06, SE = 6.35, ER10 = 22.65), and slightly more pro- nounced compared to the Story condition (Est = −6.05, SE = 6.31, ER10 = 4.98). The observed on the Brooding VAS score in the Orofacial condition was larger than in the Arm condition (Est = −9.98, SE = 6.07, ER10 = 18.85), and slightly more important compared to the Story condition (Est = −5.23, SE = 6.01, ER10 = 4.27).

3.3.2.2 EMG

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

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

Concerning the OOS, the observed decrease in the Orofacial condition was more pronounced than in the Arm condition (Est = −0.34, SE = 0.14, ER10 = 140.73), as well as concerning the OOI (Est = −0.35, SE = 0.19, ER10 = 29.46), while we observed no noticeable differences between the two kinds of relaxation concerning the EMG amplitude of the FRO (Est = -0.04, SE = 0.14, ER10 = 1.53).

3.4 Discussion

3.4.1 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.

As predicted by the Motor Simulation view, we observed an increase in the activity of the two speech-related muscles (OOS & OOI) as well as in the negative-affect-related muscle (FRO) and no change in FCR activity. The increase in facial EMG together with the increase

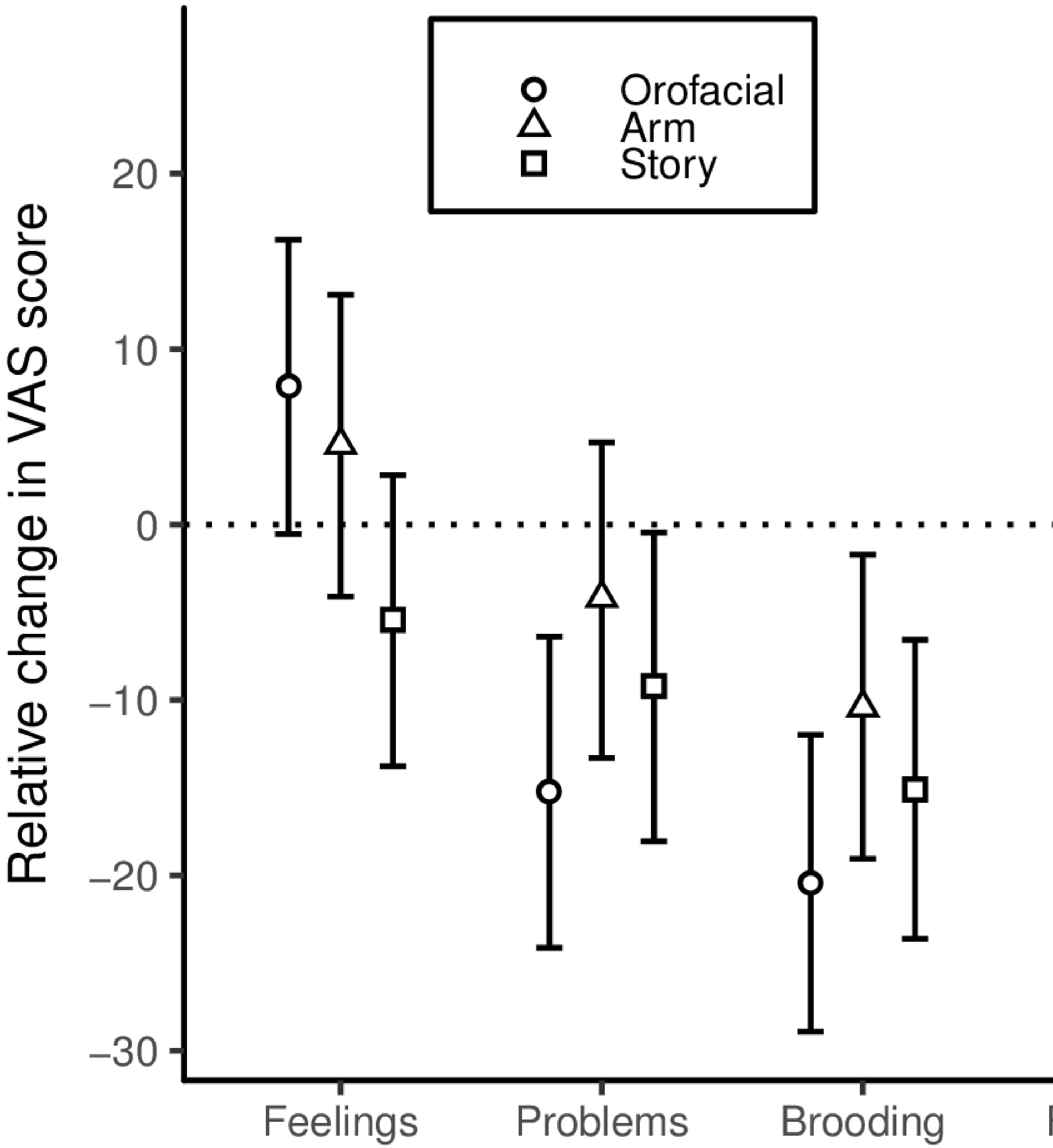

Figure 3.3: Posterior mean and 95% credible intervals for the VAS score (expressed in relative change from post-induction level).

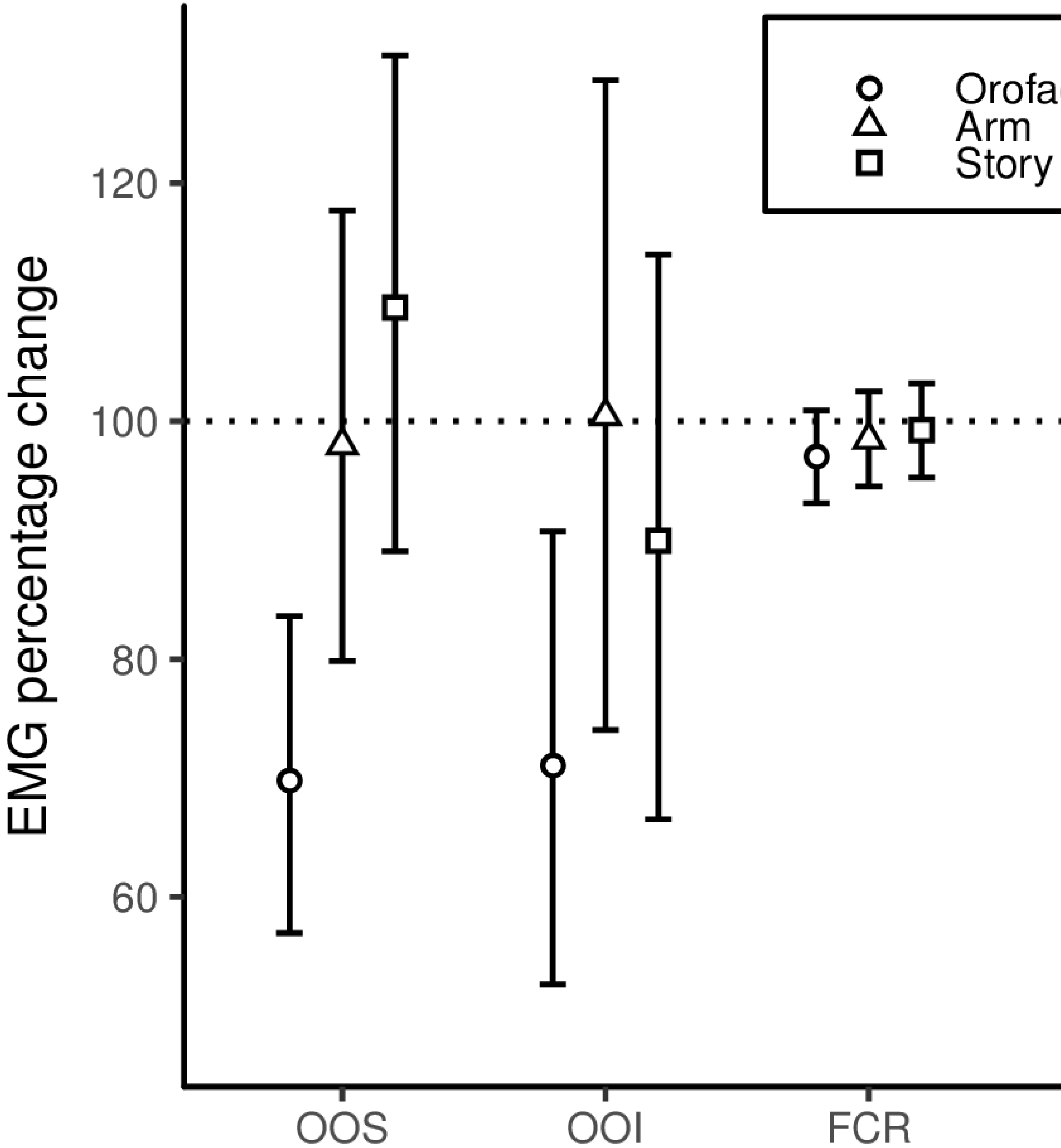

Figure 3.4: Posterior mean and 95% credible intervals for the VAS score (expressed in relative change from post-induction level).

in the subjective reports of rumination suggests that facial EMG increase is a correlate of verbal rumination. As supported by several studies results, the forehead muscle activity has been associated with unpleasant emotions (Jäncke et al., 1996) or anxiety (Conrad & Roth, 2007). The increase in FRO activity observed here is consistent with the increase in negative emotions induced by our negatively valenced induction procedure. Orbicularis oris lip muscles are associated with speech production. The increase in lip activity observed here suggests that the speech motor system was involved during the ruminative phase. The fact that the FCR remained stable after rumination induction suggests that the observed facial activity increase was not due to general body tension induced by a negative mental state. These facial EMG results therefore support the hypothesis that rumination is an instance of articulatory-specified inner speech.

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

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

Scores on the VAS need to be discussed in further detail. We examined which VAS scales were most suitable to capture changes in state rumination to allow focused analyses. Due to the “pre-baseline” relaxation session, during which participants were asked to concentrate on their body and breathing cycles, participants reported a high level of attentional self-focus at baseline (“Feelings” and “Focused” VAS). Because of the high level of self-focused attention at baseline, it is likely that the scores on the “Feelings” and “Focused” VAS did not show the expected increase after rumination induction (ceiling effect). The scores on the scales “Problems” and “Brooding”, which are more representative of maladaptive rumination, did increase after our rumination induction paradigm, however. Interestingly, the “Brooding” VAS corresponded to a larger increase and seemed to be more sensitive to rumination induction than the “Problems” VAS. Given this greater sensibility and the strong positive correlation between the “Brooding” and the “Problems” VAS, it thus make sense to consider the “Brooding” VAS as a better estimate of ruminative state, at least within our paradigm. We will therefore only use this scale to assess rumination in the following.

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

3.4.2 Experiment 2

In the second experiment, we studied the effects of two muscle- specific relaxation sessions: Orofacial relaxation and Arm relaxation. We compared their effects to a third control condition (Story), which did not involve the deliberate relaxation of any specific muscle. Our predictions were that a decrease in facial EMG activity should be observed in each condition. If the Motor Simulation view is correct, we expected a larger decrease in the activity of all facial muscles in the “Orofacial relaxation” condition than in the “Arm relaxation” condition, associated with a larger decrease in self-reported rumination. Additionally, we expected a more pronounced decrease in the two relaxation conditions (orofacial and arm relaxation conditions) than in the control (“Story”) condition. We also expected no difference between relaxation conditions regarding the change in the forearm muscle activity.

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

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

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

Interestingly, we observed no changes of forearm EMG activity in any of the three conditions of experiment 2. The fact that the relaxation session focused on the forearm was not associated with a decrease in FCR activity has a simple explanation: FCR activity had not increased after rumination induction and had remained at floor level. The forearm was thus already relaxed and the Arm relaxation session did not modify FCR activity. Another interesting conclusion related to this absence of modification of forearm activity is that relaxation does not spuriously decrease muscle activity below its resting level. One possible interpretation of the increase in lip EMG after rumination induction could have been that baseline relaxation artificially decreased baseline activity under its resting level.

The facts that forearm activity did not decrease after arm-focused relaxation contradicts this interpretation.

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

3.4.3 General discussion

We set out two experiments to examine whether rumination involves motor simulation or is better described as linguistically abstract and articulatory impoverished. We used labial, facial, and arm EMG measures to assess potential articulatory correlates of rumination. The patterns of results of our study seem to be in favour of the motor nature of verbal rumination. In Experiment 1, rumination induction was associated with a higher score on the scale “I am brooding about negative things” which is representative of abstract- analytical rumination, considered as verbal rumination. This maladap- tive rumination state was associated with an increase in the activity of two speech-related muscles, without modification of the arm muscle activity, which indicates that rumination involves activity in speech articulatory muscles, specifically. The concurrent increase in forehead muscle activity could be explained by an increase in negative emotions induced by our negatively valenced induction procedure. The results of Experiment 1 therefore show the involvement of the speech muscula- ture during rumination. This is in line with the Motor simulation view, according to which inner speech is fully specified at the articulatory level, not just the lexical level.

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

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

Our results should be interpreted with some limitations in mind. Firstly, our sample consisted exclusively of women. Although this methodological choice makes sense considering the more frequent occurrence of rumination in women, further studies should be con- ducted to ascertain that our results may generalize to men. Secondly, in Experiment 1, no between-subject control condition was used to compare with the group of participants who underwent rumination induction. Thus, we cannot rule out that other processes occurred between baseline and rumination induction, influencing responding. Thirdly, substantial inter-individual differences were observed concern- ing the size of the effect of rumination induction on facial EMG activity. The results of Jäncke (Jäncke, 1996; Jäncke et al., 1996) can shed light on this last result. Jäncke used a similar procedure (i.e., negative mood induction using a false I.Q. test and facial EMG measurements to assess emotions), except that the experimenter was not in the room while participants performed the test and acknowledged their results. The experimenter then came back to the room and analysed participants' behaviours. Jäncke observed an increase in facial muscular activity (assessed when participants were reading their results) only in partici- pants who were prone to express their distress when the experimenter came back, while more introverted participants did not show any increased facial activity when reading their results. Jäncke interpreted these results in the framework of an ecological theory of facial expression, suggesting that facial expressions would not only be guided by underlying emotions, but also by their communicative properties. Considering these results, it seems likely that the proneness of participants to communicate their emotions could have mediated effects of the induction on their facial EMG activity. This could partially explain the observed inter-individual variability in facial EMG activity associated with rumination. Moreover, even though rumination is a predominantly verbal process, one cannot exclude that some of our participants experienced rumination in another modality (e.g., ima- gery-based rumination), which would explain their lower than average lip activity.

Thus, a logical next step is to examine qualitative factors that mediate the link between rumination and facial muscular activity. These factors (among others) could be proneness to communicate emotion or proneness to verbalize affects. Additionally, recent studies suggest a link between verbal aptitudes and propensity to ruminate. Uttl, Morin and Hamper (2011) have observed a weak but consistent correlation between the tendency to ruminate and scores on a verbal intelligence test. Penney, Miedema and Mazmanian (2015) have observed that verbal intelligence constitutes a unique predictor of rumination severity in chronic anxious patients. To our knowledge, the link between verbal intelligence and induced rumination has never been studied. It would be interesting to examine whether the effects of a rumination induction could be mediated by verbal intelligence, and to what extent this could influence related facial EMG activity.

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

3.5 Acknowledgements

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3.6 Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.biopsycho.2017.04.013.

Chapter 4

Dissociating facial electromyographic correlates of visual and verbal induced rumination

Second EMG study with Sonja...

Chapter 5

Zygoto experiment

...

Chapter 6

Articulatory suppression effects on induced rumination

Summary of the research...[1]

6.1 Introduction

A large part of our inner experience involves verbal content, with internal monologues and conversations. Inner speech is considered as a major component of conscious experience and cognition (**???**). An important issue related to inner speech concerns its format and nature and whether it is better described as a mere evocation of abstract amodal verbal representations or as a concrete motor simulation of actual speech production. In the first case, inner speech is seen as divorced from bodily experience, and includes, at most, faded auditory representations. In the second case, inner speech is considered as a physical process that unfolds over time, leading to an enactive re-creation of auditory a well as articulatory percepts. The latter hypothesis is interesting in the context of persistent negative and maladaptive forms of inner speech, such as rumination. If this hypothesis is correct, we could expect rumination –as a particular type of inner speech– to be disrupted by concurrent involvement of the speech muscles.

6.1.1 Multisensory and motor components of inner speech

Introspective explorations of the characteristics of inner speech have led to different views on the relative importance of its auditory and articulatory components, and on the involvement of motor processes. For **?**, "speech representations are motor representations", while **?** believed that auditory representations are dominant in inner speech and that

[1] This experimental chapter is a manuscript reformatted for the need of this thesis. Source: The manuscript has been submitted to Psychological Research. Pre-registered protocol, preprint, data, as well as reproducible code and figures are available at: https://osf.io/3bh67/.

motor representations are not always present. However, as noted by **?**, these contradictory hypotheses might stem from an over-generalization of their own introspective findings, the former discovering motor feelings and the latter auditory images (**?**). In the same vein, **?** claimed that inner speech involves both auditory and motor images, defining motor images as the sensations in the speech organs (larynx, tongue, lips) that sometimes accompany inner speech. Therefore, Paulhan's notion of *motor images* are in fact related to somatosensory representations rather than to the involvement of actual speech movements (as claimed by Stricker). It remains, however, that a distinction was introduced by 19th century authors between sensory and motor phenomena in inner speech, with sensory phenomena including auditory as well as articulatory (or somatosensory) percepts. The intuitive distinction between auditory and motor phenomena is referred to in contemporary research by the terms of *inner ear* and *inner voice*, in line with Baddeley's classic model of working memory (e.g., **?**; see also **?**). Baddeley's model relies on a partnership between an *inner ear* (i.e., storage) and an *inner voice* (i.e., subvocal rehearsal; see **?**).

Empirical arguments supporting the crucial role of the inner voice in verbal memory (subvocal rehearsal) and auditory imagery can be found in studies using articulatory suppression, in which the *action* component (i.e., the *inner voice*) of inner speech is disrupted. Articulatory suppression usually refers to a task which requires participants to utter speech sounds (or to produce speech gestures without sound), so that this activity disrupts ongoing speech production processes. Articulatory suppression can be produced with different degrees of vocalisation, going from overt uttering of irrelevant words, to whispering, mouthing (i.e., silent articulation), and simple clamping of the speech articulators. Many verbal working memory studies have shown that articulatory suppression impairs recall performance (e.g., **?**).

In a study aiming at investigating the role of *covert enactment* in auditory imagery, **?** observed that the verbal transformation effect (VTE, **?**), namely the alteration of speech percepts when certain speech sounds are uttered in a repetitive way, also occurred during inner speech (although the VTE was smaller than during overt speech), but was suppressed by concurrent articulation (e.g., chewing) or clamping the articulators. The fact that the VTE was observed during inner speech and that it was reduced by concurrent chewing, even in inner speech, speaks in favour of the view of inner speech as an enacted simulation of overt speech.

Another piece of evidence for the effect of articulatory suppression on inner speech comes from a recent study by **?** on the mere exposure effect, namely the fact that repeated exposure to a stimulus influences the evaluation of this stimulus in a positive way (**?**). Topolinski and Strack's study showed that the mere exposure effect for visually presented verbal material could be completely suppressed by blocking subvocal rehearsal (i.e., inner speech) when asking participants to chew a gum. The effect was preserved, however, when participants kneaded a soft ball with their hand (**?**). This finding suggests that blocking speech motor simulation interfered with the inner rehearsal of the visually presented verbal stimuli, thereby destroying the positive exposure effect. It provides additional experimental support to the view that inner speech involves a motor component.

The occurrence of motor simulation during inner speech is further backed by several studies using physiological measures to evaluate inner speech production properties. Using electrodes inserted in the tongue tip or lips of five participants, **?** was able to detect electromyographic (EMG) activity during several tasks requiring inner speech. Similarly, **?** recorded intense lip and tongue muscle activation when participants had to perform complex tasks that necessitated substantial inner speech production (e.g., problem solving). Another study using surface electromyography (sEMG) demonstrated an increase in activity of the lip muscles during silent recitation tasks compared to rest, but no increase during the non-linguistic visualisation task (**?**). An increase in the lip and forehead muscular activity has also been observed during induced rumination (**?**). Furthermore, this last study also suggested that speech-related muscle relaxation was slightly more efficient in reducing subjective levels of rumination than non speech-related muscle relaxation, suggesting that relaxing or inhibiting the speech muscles could disrupt rumination.

6.1.2 Rumination

Rumination is a "class of conscious thoughts that revolve around a common instrumental theme and that recur in the absence of immediate environmental demands requiring the thoughts" (**?**). Despite the fact that depressed patients report positive metacognitive beliefs about ruminating, which is often seen as a coping strategy in order to regulate mood (e.g., **?**), rumination is known to significantly worsen mood (e.g., **??**), impair cognitive flexibility (e.g., **??**), and to lead toward pronounced social exclusion and more interpersonnal distress (**?**). Although partly visual, rumination is a predominantly verbal process (**??**) and can be considered as a maladaptive type of inner speech.

In a study on worry, another form of repetitive negative thinking, **?** observed a *tendency* for articulatory suppression, but not for visuo-spatial tasks, to produce some interference with worrying. He concluded that worry involves the phonological aspect of the central executive of working memory. We further add that, since repeating a word seems to reduce the ability to worry, this study suggests that articulatory aspects are at play during worry.

In this context, the question we addressed in this study is whether verbal rumination consists of purely abstract verbal representations or whether it is better described as a motor simulation of speech production, engaging the speech apparatus. If the latter hypothesis is correct, rumination experienced in verbal form (in contrast to a non-verbal form) should be disrupted by mouthing (i.e., silent articulation), and should not be disrupted by a control task that does not involve speech muscles (e.g., finger-tapping). Specifically, we thus sought to test the hypotheses that rumination could be disrupted by articulatory suppression (but not by finger-tapping), and that this disruption would be more pronounced when rumination is experienced in a verbal form than in a non-verbal form.

6.2 Methods

In the *Methods* and *Data analysis* sections, we report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study (**?**). A pre-registered version of our protocol can be found on OSF: https://osf.io/3bh67/.

6.2.1 Sample

We originally planned for 128 participants to take part in the study. This sample size was set on the basis of results obtained by **?**, who observed an effect size around $\eta_p^2 = .06$. We expected a similar effect size for the current rumination disruption, since rumination can be conceived of as a subtype of inner speech[2].

As we anticipated drop-out of participants due to our inclusion criteria (see below), a total of 184 undergraduate students in psychology from the Université Grenoble Alpes took part in this experiment, in exchange for course credits. They were recruited via mailing list, online student groups, and posters. Each participant provided a written consent and this study was approved by the local ethics committee (CERNI N° 2016-05-31-9). To be eligible, participants had to be between 18 and 35 years of age, with no history of motor, neurological, psychiatric, or speech-development disorders. All participants spoke French as their mother tongue. After each participant gave their written consent, they completed the Center for Epidemiologic Studies - Depression scale (CES-D; **?**). The CES-D is a 12-item questionnaire, validated in French (**?**), aiming to assess the level of depressive symptoms in a subclinical population. Participants exceeding the threshold of clinical depressive symptoms (i.e., >23 for females and >17 for males; **?**) were not included in the study for ethical reasons (N = 26).

To investigate articulatory suppression effects in the context of rumination, a successful induction of rumination is a prerequisite. Therefore, analyses were only conducted on participants who showed an effect of the rumination induction (i.e., strictly speaking, participants who reported more rumination after the induction than before). We thus discarded participants who did not show any increase in rumination level (N = 52, 32.91% of total sample). The final sample comprised 106 participants (Mean age = 20.3018868, SD = 2.5728064, Min-Max = 18-31, 96 females).

6.2.2 Material

The experiment was programmed with OpenSesame software (**?**) and stimuli were displayed on a DELL latitude E6500 computer screen.

[2] In the original power calculations included in the OSF preregistration platform, we had inadequately specified the effect size in GPower, but we only realised this erroneous specification after the freezing of the preregistration on the OSF platform. Therefore, the current sample size slightly differs from the preregistered one.

6.2.2.1 Questionaires

To control for confounding variables likely to be related to the intensity of the induction procedure, we administered the French version of the Positive and Negative Affect Schedule (PANAS; ?), adapted to French by ?. This questionnaire includes 20 items, from which we can compute an overall index of both positive (by summing the scores on 10 positive items, thereafter *PANASpos*) and negative affect (*PANASneg*) at baseline. This questionnaire was administered at baseline. In order to evaluate trait rumination, at the end of the experiment participants completed the short version of the Ruminative Response Scale (RRS-R, ?), validated in French (Douilliez, Guimpel, Baeyens, & Philippot, *in preparation*). From this questionnaire, scores on two dimensions were analysed (*RRSbrooding* and *RRSreflection*).

6.2.2.2 Measures

Measures of state rumination were recorded using a Visual Analogue Scale (VAS) previously used in ?. This scale measured the degree of agreement with the sentence “At this moment, I am brooding on negative things” (translated from French), on a continuum between “Not at all” and “A lot” (afterwards coded between 0 and 100). This scale is subsequently referred to as the *RUM* scale. It was used three times in the experiment, at baseline (after training but before the experiment started), after rumination induction, and after a motor task.

Additionally, participants answered questions about the modality of the thoughts that occurred while performing the motor task. This last questionnaire consisted of one question evaluating the occurrence frequency of different modalities of inner thoughts (e.g., visual imagery, verbal thoughts, music). Then, a verbal/non-verbal ratio (i.e., the score on the verbal item divided by the mean of the score on the non-verbal items) was computed, hereafter referred to as the *Verbality* continuous predictor (this scale is available online: https://osf.io/3bh67/).

6.2.2.3 Tasks

In the first part of the experiment, ruminative thoughts were induced using a classical induction procedure. Then a motor task was executed. Participants were randomly allocated to one of two conditions. In the *Mouthing* condition, the task consisted of repetitively making mouth opening-closing movements at a comfortable pace. This condition was selected as it is commonly used in articulatory suppression studies (e.g., ?). As a control, a finger-tapping condition was used (the *Tapping* condition), that consisted of tapping on the desk with the index finger of the dominant hand at a comfortable pace.

Although finger-tapping tasks are generally considered as good control conditions when using speech motor tasks, since they are comparable in terms of general attentional demands, it may be that orofacial gestures are intrinsically more complex than manual gestures (i.e., more costly, ?). To discard the possibility that orofacial gestures (related to the *Mouthing* condition) would be cognitively more demanding than manual ones (related to the *Tapping* condition), we designed a pretest experiment in order to compare the two interference motor tasks used in the main experiment. Results of this control experiment showed no difference on reaction times during a visual search task between the two interference tasks (i.e., mouthing and finger-tapping). Full details are provided in Appendix A.

6.2.3 Procedure

The experiment took place individually in a quiet and dimmed room. The total duration of the session ranged between 35min and 40min. Before starting the experiment, participants were asked to perform the motor task during 1 min, while following a dot moving at a random pace on the screen in front of them. This task was designed to train the participants to perform the motor task adequately. Following this training and after describing the experiment, the experimenter left the room and each participant had to fill-in a baseline questionnaire (adaptation of PANAS, see above) presented on the computer screen. Baseline state rumination was then evaluated using the *RUM* scale. The whole experiment was video-monitored using a Sony HDR-CX240E video camera, in order to check that the participants effectively completed the task.

6.2.3.1 Rumination induction

Rumination induction consisted of two steps. The first step consisted of inducing a negative mood in order to enhance the effects of the subsequent rumination induction. Participants were asked to recall a significant personal failure experienced in the past five years. Then, participants were invited to evaluate the extent to which this memory was "intense for them" on a VAS between "Not at all" and "A lot", afterwards coded between 0 and 100, and referred to as *Vividness*.

The second step consisted of the rumination induction proper. We used a French translation of the **?** rumination induction procedure. Participants had to read a list of 44 sentences related to the meaning, the causes and the consequences of their current affective or physiological state. Each phrase was presented on a computer screen for 10 seconds and the total duration of this step was 7 minutes and 20 seconds. State rumination was then evaluated again using the same VAS as the one used at baseline (*RUM*).

6.2.3.2 Motor task

After the rumination induction, participants were asked to continue to think about "the meaning, causes, and consequences" of their feelings while either repetitively making mouth movements (for participants allocated in the "Mouthing" condition) or finger-tapping with the dominant hand for five minutes (for participants allocated in the "Tapping" condition). Afterwards, state rumination was again evaluated using the *RUM* scale.

In order to evaluate trait rumination, participants completed the short version of the RRS (see above). Then were filled in the questionnaire on the modality of the thoughts that occurred while performing the motor task (see above). Figure 6.1 summarises the full procedure.

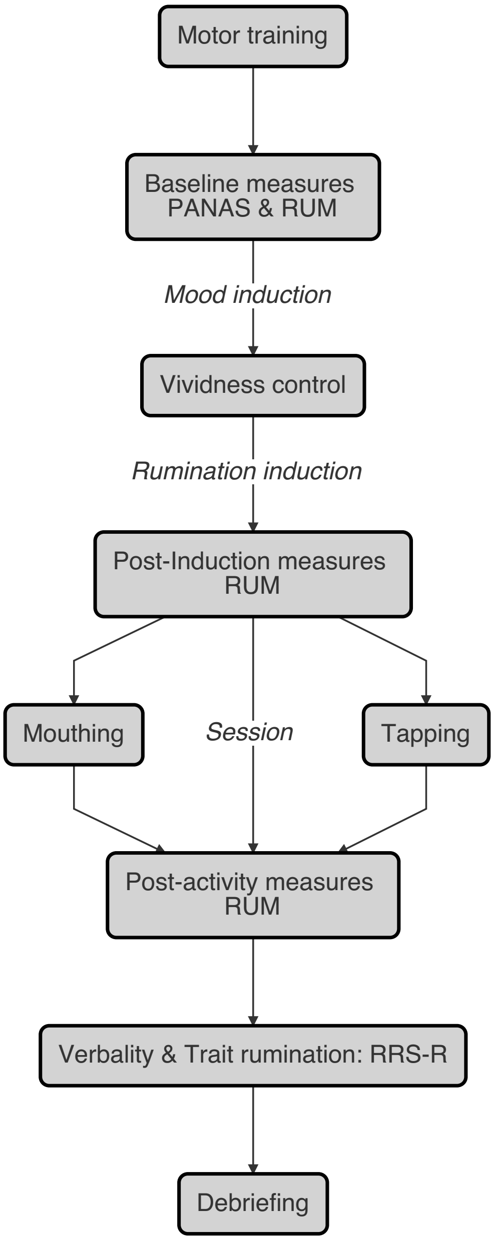

Figure 6.1: Timeline of the experiment, from top to bottom.

6.2.4 Data analysis

Statistical analyses were conducted using R version 3.4.3 (R Core Team, 2018), and are reported with the `papaja` (Aust and Barth, 2018) and `knitr` (Xie, 2018) packages.

6.2.4.1 Rumination induction

We centered and standardised each predictor in order to facilitate the interpretation of parameters. Data were then analysed using *Induction* (2 modalities, before and after induction, contrast-coded) as a within-subject categorical predictor and *RUM* as a dependent variable in a multilevel linear model (MLM). Data were fitted using the `lmer` function, within the `lme4` package (**?**). This model was compared with more complex models including effects of control variables, such as baseline affect state (*PANAS* scores) or the vividness of the memory chosen during the induction (*Vividness* score). Models were compared using the corrected Akaike Information Criterion (AICc) and evidence ratios (**???**). AICc provides a relative measure of predictive accuracy of the models (the AIC is an approximation of the out-of-sample deviance of a model) and balances underfitting and overfitting by sanctioning models for their number of parameters. We computed the difference between the best (lower) and other AICcs with $\Delta_{AICc} = AICc_i - AICc_{min}$ and then expressed the weight of a model as:

$$w_i = \frac{exp(-\Delta_i/2)}{\sum_{r=1}^{R} exp(-\Delta_r/2)}$$

From there, we computed evidence ratios (ERs) as the ratios of weights: $ER_{ij} = \frac{w_i}{w_j}$, where w_i and w_j are the Akaike weights of models i and j, respectively. These weights can be interpreted as the probability of the model being the best model in terms of out-of-sample prediction (**?**). Instead of reporting null-hypothesis tests for our MLMs, we report 95% confidence intervals for the constant effects estimates[3].

Whereas the use of AICc is appropriate for model comparison and selection, it tells us nothing about the absolute fit of the model. To estimate this fit, we computed two types of R^2 for MLMs using the `MuMIn` package (**?**). The first, called the marginal R^2 ($R^2_{marg.}$), estimates the proportion of variance accounted for by the constant effects, whereas the second, called the conditional R^2 ($R^2_{cond.}$), estimates the proportion of variance accounted for by the constant and the varying effects taken together (**???**).

6.2.4.2 Articulatory suppression effects

Data were analysed in the same fashion as in the first part of the experiment, using *Session* (2 modalities, before and after motor activity, contrast-coded) as a within-subject categorical predictor, and *Condition* (2 modalities, Mouthing and Tapping) as a between-subject categorical predictor and *RUM* as a dependent variable, in a MLM.

[3]These may be interpreted as tests of significance: if the confidence interval for an estimated parameter does not contain zero, this estimate may be considered significant at α <.05.

Table 6.1: Descriptive statistics (mean and standard deviation) of each recorded variable, for the final sample of participants that were included in the study.

Variables	Baseline	Post-induction	Post-motor	Baseline	Post-induction	Post
RUM	28.5 (26.49)	54.66 (25.16)	45.47 (27.25)	20.96 (21.82)	46.77 (25.74)	43.54
Age	20.3 (2.65)	-	-	20.31 (2.53)	-	
PANASneg	15.65 (5.67)	-	-	15.46 (5.08)	-	
PANASpos	30.91 (4.48)	-	-	31.25 (4.4)	-	
RRSbrooding	12.2 (2.43)	-	-	12.06 (2.62)	-	
RRSreflection	12.22 (3.22)	-	-	11.71 (3.26)	-	
Valence	23.56 (22.4)	-	-	37.53 (24.61)	-	
Verbality	1.67 (1.18)	-	-	1.67 (1.26)	-	
Vividness	54.17 (28.94)	-	-	59.78 (24.63)	-	

6.3 Results

6.3.1 Correlation matrix between main predictors and control variables

In order to prevent multicollinearity, we estimated the correlation between each pair of continuous predictors. Figure 6.2 displays these correlations along with the marginal distribution of each variable. The absence of strong correlations ($r > 0.8$) between any of these variables suggests that they can each be included as control variables in the following statistical models. Summary statistics (mean and standard deviation) for all these variables can be found in Table 6.1.

6.3.2 Rumination induction

To examine the efficiency of the induction procedure (i.e., the effect of *Induction*) while controlling for the other variables (i.e., *Vividness*, *RRSbrooding*, *RRSreflection*, *PANASpos*, and *PANASneg*), we then compared the parsimony of models containing main constant effects and a varying intercept for *Participant*. Model comparison showed that the best model (in the sense of the lowest AICc model) was the model including *Induction*, *PANASpos*, *PANASneg*, *RRSbooding*, and an interaction term between *Induction* and *Vividness* as predictors (see Table 6.2). Fit of the best model was moderate as marginal R^2 was of 0.3801215 while conditional R^2 was of 0.6838429.

Constant effect estimates for the best model are reported in Table 6.3.2. Based on these values, it seems that *Induction* (i.e., the effects of the rumination induction) increased *RUM* scores by approximately 26 points in average (d_{av} = 1.037, 95% CI [0.748, 1.325]). The main negative effect of *PANASneg* and the main positive effects of *PANASpos* indicate, respectively, that negative baseline mood was associated with higher levels of rumination while positive baseline mood was associated with lower levels of self-reported rumination.

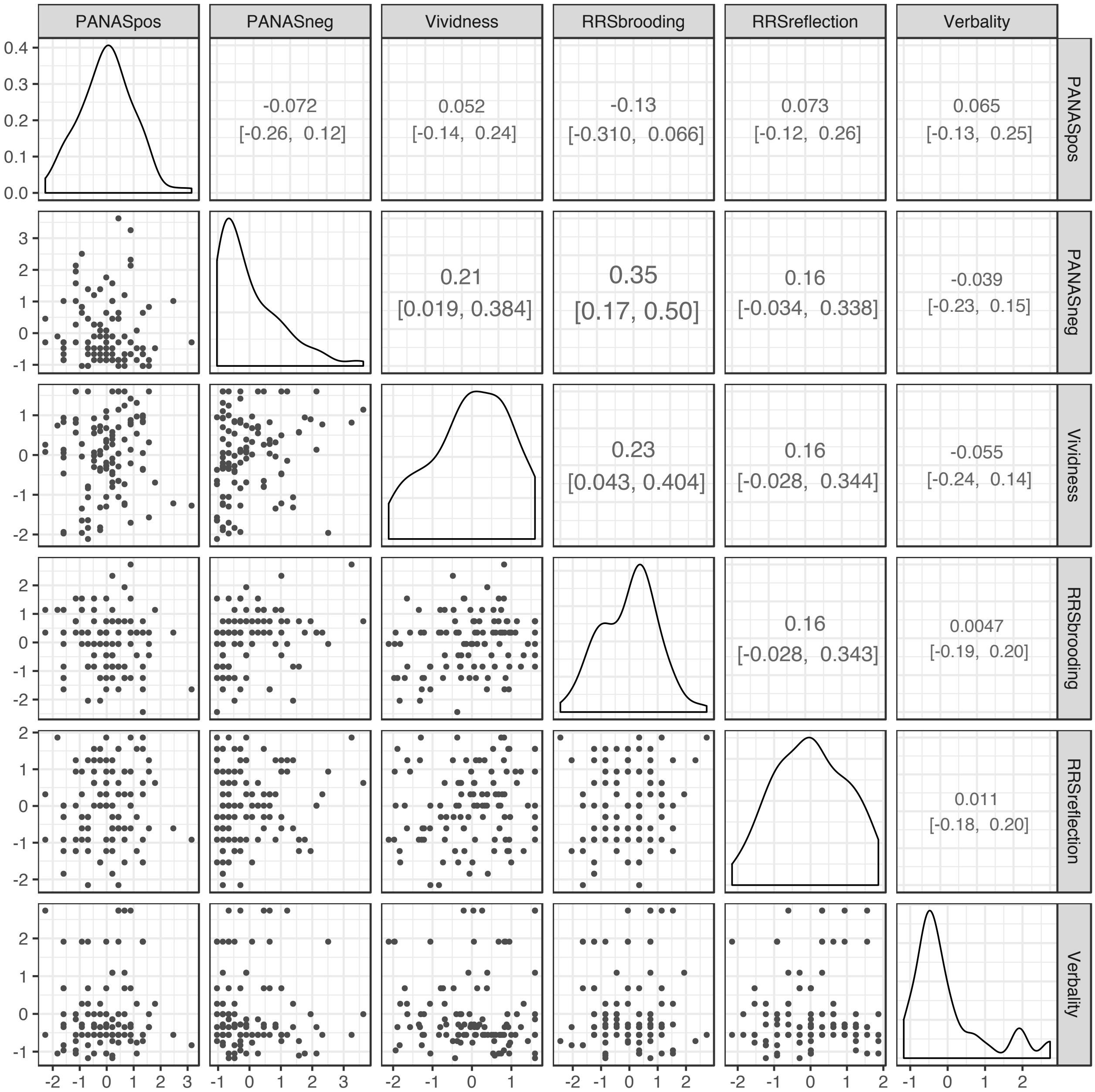

Figure 6.2: Diagonal: marginal distribution of each variable. Panels above the diagonal: Pearson's correlations between main continuous predictors, along with 95% CIs. The absolute size of the correlation coefficient is represented by the size of the text (lower coefficients appear as smaller). Panels below the diagonal: scatterplot of each variables pair.

Table 6.2: Comparison of models, ordered by AICc relative to the model with the lowest AICc.

	K	$AICc$	Δ_{AICc}	W
$Int + Ind + PANASpos + PANASneg + Ind : Viv + RRSbro$	8	1903	0	
$Int + Ind + PANASpos + PANASneg + Ind : Viv + RRSref$	8	1903	0	
$Int + Ind + PANASpos + PANASneg + Ind : Viv + RRSbro + RRSref$	9	1904	1	
$Int + Ind + PANASneg + Ind : Viv$	6	1914	11	
$Int + Ind + PANASneg$	5	1916	12	
$Int + Ind + PANASpos + Ind : Viv$	6	1917	14	
$Int + Ind + PANASpos$	5	1919	15	
$Int + Ind + Ind : Viv$	5	1928	25	
$Int + Ind$	4	1930	27	

\begin{table}

\caption{Coefficient estimates (Est), standard errors (SE), and 95% CIs (Lower, Upper).}

	Est	SE	Lower	Upper
(Intercept)	37.796	1.859	34.153	41.438
Induction	25.986	2.175	21.724	30.249
PANASpos	-6.805	1.877	-10.485	-3.126
PANASneg	6.995	1.986	3.104	10.887
RRSbrooding	2.688	1.997	-1.225	6.601
Induction:Vividness	4.273	2.178	0.003	8.542

\end{table}

Higher scores on *Vividness* were associated with higher increase in self-reported rumination after induction, as revealed by the positive coefficient of the interaction term. This suggests that participants who recalled a more vivid negative memory tended to show a higher increase in rumination after the induction procedure than participants with a less vivid memory.

6.4 Articulatory suppression effects on induced rumination

We then examined the effect of the two motor tasks (articulatory suppression and finger-tapping) on *RUM*, while controlling for other variables (i.e., *Vividness*, *RRSbrooding*, *RRSreflection*, *Verbality*, *PANASpos*, and *PANASneg*). Given the group differences on *RUM* score at baseline (i.e., after training), we also included this score as a control variable in our models, as the *RUMb* variable. Based on our hypotheses, we expected that the model comparison would reveal a three-way interaction between *Session*, *Condition* and

Table 6.3: Comparison of models, ordered by AICc relative to the model with the lowest AICc.

$Int + Session + Cond + RUMb + PANASneg + RRSbro + RRSref$
$Int + Session + Cond + Session : Cond + RUMb + PANASneg + RRSbro + RRSref$
$Int + Session + Cond + Session : Cond + Session : Cond : Verb + RUMb + PANASneg + RRSbr$
$Int + Session$
$Int + Session + Cond$
$Int + Session + Cond + Session : Cond$
$Int + Session + Cond + Session : Cond : Verb$
Int

Verbality. However, the best model identified by AICc model comparison did not include this interaction as a constant effect. Nonetheless, the best model was only slightly better than the model including the three-way interaction (the second model in Table 6.3), as the best model was only 1.1704261 more *credible* than the interaction model. As our goal is precise estimation of effects rather than dichotomic decision about the presence or absence of an effect, we chose to present the estimations of the second model as well. Fit of this model was moderate as marginal R^2 was 0.2928069 while conditional R^2 was 0.6626111.

Parameter values of the best model for the second part of the experiment are reported in Table 6.4. Based on these values, it seems that self-reported rumination decreased after both motor tasks (the coefficient for *Session* is negative), but this decrease was substantially larger in the *Mouthing* condition (d_{av} = -0.351, 95% CI [-0.735, 0.034]) than in the *Tapping* condition (d_{av} = -0.117, 95% CI [-0.506, 0.273]), as can be read from the coefficient of the interaction term between *Session* and *Condition* (*Est* = 5.965, *SE* = 4.320, *95% CI* [-2.502, 14.433]). However, the large uncertainty associated with this result (as expressed by the width of the confidence interval) warrants a careful interpretation of this result, that should be considered as suggestive evidence, rather than conclusive evidence.

The large variation between participants can be appreciated by computing the *intra-class correlation* (ICC), expressed as $\sigma^2_{intercept}/(\sigma^2_{intercept} + \sigma^2_{residuals})$. For the best model, the ICC is equal to 0.5229, indicating that 52.29% of the variance in the outcome that remains after accounting for the effect of the predictors, is attributable to systematic inter-individual differences.

\begin{table}

\caption{Estimates (Est), standard errors (SE), and 95% CIs (Lower, Upper).}

	Est	SE	Lower	Upper
(Intercept)	47.645	1.930	43.862	51.427
Session	-6.214	2.160	-10.448	-1.980
Condition	-0.948	3.921	-8.633	6.736
RUMbaseline	13.394	2.205	9.073	17.716
RRSbrooding	2.449	2.088	-1.643	6.541
RRSreflection	-2.039	1.981	-5.921	1.843
PANASneg	0.300	2.245	-4.100	4.700
Session:Condition	5.965	4.320	-2.502	14.433
sd_(Intercept).Participant	16.462	NA	NA	NA
sd_Observation.Residual	15.724	NA	NA	NA

\end{table}

Figure 6.3 shows the evolution of the mean *RUM* scores all through the experiment according to each session (Baseline, Post-induction, Post-motor) and *Condition* (Mouthing, Tapping). This figure reveals important inter-individual variability, in all conditions. After the rumination induction, *RUM* score increased in both groups, and decreased after the motor task, with a stronger decrease in the *Mouthing* condition.

Figure 6.4 shows the effects of *Verbality* on the relative change (i.e., after - before) in self-reported rumination after both motor activities (i.e., *Mouthing* and *Tapping*). As *Verbality* was centered before analysis, its score cannot be interpreted in absolute terms. However, a high score on this index indicates more verbal than non-verbal (e.g., visual images, non-speech sounds) thoughts, while a low score indicates more non-verbal than verbal thoughts. Contrary to our predictions but consistent with the model comparison, this figure depicts a similar relationship between *Verbality* and the change in *RUM* score (between before and after the motor task), according to the Condition.

6.5 Discussion

The purpose of the current study was to investigate the effects of articulatory suppression on induced verbal rumination. We predicted that if verbal rumination, which can be construed as a type of inner speech, does involve the mental simulation of overt speech production, its generation should be disrupted by articulatory suppression, but not by finger tapping. This prediction was not strictly corroborated by the data, as we observed a decrease of self-reported rumination after both types of motor activities (see Figure 6.3 and Table 6.3), with a somewhat stronger decrease in the Mouthing condition. In the following, we examine the validity of our methods and discuss interpretations of our results. Finally, we formulate how subsequent research should address this kind of question and suggest alternative ways to test the above mentioned hypothesis. We begin by discussing the results of the rumination induction procedure.

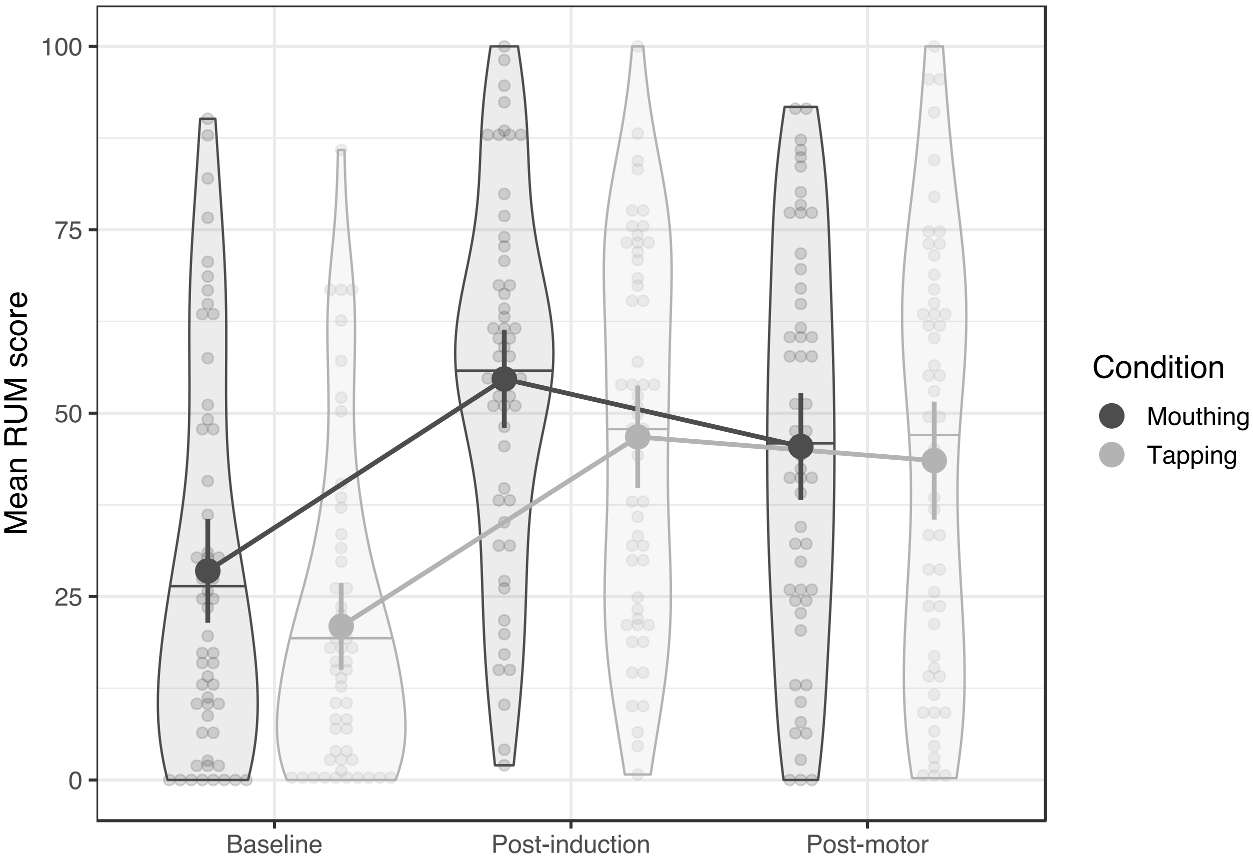

Figure 6.3: Mean RUM score by Session and Condition, along with violin plots and individual data. Error bars represent 95% CIs. The horizontal bar inside the violin plots represents the median of the conditional distribution.

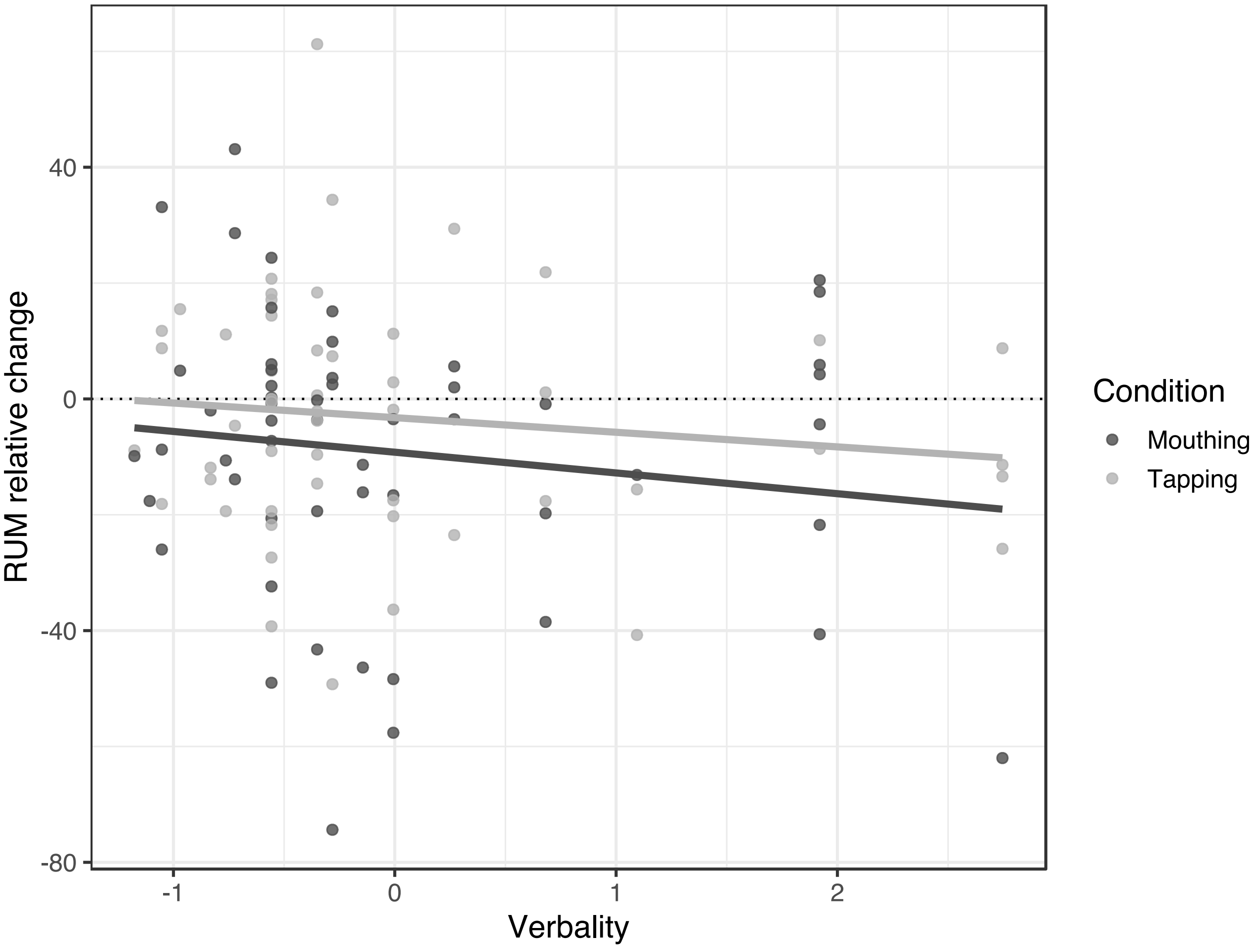

Figure 6.4: Mean RUM relative change after motor activity, as a function of the degree of Verbality, in the mouthing (the dark grey dots and regression line) and finger tapping (the light grey dots and regression line) conditions.

6.5.1 Rumination induction

It is noteworthy that 32.91% of the total sample of participants who were recruited did not respond to this induction, and were therefore not included in the analyses. Moreover, as reported in Table 6.3.2, it seems that the *Vividness* of the memory chosen by the participant during the mood induction was moderating the effect of the rumination induction. In other words, the more vivid (i.e., the more "intense") the memory, the more successful the rumination induction was. This highlights the fact that this aspect should be carefully controlled each time a mood induction is used in order to foster subsequent repetitive negative thinking.

Moreover, we observed a group difference of approximately 7.5 points in the average *RUM* score at baseline. This difference might be explained by motor training, which took place before baseline measurement of state rumination. During this training, participants had to perform the motor task (either finger-tapping or mouthing) in front of a screen on which a white dot was moving randomly on a black screen, for 1 min. During the task, the experimenter stayed in the room (out of the participant's sight) to check that participants were performing the motor task adequately. Being an unusual and potentially embarrassing motor activity, mouthing might have been an higher source of stress for the participants, as compared to the more common activity of finger-tapping. This group difference in baseline state rumination subsisted after the induction, as the group difference after the induction is of approximately 8 points (see full dataset and summary statistics in the supplementary materials).

6.5.2 Articulatory suppression effects

In the following section, we discuss in more depth the results of the second part of the study, which aimed at comparing the effects of articulatory suppression and finger-tapping on self-reported rumination.

First, it is important to examine whether our failure to detect the predicted interaction could come from a lack of statistical power. We planned 128 participants in order to reach a power of .80 for a targeted effect size of $\eta_p^2 = .06$. As explained above, out of the 184 recruited participants, only 106 could be included in the study. With 106 participants, the a priori power was approximately of .70, which is much higher than the median power in typical psychological studies.

Second, it is important to acknowledge that despite the absence of the predicted difference between the two conditions in their influence on the level of self-reported rumination (i.e., *RUM*), both activities did lead, on average, to a decrease in self-reported rumination of approximately 6 points on the VAS (as indicated by the slope for *Session* in Table 6.4). This decrease might be interpreted in at least two ways. First, it might be explained by the simple exposition to the VAS and by compliance effects. When asked to rate their level of rumination again after five minutes of motor activity, some participants might be prompted to indicate a lower level of rumination than before the motor task. But compliance effects could similarly lead participants to consider the motor task as irritating, and therefore as prone to rumination increase. Some participants could therefore also be biased towards indicating a higher level of rumination after the motor task. Second, it might be considered that this decrease reflects a genuine decrease in rumination. In the following, we adopt the latter perspective and discuss explanations for the weak difference between the two conditions.

6.5.2.1 Effect of the rumination quality (verbality)

Our prediction was that rumination in verbal form would be more disrupted by mouthing than rumination in non-verbal form, while both kinds of rumination would not be disrupted (or similarly disrupted) by finger-tapping. In other words, we hypothesised a three-way interaction, between the effect of time (i.e., *Session*), *Condition*, and *Verbality*. In the following, we discuss the absence of this interaction. Then, we focus on the weak difference between the two conditions (omitting *Verbality*), and discuss some explanations for this weak difference.

First, the absence of the three-way interaction might come from a difficulty for the participants to have clear introspective access to the ruminative thoughts they experienced during the experiment. For instance, we know that introspective description of inner speech differs considerably, between people trained to regularly report on their episodes of inner speaking, and people without such training (e.g., **?**). Moreover, as the *Verbality* questionnaire was presented at the end of the experiment, one cannot exclude that it was partly contaminated by recall, which, when done verbally, has been shown to artificially increase the subjective verbality index (**?**).

6.5.2.2 Difference between motor conditions

Leaving the self-reported quality of rumination aside, we now turn to a discussion of the weak difference between the two conditions. We think this result can be explained in at least two non-exclusive ways. First, we could argue that the decrease observed in both conditions was due to an unexpected effect of finger-tapping on rumination. Second, we could argue that the effect of the articulatory suppression was somehow weaker than expected. In the following, we provide arguments and explanations for each of these possibilities.

Steady finger-tapping is usually considered as a relevant control condition for evaluating articulatory suppression, since it specifically recruits the hand motor system and should not interfere with the oral motor system, while being comparable in terms of general attentional demands (e.g., **??**). However, using more complex rhythmic patterns of finger-tapping, **?** observed a fade-out of the phonological similarity effect in a verbal memory task with spoken recall, when subjects were asked to tap with either their right (dominant) or left hand, while the phonological similarity effect was conserved in the control condition (no tapping). The author concluded that a complex rhythmic tapping task can suppress the activity of the articulatory control process, by *suppressing* the running of speech motor programs (**?**, page 185). More specifically, he suggested that complex, non-automatised, rhythmic finger tapping could use speech motor programs, which are useful to control speech prosody, and therefore can deal with rhythmic activity. We further suggest that a novel complex rhythmic task might require silent verbalisation and, therefore, might itself be an articulatory suppression task. In line with these findings, another study showed that for right-handed subjects, tapping with a finger of the right hand is more effective at interfering with performance of a verbal memory task than is tapping with a finger of the left hand (**?**). Although Friedman et al.'s findings are difficult to interpret, because task priority was manipulated and this may have led to conflict resolution, which might have been dealt with differentially according to the hand involved, they do suggest that a finger tapping task is not always the best control for articulatory suppression. This might explain the decrease of self-reported rumination observed in our own study, after the finger-tapping, and suggests that we might observe different results by asking participants to tap with the finger of their non-dominant hand. We think it is important to note for future studies that our results, together with those of **?** and **?**, suggest that finger-tapping could in fact interfere with inner speech. In other words, finger-tapping, with the dominant hand, is probably not an appropriate control condition when studying articulatory suppression.

As suggested previously, an alternative way to explain the absence of differences between the two motor conditions is to suppose that the effects of the articulatory suppression were weaker than we expected. The rhythmic mouthing task might have become too automatised to disrupt inner speech programming. This idea finds some support in the results of **?**, who observed an effect of articulatory suppression on the phonological similarity effect in a memory task only when the articulatory suppression was *intermittent* (i.e., "ah, ah, ah…") but no effect when participants had to utter a continuous "ah–". This can be explained by considering that the intermittent articulatory suppression would impose a greater load on speech motor programming than the continuous articulatory suppression (**?**, page 569). In a similar vein, **?** found stronger effects of articulatory suppression when participants were asked to repeat a sequence of different letters than when they were asked to repeat a single letter. One way to examine this hypothesis with our own protocol would be to ask participants to make sequences of various mouth movements, rather than repeating a single movement.

In a broader perspective, relating to the original research question, we should mention two additional interpretations of our results. So far, we considered different ways to explain either how the finger-tapping task could interfere with rumination or how the articulatory suppression task might have failed to disrupt rumination. However, if we assume that our scales (especially the *RUM* outcome response and the *Verbality* scale) are reliable and that the articulatory suppression was efficient in its intended purpose, we are forced to admit that either i) rumination is not a type of inner speech that can be disrupted by peripheral muscle perturbation (i.e., it could be described as a more abstract form of inner speech) or that ii) inner speech, more broadly, does not depend on peripheral speech muscle activity. Although we think that these questions cannot be answered from our present results, we acknowledge that these two possibilities are compatible with our results.

In summary, the current research is one of the first behavioral studies exploring the association between verbal rumination and the speech motor system. While the observed data did not strictly corroborate our original hypotheses, we explored several explanations for the weak difference between articulatory suppression and the control task, and related our findings to previous works on the role of inner speech in verbal working memory. These results have important implications for future studies on articulatory suppression during inner speech or working memory tasks. More precisely, they highlight the need for further investigation of the most appropriate control task when studying the effects of articulatory suppression.

6.6 Supplementary materials

Pre-registered protocol, preprint, data, as well as reproducible code and figures are available at: osf.io/3bh67.

A lot of useful packages have been used for the writing of this paper, among which the `papaja` and `knitr` packages for writing and formatting (Aust and Barth, 2018; Xie, 2018), the `ggplot2`, `ggforce`, `GGally`, `DiagrammeR`, and `plotly` packages for plotting (Wickham et al., 2018; Pedersen, 2018; Schloerke et al., 2018; Iannone, 2018; Sievert et al., 2017), the `AICcmodavg`, and `Rmisc` packages for data analysis (Mazerolle., 2017; Hope, 2013), as well as the `tidyverse` and `broom` packages for code writing and formatting (Robinson, 2018; Wickham, 2017).

6.7 Acknowledgements

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6.8 Appendix A. Eye-tracking control experiment

The purpose of this control experiment was to demonstrate that the two motor tasks used in the main experiment, namely, finger tapping and articulatory suppression (mouth movements) were equivalent in terms of task difficulty or general dual-task demand (**?**). Participants performed a computer-based visual search task (i.e., finding a T among an array of Ls), adapted from the **?** paradigm (see below for details).

6.8.1 Sample

Twenty-four participants (Mean age = 19.46, SD = 1.18, Min-Max = 18-21, 21 females, 21 right-handed), drawn from the same population (i.e., undergraduate psychology students) as the main experiment took part in this eye-tracking pretest.

6.8.2 Sample size

As we aimed to compare four conditions (i.e., visual search (VS) task alone, VS + finger tapping, VS + foot tapping and VS + mouth movements), we recruited 24 participants in order to have at least one participant per order in our random counter-balanced repeated measures design ($n = k!$ where n is the number of possible orders of conditions for k conditions, then $n = 4! = 24$).

6.8.3 Material

Experiment took place individually in a dark room. Participants had to seat in front of a 22 inches, Iyama Vision Master Pro 513-MA203DT CRT Monitor (resolution: 1024x768 pixels, refresh rate: 85 Hz) with a NVIDIA GeForce 9800 GTX+ graphic processor. A camera-based eye-tracker (EyeLink® 1000 from SR Research) with a sampling rate of 250 Hz and a minimum accuracy of 0.5° was used, in the pupil-corneal reflection tracking mode. Participants were positioned on a seat so as to keep distance from the camera to the forehead target between 50 and 60 cm. A five-point calibration was completed before presenting stimuli, at the beginning of each condition.

6.8.4 Procedure

The target (i.e., the letter “T”) was present at each trial, either on the right or on the left of the central vertical axis of the grid. The grid was an array of 6*6 items. Each stimulus was displayed until the participant response (maximum duration in case of no response: 5 seconds). Each grid of letters was preceded by a central fixation circle, that was displayed for 500ms after the participant moved his/her gaze towards it. In order to give their response (“left” or “right”), participants had to gaze towards a large filled gray circle, situated either on the left or on the right side of the grid. Each participant went through each condition, in a random order. A first general training session was proposed, at the beginning of the experiment, using ten items that were not used subsequently in the four conditions. Each condition was composed of 90 trials (45 left and 45 right), knowing that the first ten trials of each condition were considered as training trials and thus not included in analysis. All participants were filmed in order to ensure that they effectively performed the motor activity. Our measure of interest was the delay between the apparition of the grid and the participant’s response (the time at which his/her gaze reached the response circle), below referred to as “response time” (RT).

Table 6.4: Coefficient estimates (Est), standard errors (SE), and 95% CIs (Lower, Upper) of each contrast.

	Est	*SE*	*Lower*	*Upper*
Control vs all	-0.00996	0.00269	-0.01524	-0.00468
Foot vs Finger + Mouth	0.00503	0.00381	-0.00244	0.01250
Finger vs Mouth	-0.00637	0.00660	-0.01929	0.00656

6.8.5 Data preprocessing

Raw data from EyeLink® includes gaze on screen spatial coordinates, pupil diameter and forehead target spatial coordinates, with its distance from the camera. For this experiment, since only RTs (in ms) of correct trials are interesting, invalid trials (when no response has been given) and wrong responses were removed from the analysis.

6.8.6 Data analysis

Data were analysed using *Condition* (4 modalities) as a within-subject predictor and the natural logarithm of the RT as a dependent variable in a MLM, including a varying intercept for both *participant* and *item*. Comparisons of interest were computed using Helmert contrasts. Estimates and confidence intervals are reported for each comparison in the log scale.

6.8.7 Results

Results of the MLM are reported in Table 6.4 and Figure 6.5. Contrast analysis revealed a slight difference between the *Control* condition and the mean of the three other conditions (Est = -0.0099591, 95% CI = [-0.015235, -0.0046832]) as well as a slight difference between the *Foot* condition and the mean of the *Finger* and the *Mouth* conditions (Est = 0.0050298, 95% CI = [-0.0024395, 0.0124992]) while no apparent differences between the *Mouth* and the *Finger* conditions (Est = -0.0063662, 95% CI = [-0.0192938, 0.0065614]).

6.8.8 Discussion

This control experiment shows that there is no apparent difference (or a negligible one) in terms of attentional demand between the two motor tasks used in the main experiment (i.e., finger-tapping and mouthing), although performing a dual motor task (of any type) does seem costly, because of the observed difference between the control condition and the mean of the three others conditions. These results are in line with the results obtained by **?** in their control experiment.

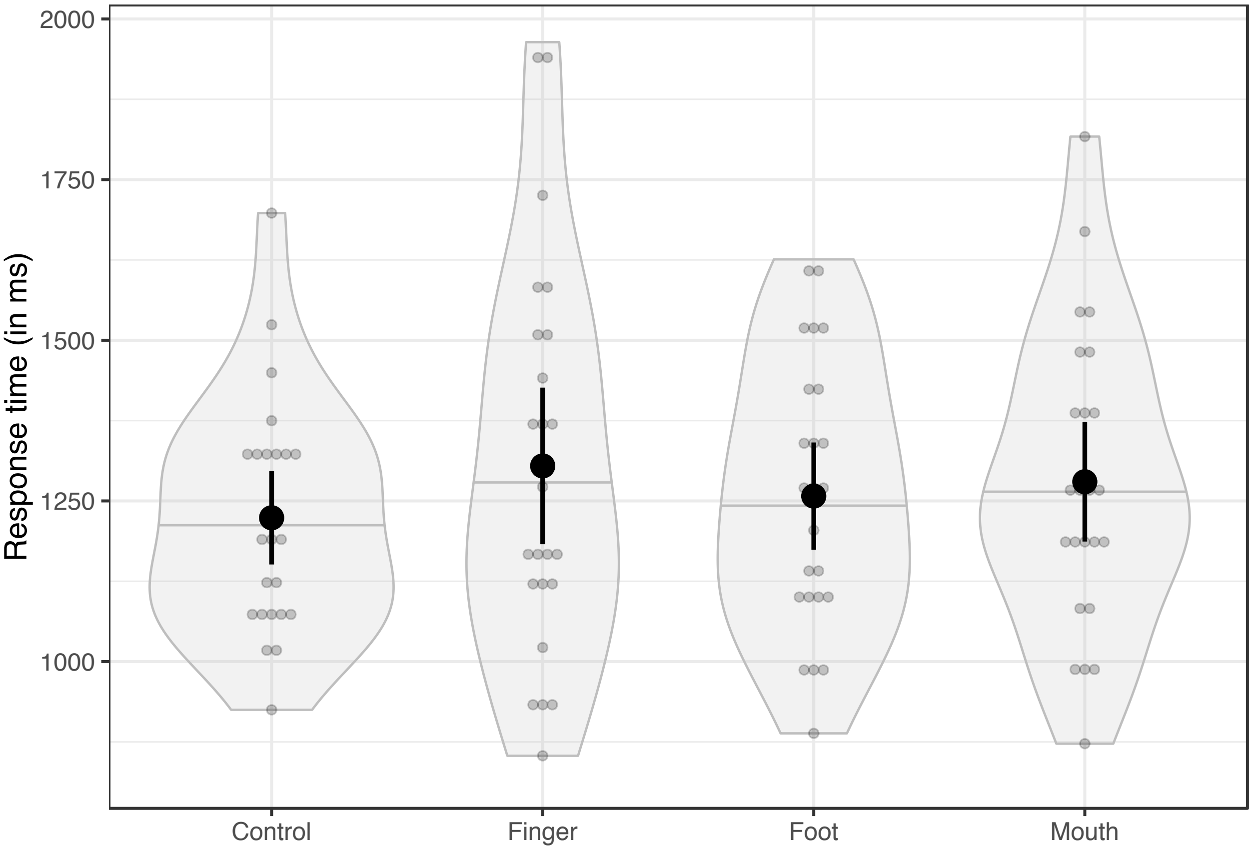

Figure 6.5: Mean RTs by Condition along with 95% CIs and violin plots (the horizontal line represents the median of the conditional distribution). Grey dots represent mean RTs by participant.

Chapter 7

TMS study

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Chapter 8

Discussion

8.1 Summary of the results

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8.2 Limitations and ways forward

...

8.3 Conclusion

...

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