Please be logical, I am in a bad mood: ~~an~~An electrophysiological study of mood effects on reasoning

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Abstract

Several behavioral studies have reported a detrimental effect of emotion on reasoning tasks, either when the content of the reasoning and/or the mood state of the individual are emotionally loaded. However, the neural mechanisms involved in this phenomena remain largely unexplored. In an event-related potentials (ERPs) study, we examined the consequences of an induced mood over the electrophysiological signals obtained while processing logical and illogical categorical conclusions. Prior to performing a syllogism reading task, we aimed to induce, by using short film clips, high arousal negative and positive moods and neutral affective states to participants in three separate recording sessions. Our mood induction procedure was only successful at inducing a highly arousing negative state. Behaviorally, participants committed more errors overall while judging the invalidity versus the validity of illogical and logical conclusions, respectively, but no influences from mood state emerged at this logical validity task. Electrophysiologically and overall a negative going N400 deflection was larger for illogical relative to logical conclusions in a parietal region between ~~300–420 ms.~~ 300 and 420 ms. However, further analysis revealed that the logical conclusions were only more expected (smaller N400 amplitudes) in the negative relative to the neutral and the positive sessions, providing support to theoretical views that posit that a more analytic reasoning style might be implemented under a negative mood state. These results provide further electrophysiological evidence of the influence of mood on other cognitive processes, particularly on the anticipation and processing of logical conclusions during online reasoning tasks.

Keywords: Mood; Reading; Categorical ~~Syllogisms~~syllogisms; Reasoning; ERPs; N400

1 Introduction

Reasoning is the psychological process through which individuals organize, structure, and draw inferences from information (Blanchette, 2014a, 2014b). The dual process model of reasoning postulates a distinction between heuristic (implicit, automatic, associative, and intuitive) and analytic processes (more effortful, explicit, rule-based, and slower) (Evans, 2003). Just like for other cognitive processes such as attention, perception, memory, and problem solving, reasoning has been found to be influenced by emotional content and emotional state (see review by Blanchette and Richards, 2010a, 2010b). Working memory load (i.e., requirement of additional cognitive resources to process emotional information) has been proposed as one of the potential mechanisms mediating this interference of emotion on logical reasoning tasks (Tremoliere et al., 2016, 2018).

Formal logical reasoning has been shown to be impaired (prompted to error) both when the content of the matter is emotional versus neutral (Blanchette and Richards, 2004a, 2004b; Lefford, 1946; Tremoliere et al., 2016) and also under negative and positive induced emotional states (e.g. Jung et al., 2014; Melton, 1995; Salovey, 1993).

Despite early studies on emotion and reasoning led to the simplified conclusion that “emotion leads to faulty reasoning”, recent studies suggest that the interplay between emotion and reasoning is more nuanced and complex (Blanchette, 2014a, 2014b). For example, emotion can lead to better, not worse, logical reasoning as it may facilitate access to relevant information during reasoning (Gangemi et al., 2014). Moreover, rather than postulating whether reasoning is either right or wrong under emotional conditions, some authors posit that mood influences an overall individual´s processing style. In their own words, `being happy or sad influences the content and style of ~~thought´ (~~thought´ (Clore and Huntsinger, 2007). The mood-influenced cognitive styles hypothesis (also called the affect-as-information hypothesis) suggests that, generally speaking, positive mood is associated with a more global and flexible processing mode that relies on heuristics (Ruder and Bless, 2003), whereas negative mood is thought to promote a relatively analytical, careful and effortful processing style (Clore and Huntsinger, 2007). This view, has however been challenged by a recent review (Huntsinger and Clore, 2014) that posits that positive affect may also lead to detailed processing and a narrowed focus, and negative affect may lead to heuristic processing and broadened focus.

From an anatomical perspective, even in the absence of behavioral effects (a similar accuracy in logical decision tasks under different emotionally induced conditions) some functional Magnetic Resonance Imaging (fMRI) studies reveal the existence of mood-dependent differences with regard to the pattern of brain activations at the time of syllogistic reasoning (Smith et al., 2015, 2014). Other fMRI studies found a worse behavioral performance in syllogisms together with a lateral/dorsolateral prefrontal cortex (lat/dlPFc) increased activation under negative mood conditions (Brunetti et al., 2014). Thus, brain imaging studies point to a differential recruitment of brain areas for reasoning under the influence of a negative mood, but it is not clear yet when, if so, emotional state exerts its influence upon reasoning tasks.

In recent years, the Event-Related Potential (ERP) technique has been used to examine the online processing of both conditional (Blanchette and El-Deredy, 2014; Bonnefond and Henst, 2013; Bonnefond et al., 2014; Bonnefond and Van der Henst, 2009; Qiu et al., 2007) and categorical reasoning (Rodríguez-Gómez ~~et al.,~~ et al., 2018a, 2018b). Conditional reasoning uses arguments in the form: “If you water the plants, then they will grow; You water the plants; The plants grow.” (i.e., the “Modus Ponens” argument form), whereas categorical reasoning uses syllogisms such as: “All cats are mammals. All mammals have lungs. Therefore, all cats have lungs”. In both cases, reading the argument and following its logic allows the reader to most likely anticipate the last word of the conclusion (grow and lungs, in previous examples). The ERP technique, with a high temporal resolution, allows to examine the time course at which a variable such as emotion can exert its influence over an ongoing process, in our case, a reading for comprehension task.

The study by Blanchette and El-Deredy (2014) manipulated the emotionality of the verbal content upon which conditional reasoning was performed (e.g. If a country is at war, then people die; Britain is at war; British people have died). They found that emotional content had no influence on early ERP components, nor interaction with inference making ERP responses at middle time ranges (N400) and only marginal main effects at late latencies ~~(800–1050 ms).~~ (800–1050 ms). The authors concluded that the effect of emotional content on conditional reasoning “might occur after actual inference making has taken place, maybe at the stage of conclusion maintenance, or response selection” (Blanchette and El-Deredy, 2014).

In contrast, the temporal dynamics of an individual´s emotional state upon reasoning tasks with emotionally neutral materials remains unexplored. We carried out an adaptation of a previous ERP study on categorical reasoning (Rodríguez-Gómez ~~et al.,~~ et al., 2018a, 2018b). In the original study we were interested in the processing of syllogisms conclusions as a function of whether the major premises of the syllogism had previously been rated as true or false. In the condition in which the major premises had been rated as true, illogical conclusions lead to an increase of the N400 ERP component (between ~~380–512 ms)~~ 380 and 512 ms) compared to logical ones. The N400 ERP component was first discovered as the response to words that render a sentence semantically incongruent (i.e. a nonsense word) (Kutas and Hillyard, 1980a, 1980b). Nowadays, a reduction of amplitude of the N400 is best viewed as an index of a facilitatory process for word items that could have been pre-activated or anticipated based on prior contextual constraints (Federmeier, 2007; Federmeier and Kutas, 1999).

Thus, according to N400 functional significance (Kutas and Federmeier, 2011), our result demonstrated that in the context of a reading task participants were most likely to anticipate logical rather than illogical conclusions as far as the major premises held true. Considering prior literature on how an emotional state might alter an individual´s cognitive load, attentional resources and reasoning style, we replicated this part of the study manipulating current mood in three separate sessions. A large number of emotion-elicitation techniques have been used so far to induce emotional states: exposure to emotional slides (Bradley and Lang, 2000; Schaefer et al., 2009), autobiographical recollection (Schaefer and Philippot, 2005), mental imagery (Schaefer et al., 2003; Vrana et al., 1986), Velten mood-induction technique (Velten, 1968), facial feedback (Matsumoto, 1987), respiratory feedback (Philippot et al., 2002), and real-life techniques (Landis, 1924; Stemmler et al., 2001), but viewing emotional clips was chosen as it is one of the most commonly used and effective procedures to induce mood in participants (Gerrards-Hesse et al., 1994; Gross and Levenson, 1995; Schaefer et al., 2010; Westermann et al., 1996; Zhang et al., 2014).

Behaviorally, our results could either match those studies in which emotional states prompted to more errors in logical decision tasks (Jung et al., 2014) or those who failed to find such mood-related effects on logicality error rates (Smith et al., 2014).

Regarding brainwave responses, the study by Blanchette and El-Deredy (2014) only found a late marginal effect of emotional content during conditional reasoning. We aim to determine whether emotional state, in contrast, influences reasoning (i.e. categorical) and the time-course at which it might exert its influence, if any. Prior ERP work has shown that an induced positive mood facilitates the integration (smaller N400) of more distantly related semantic information during sentence comprehension (Federmeier et al., 2001; Pinheiro et al., 2013). However, influences of a negative mood have also been described (Chwilla et al., 2011), with a reduction of the N400 cloze probability effect (i.e. a reduction of the commonly larger N400 to low vs. high cloze probability target words embedded in sentences). Using ERP measurements, other linguistic phenomena have also been described to be mood-dependent, such as a better referential anticipation under a happy versus a sad mood (Van Berkum et al., 2013) or a better sensitivity to semantic reversals under a happy than a sad mood (Vissers et al., 2013). The results of these studies indicate that indeed mood is able to influence processes of language comprehension. The question is whether these mood effects also arise during the anticipation of conclusions for categorical syllogisms (reasoning), and whether the influence is early (at the stage of semantic integration) or late (at the stage of reanalysis processes). As we saw, the latter is the finding for conditional reasoning with emotional vs. neutral content (Blanchette and El-Deredy, 2014).

In summary, the goal of the current ERP study is to provide a direct test of the effects of mood state on categorical reasoning, particularly on whether the logical conclusion might have better be anticipated under the influence of a particular induced mood or alternatively whether the response to illogical conclusion is enhanced for a particular mood state. To achieve this purpose, we tried to induce positive, negative and neutral moods using short-duration videos in three different recording sessions. Subsequently, participants were engaged in a silent reading task of categorical syllogisms, while they were asked to decide whether the logical conclusion followed from prior premises.

Based on the results of the studies reviewed here and on theoretical accounts that posit that reasoning style is more analytic under a negative mood (Clore and Huntsinger, 2007), we expect to obtain a smaller N400 to logical conclusions under a negative mood, indicating that it facilitates anticipation of logically valid analytical conclusions. Likewise, if positive mood is associated with a more global and flexible processing mode that relies on heuristics (Ruder and Bless, 2003), the ERP response to illogical conclusions under a positive mood might show a reduced N400 response indicating that they became more acceptable. Alternatively, the influence of emotional state in online reasoning tasks might only be manifested in later ERP components in line with the study on conditional reasoning with emotional content that was conducted by Blanchette and El-Deredy (2014).

2 Materials and methods

2.1 Participants

Thirty native Spanish speakers (27 females, mean age = 19.6 = 19.6 years, range = 18–29 = 18–29 years) volunteered to participate in the study in exchange for course credits. All participants gave written informed consent. All except for one reported being right handed. The average handedness score (Oldfield, 1971) was +78.8 + 78.8 (range, +100 to -44.4). –44.4). All participants reported normal or corrected-to-normal vision and none had a history of neurological or psychiatric disorders.

2.2 Stimuli

Twelve clips of about 40′′ each were selected and divided into three groups according to the emotion they elicit: positive, negative and neutral clips. Positive clips were collected from the database by Carvalho et al. (2012) and consisted of different heterosexual couples engaged in sexual intercourse (with no genitalia exposure). We decided to include this videos in our experimental design because they are assessed as the most arousing and pleasant ones (Lang et al., 1990, 1998, 1997). The negative clips were 4 films excerpts from commercial movies: *Saving Private Ryan*, *Schindler's List*, *The Piano* and *The Rest Stop* (collected from both Carvalho et al., 2012; Megías et al., 2011). These negative clips were rated as highly arousing as well. In contrast, neutral clips were included to distract participants from any emotional bias and to better define the relationship between positive and negative moods and their interaction with reasoning (Egidi and Nusbaum, 2012; Mitchell and Phillips, 2007). Neutral videos included people riding their bicycle or silently riding the tube, and an old woman knitting. Mean valence and arousal ratings are reported in Table 1. Positive and negative videos ratings differed both in valence and arousal levels from neutral ones. The order of presentation of the four films within a particular mood induction session was random across participants.

Table 1 Characteristics of the stimuli used in the present study. Means and standard deviations (in parentheses) of Valence (1, very negative, to 9, very positive), and Arousal (1, very calming, to 9, very arousing), according to Carvallo (2012) and Megías et al. (2011) databases. ** $p<0.01$. $p < 0.01$. ^ANOVAs were followed up by Bonferroni-corrected post hoc pairwise comparisons ($p<0.05$). ($p < 0.05$).

alt-text: Table 1

	Positive clips	Negative clips	Neutral clips	One-way ANOVA on each factor	Post-hoc comparisons^
Valence	6.48 (0.09)	2 (0.29)	3.41 (0.35)	$F_{(2,9)} = 348.275$**	Pos > Neu
					Neg < Neu
Arousal	6.06 (0.043)	6.06 (0.29)	1.57 (0.33)	$F_{(2,9)} = 243.428$**	Pos > Neu
					Neg > Neu

In a previous study by Rodríguez-Gómez et al. et al. (2018a), (2018b) a set of syllogisms containing true and false major premises was used to study the effect of the premises veracity upon reasoning. For the present study, we selected only those syllogisms including true major premises. Thus, we had an initial set of 240 logical syllogisms. Following a logical sequence, every major premise was continued with a minor premise and a conclusion. Major premises were universal statements. Minor premises consisted of a particular case related to these general statements. For example: *All men are mortal* (major premise); *Juan is a man* (minor premise); *Therefore, Juan is mortal* (conclusion). This type of syllogism is called DARII and its conclusion is valid, since it combines the information of both premises following a logical sequence. To create illogical syllogisms, we swapped the order of the minor premise and the conclusion. For example: *All men are mortal* (major premise); *Juan is mortal* (minor premise); *Therefore, Juan is a man* (conclusion). This type of syllogism is a fallacy and its conclusion is invalid because the fact that "*All men are mortal*" does not imply that "*All mortals are men*" (i.e., illicit conversion of the major premise). Therefore, the conclusion that "*Juan is a man*" is not warranted and logically invalid. Thus, the experimental set consisted of 240 logical and

240 illogical syllogisms. Table 2 contains some examples of the different stimuli conditions. The frequency of use (Sebastián-Gallés et al., 2000) of the last word of the conclusions was contrasted via one-way analysis of variance (ANOVA). There was no difference between logical and illogical conclusions $F(1478) = 0.004$; $p < 0.951$.

Table 2 Examples of syllogisms presented in the experiment in Spanish and their English translation (in italics).

alt-text: Table 2

Major premise	Minor premise	Conclusion	Validity of the conclusion
Todos los hombres son mortales.	Juan es un hombre.	Juan es mortal.	Valid
All men are mortal.	*Juan is a man.*	*Juan is mortal.*	*Valid*
Todos los hombres son mortales.	Juan es mortal.	Juan es un hombre.	Invalid
All men are mortal.	*Juan is mortal.*	*Juan is a man.*	*Invalid*
Todos los adultos fueron niños.	Mario es un adulto.	Mario fue un niño.	Valid
All adults were kids.	*Mario is an adult.*	*Mario was a kid.*	*Valid*
Todos los adultos fueron niños.	Mario fue un niño.	Mario es un adulto.	Invalid
All adults were kids.	*Mario was a kid.*	*Mario is an adult.*	*Invalid*
Todos los rascacielos son altos.	Este edificio es un rascacielos.	Este edificio es alto.	Valid
All skyscrapers are tall.	*This building is a skyscraper.*	*This building is tall.*	*Valid*
Todos los rascacielos son altos.	Este edificio es alto.	Este edificio es un rascacielos.	Invalid
All skyscrapers are tall.	*This building is tall.*	*This building is a skyscraper.*	*Invalid*
Todos los gorriones son pájaros.	Este animal es un gorrión.	Este animal es un pájaro.	Valid
All sparrows are birds.	*This animal is a sparrow.*	*This animal is a bird.*	*Valid*
Todos los gorriones son pájaros.	Este animal es un pájaro.	Este animal es un gorrión.	Invalid
All sparrows are birds.	*This animal is a bird.*	*This animal is a sparrow.*	*Invalid.*

In addition, 120 fillers were added to the stimuli set. Eighty of these fillers consisted of different types of syllogisms: BARBARA, DATISI and DISAMIS syllogistic forms, and the resultant conclusion could be valid or invalid as well (80 logical fillers and 80 illogical fillers). The rest of fillers (40) were non-sense syllogisms. In half of these fillers the minor premise was not related to the major premise, so it was not linked to the conclusion either. In the other half, the conclusion was unrelated to the major and minor premise. The inclusion of these fillers was done to avoid the participants' automatization of responses when solving the validity of the conclusions decision task.

Finally, we created two experimental lists, containing each: 120 logical syllogisms, 120 illogical syllogisms and 120 fillers (fillers were the same for both lists). A syllogism with a logical structure in the first list would have an illogical structure in the second list, and vice versa. Nevertheless, the major premises were all the same for the two experimental lists. The 120 logical and the 120 illogical syllogisms were then divided into three sets ~~(40 + ~~(40 + 40 each) for each mood session, such that participants never saw the same syllogisms across sessions. Participants were randomly assigned to one of these lists in each of the three sessions.

2.3 Experimental procedure

Participants were tested in three separate recording sessions (with a one week interval, +/- one day), in which a different mood was induced to them. We performed a within-subject design with the factor EMOTION (positive, negative and neutral) to take advantage of the statistical efficiency of these designs (Greenwald, 1976). The order of mood induction, as well as the assignment to an experimental list was counterbalanced across participants. Moreover, the order of presentation of syllogisms within a given list was randomized for each participant.

Upon arrival at the laboratory, and after signing informed consent, participants filled out a questionnaire rating their current emotional state. The questionnaire consisted of a scoresheet including scales of valence (from ~~-5,~~ −5, extremely negative, to +5, extremely positive), and arousal (from ~~-5,~~ −5, extremely calmed, to +5, extremely activated) dimensions. This is a short method to use in comparison with other widely used mood-assessment scales such as the

PANAs (Egidi and Nusbaum, 2012; Kross et al., 2011; Sereno et al., 2015; Verhees et al., 2015). Participants were then fitted with encephalogram (EEG) electrodes while they filled out additional handedness, vision and health questionnaires. They were seated approximately ~~100~~100 cm in front of 19” computer monitor. The session began with a short set of practice syllogisms to acclimate the participants to the silently reading and the logical decision tasks.

The experiment was divided into four blocks with the same structure: display of a clip, current-mood questionnaire and reasoning task (Fig. 1). In each of these blocks, the clip was displayed. After that, participants were asked to rate the current state of their mood using the same questionnaire they filled out upon arrival. Thus, participants fulfilled the questionnaire a total of six times: when they arrived at the laboratory, after each clip, and at the end of the experimental session. Once the questionnaire was fulfilled, the presentation of the syllogisms began. After they read the major premise, the minor premise, and the conclusion, they decided whether the conclusion was logically valid or not. They were informed that their task was to decide whether the conclusion correctly followed from the premises. We asked them to do this validity decision to ensure they would pay attention to the conclusion of the argument. Both initial premises were presented in the screen as a full sentence. The conclusion appeared word by word in the center of the screen in order to avoid eye movements and obtain a precise time-lock to the final word of the conclusion. All words in premises and in the conclusion were shown in a black 30-point lower-case Arial font on a white background. The major premise was presented in the screen for ~~2000 ms~~ 2000 ms with an interval of ~~100 ms~~ 100 ms before the minor premise. The minor premise appeared in the screen for ~~2000 ms.~~ 2000 ms. Once the minor premise disappeared, there was an interval of ~~100 ms~~ 100 ms and a fixation point was shown in the center of the screen. Participants had to press the space bar to initiate the conclusion. Each word of the conclusion was presented for ~~300 ms~~ 300 ms with an inter-word interval of ~~300 ms,~~ 300 ms, except for the last word of the conclusion that lasted ~~500 ms.~~ 500 ms. This approach was taken to avoid overlap of the response to the disappearance of the word from screen with ongoing EEG activity. Once the conclusion was over, the participants encountered the question: “Do you think that the conclusion is logically valid?”. They could press two different buttons: one for “Yes” and one for “No” (Fig. 2). These buttons were counterbalanced across participants. Participants read a total of 90 syllogisms per block (30 logical syllogisms, 30 illogical syllogisms and 30 fillers). Each block's duration was approximately ~~7–8~~7–8 mins. There was a break between blocks. Break's duration was unlimited; participants decided when to start next block. The whole session lasted about ~~40–45~~40–45 min.

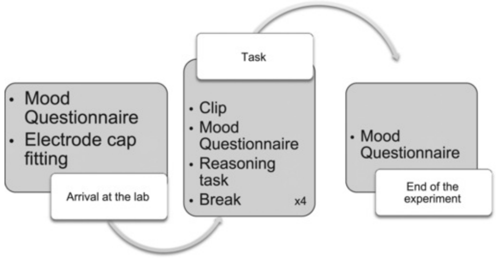

Fig. 1 Schedule of each experimental session (three sessions per participant).

alt-text: Fig. 1

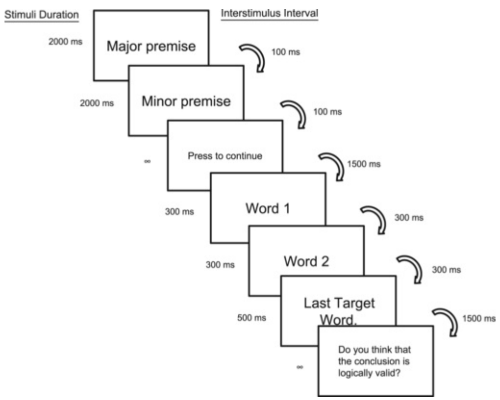

Fig. 2 Sequence of events during the experiment.

alt-text: Fig. 2

2.4 EEG data recording and preprocessing

EEG data were recorded from 64 Ag/AgCl electrodes distributed according to the 10–20 international system ("American Electroencephalographic Society guidelines for standard electrode position nomenclature", 1991). These electrodes were mounted in an electrode cap (Electro-Cap International) and their impedances were kept below ~~5 kΩ.~~ 5 kΩ. Electrodes were referenced online to the left mastoid and amplified with a Brain Amps amplifier at a sampling rate of ~~1000~~1000 Hz. The signal was filtered through a ~~0.1–100~~0.1–100 Hz online band-pass filter. The electrooculographic activity was recorded using vertical and horizontal bipolar electrodes placed at a supra-infraorbital level of the right eye and on the outer canthus of both eyes, respectively.

Data was processed using BrainVision Analyzer software (Brain Products, Munich), re-referenced off-line to the mastoid average. For artifact rejection purposes, the following thresholds were set: maximal allowed voltage step, ~~50 µV;~~ 50 µV; minimal and maximal allowed amplitude, ~~± 100 µV;~~ ± 100 µV; lowest allowed activity (max-min), ~~5 µV~~ 5 µV for a ~~1500 ms~~ 1500 ms interval length. Once any threshold was met in the continuous EEG file, data recorded at that point were marked and discarded, together with data recorded during the ~~200 ms~~ 200 ms before and after the detection. This was performed to avoid including any residual artifacts in subsequent computations of ERP averages. EEG raw data from all subjects were scanned and marked using the same criteria. Four participants with less than 15 artifact-free trials in at least one condition were excluded from analysis. Trials for which subjects responded erroneously were eliminated from further analyses. Moreover, 6 participants were excluded as well due to their high number of errors (more than 50% of trials). For the 20 remaining participants, 18.9% of trials were discarded and an average of 32.4 trials remained per experimental condition. A Butterworth zero phase filter was applied to the EEG data (low cutoff at ~~0.1~~0.1 Hz, time constant ~~= 1.6~~= 1.6 s, 24 db/oct; high cutoff at ~~20~~20 Hz,~~Hz, 24~~ 24 dB/oct). Thus, we used a widely used offline high pass filter setting in most ERP studies of language comprehension (see e.g., Rommers and Federmeier, 2018, for a recent report) while following the recommendations of Tanner et al. (2015) for an optimal trade-off between statistical power and artifactual effects. The continuous EEG was segmented into ~~1000 ms~~ 1000 ms epochs starting ~~100 ms~~ 100 ms before the onset of the target word item. Artifact-free average waveforms were then computed for each condition separately, after subtraction of the pre-stimulus baseline.

2.5 Data analysis

2.5.1 Behavioral analysis

Accuracy was measured by computing the mean number of errors committed by each participant and was analyzed with a mixed factorial design (repeated measures ANOVA) including two within-subject factors: EMOTION (positive, negative and neutral) and VALIDITY (logical, illogical). Reaction times were not analyzed because the participant´s responses were delayed to avoid overlap of overt responses on ongoing EEG activity.

2.5.2 Scalp ERP analysis

ERP responses were assessed using a nonparametric cluster-based random permutation analysis approach (Maris and Oostenveld, 2007). The advantage of this approach in the ERP field is that it avoids an a priori selection of locations and/or components. In order to control for the multiple comparison problem (i.e., increase of type 1 error rate) the following procedure is implemented. First, a simple dependent-samples t-test for each contrast (e.g. valid vs. invalid conclusions) was performed at each time-electrode pair. P values below 0.05 were used to form clusters of adjacent time points and electrodes. Adjacency for electrodes was defined using a triangulation method. This triangulation algorithm tries to build triangles between nearby nodes, thereby being independent of distance of sensors. Even in a network with different clusters of nodes, the algorithm tries to build as many triangles until the whole area filled up by the nodes is covered. A minimum of two channels were used to form a cluster. Cluster-level test statistic was calculated by taking the sum of all the individual t-statistics within that cluster. Then, a null distribution was created by computing 1000 randomized cluster-level test statistics. Finally, the actually observed cluster-level statistics were compared against the null distribution and only clusters falling in the highest or lowest ~~2.5~~2.5th~~ th~~ percentile were considered significant. EEG data were analyzed with the Fieldtrip software package (http://www.ru.nl/fcdonders/fieldtrip/), a toolbox implemented in Matlab environment (The MathWorks, Natick, MA). As a first step, the most common latency range of ~~250 to 450 ms~~ 250–450 ms for N400 effects was selected and all channels were included in the analysis. Then, based on the scalp distribution of the N400 effect across mood sessions, the later ~~450–570 ms~~ 450–570 ms time-window was also selected at a region of interest including the following electrodes: FC1, FCZ, FC2, C1, CZ and C2.

3 Results

3.1 Mood induction manipulation

Participants rated the valence and arousal values of their current mood six times throughout the experiment. Mean ratings across these sessions are shown in Figs. 3 and 4. They illustrate the changes in valence (Fig. 3) and arousal (Fig. 4) at different moments throughout the experiment.

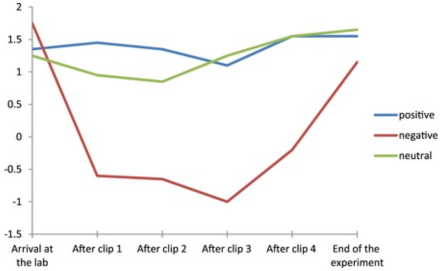

Fig. 3 Mean changes in ~~VALENCE~~valence throughout the experiment.

alt-text: Fig. 3

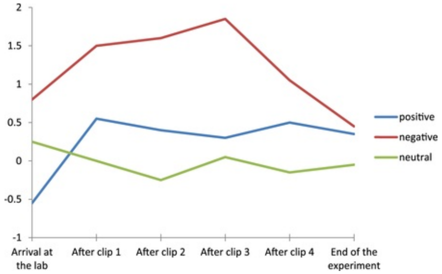

Fig. 4 Mean changes in the level of ~~AROUSAL~~arousal across the experiment.

alt-text: Fig. 4

The results of a one-factor ANOVA showed no significant differences in valence or arousal across sessions when participants arrived at the laboratory.

Differences in valence (F(2,38) ~~= 9.815; p<0.000)~~ = 9.815; p < 0.000) and arousal (F(2,38) ~~= 4.209; p<0.020)~~ = 4.209; p < 0.020) emerged after watching the first clip. Post-hoc analyses revealed that participants in the negative mood condition showed a significant decrease in valence compared to those in the neutral and positive mood conditions. In addition, participants reported higher arousal scores, compared to the neutral condition.

Similar results were found after watching the second clip. Differences in valence (F(2,38) ~~= 6.874; p < 0.002)~~ = 6.874; p < 0.002) and arousal (F(2,38) ~~= 5.599; p < 0.006)~~ = 5.599; p < 0.006) were noticeable. As in the previous questionnaire, viewing negative clips elicited a reduction in valence scores compared to those elicited by neutral and positive clips. Again, negative clips provoked a higher arousal state in participants compared to the neutral condition.

Following the tendency, effects in valence (F(2,38) ~~= 10.161; p < 0.000)~~ = 10.161; p < 0.000) and arousal (F(2,38) ~~= 5.321, p < 0.008)~~ = 5.321, p < 0.008) were also significant after watching the third clip. Participants in the negative condition presented lower levels of valence compared to those in the positive and neutral condition. Moreover, higher arousal levels were reported after watching negative clips when compared with both neutral and positive conditions.

Only differences in valence (F(2,38) ~~= 9.014; p < 0.000)~~ = 9.014; p < 0.000) emerged after viewing the last clip of the experiment. Again, valence scores were significantly lower for the negative clips when compared with the positive and neutral clips.

At the end of the experiment, no differences in valence or arousal were found.

Overall, these results show that the mood induction procedure was only successful for the negative clips. Viewing these clips elicited lower emotional state valence ratings relative to the positive and neutral clips. In addition, all except for the last clip elicited higher arousal scores than neutral videos. In contrast, viewing positive clips did not significantly increase valence or arousal levels.

3.2 Behavioral data

A repeated-measures ANOVA with the number of errors for each participant was computed including the following factors: EMOTION (positive, negative and neutral) and VALIDITY (logical and illogical). A main effect of

VALIDITY was found (F(1,19) ~~= 8.355; p < 0.009).~~ = 8.355; $p < 0.009$). A higher number of errors was committed for illogical syllogisms (2.519) compared to logical syllogisms (1.00), representing a 6.3% and a 2.5% of errors, respectively. This result suggests that participants experienced more difficulties when solving illogical syllogisms. However, no main effects of EMOTION (F(2,38) ~~= 0.505; p = 0.607)~~ = 0.505; $p = 0.607$) or interaction EMOTION by VALIDITY (F(2,38) ~~= 0.355; p = 0.704)~~ = 0.355; $p = 0.704$) were found in behavioral error rates.

3.3 Electrophysiological data

Grand-averages comparing the processing of the last word of the conclusion for logical and illogical syllogisms within moods are shown at a selection of 3 midline electrodes (front to back). (Fig. 5).

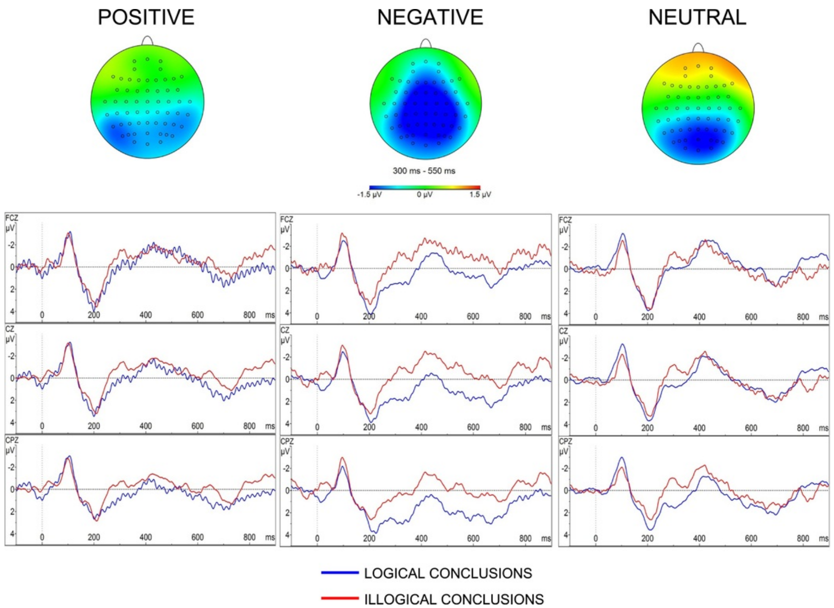

Fig. 5 ERP responses elicited by logical conclusions (black lines) and illogical conclusions (red lines) in the three inducted moods (positive, negative and neutral). Responses are plotted at a selection of 3 midline electrodes front to back (FCz, Cz and CPz). Negative voltage is plotted up. Voltage maps are also plotted at the top of the figure for each comparison. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article)

alt-text: Fig. 5

According to visual inspection, the ERP response to illogical conclusions showed an enhanced negativity compared to logical conclusions in the N400 time-window across all three sessions (positive, negative and neutral). However, the size of this effect was most prominent and longer sustained under the negative mood state, while was minimal under both positive and neutral mood states.

The cluster-based permutation test revealed a main effect of VALIDITY ~~(p = 0.033).~~ ($p = 0.033$). This effect appeared between 300 and ~~420 ms~~ 420 ms and was distributed over centro-parietal electrode sites. Of critical interest for the present study was whether logical and illogical conclusions would significantly differ as a function of the EMOTION session in which they were presented. Thus, cluster-based permutation analyses were also conducted in a selection of 6 fronto-central electrodes (FC1, FCZ, FC2, C1, CZ and C2), where the N400 seemed to vanish for the neutral and positive sessions and remain active in the negative mood session. The analysis revealed a significant interaction between VALIDITY and EMOTION in the 470 – ~~550 ms~~ 550 ms time window ~~(p=0.037).~~ ($p = 0.037$). Further analyses in this region of interest (ROI), revealed that the difference between logical and illogical conclusions was only significant in the negative mood session ~~(p = 0.0125).~~ ($p = 0.0125$).

To further characterize the nature of the effect, additional analyses were conducted to contrast all the responses to logical conclusions and all the responses to illogical conclusions (regardless of mood session). This approach was taken since an N400 effect consists of a difference wave (e.g. congruent ~~versus~~versus incongruent, high cloze ~~versus~~versus low cloze) (Kutas and Hillyard, 1980c). Thus, our effect might potentially be driven by either an increase in the response to illogical or a decrease in the response to logical conclusions. The analysis revealed that while no significant cluster of electrodes showed significant effects for the responses to the illogical conclusions, the analyses of the response to the logical ones differed as a function of mood ($p = 0.048$). Specifically, the response to logical conclusions in the negative mood session was less negative-going than the one in the positive ($p = 0.03$) and the neutral ($p = 0.08$) sessions in the frontal cluster. In contrast, mean amplitude responses for logical conclusions in positive and neutral mood sessions were not statistically significant ($p = 0.74$). Fig. 6 illustrates this contrast at a two midline electrode sites.

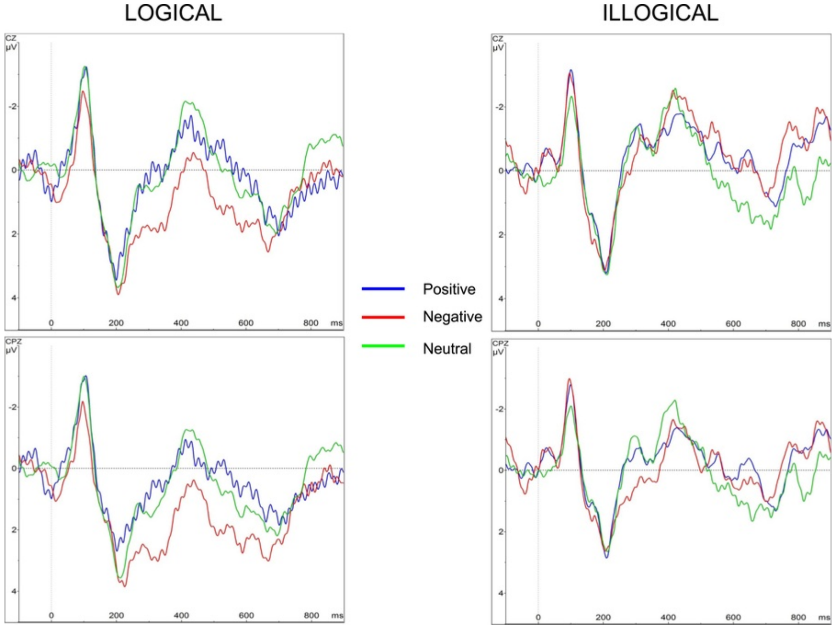

Fig. 6 ERP responses elicited by logical conclusions (left) and illogical conclusions (right) in the three inducted moods (positive, negative and neutral). Responses are plotted at two electrode sites (Cz and CPz). Negative voltage is plotted up.

alt-text: Fig. 6

4 Discussion

The current study aimed to examine the time course of potential influences of mood state on reasoning processes. In particular, we explored whether mood altered the online processing of syllogisms whose conclusions were either logically valid or invalid. First, our results confirmed previous findings with regard to an overall enhancement of the N400 ERP in response to illogical ~~versus~~versus logical conclusions for categorical syllogisms whose initial major premise had been rated as true (Rodríguez-Gómez ~~et al.,~~et al., 2018a, 2018b). This result indicated that participants overall anticipated the logical conclusions to a better extent than the illogical ones, according to the functional interpretation of classical posteriorly distributed N400 effects (Federmeier, 2007). It is a noticeable finding considering that by the time of the reading of the second premise of the syllogism, readers could potentially predict in advance whether the conclusion was going to be logical or illogical. Thus, the anticipation of logical conclusions (as indexed by the smaller N400 to the last word of the conclusion) is a rather pervasive phenomena during online reading of reasoning arguments.

It is important to bear in mind that our analysis of mood scores indicated that the method used for mood induction (video films) was only successful in eliciting a negative mood while it failed to elicit a positive mood. We attribute the failure to elicit a positive mood to the nature of the content of the positive films. Our initial purpose was to increment arousal levels both in negative and positive emotional states. Thus, we selected both negative/violent and positive/erotic videos, respectively. However, the ratings of mood after watching erotic videos did not result in an increase in positive valence nor arousal levels in our sample. Participants only reported a negative mood increase after watching clips with violent negative content. In addition, differences between negative and neutral moods were also found with regard to the level of arousal induced by the films (higher arousal for the former than the later). This contributes to a potential confound between negative valence and high arousal levels, which might together account for the current findings as we will discuss later.

Behavioral performance on the conclusion validity task, was slightly worse for illogical than for logical conclusions. Participants overall committed more errors when judging the invalidity of illogical conclusions relative to when judging the validity of logical ones. However, in line with previous studies (Smith et al., 2014) and in contrast with others (Jung et al., 2014), our results indicate that performance on this task was insensitive to the mood manipulation. In regard to the presence of absence of mood effects on task performance, we speculate that the method used to induce changes in emotional state, might be critical. The mood induction procedure that was used in the study that found effects of induced emotion on reasoning performance (Jung et al., 2014) consisted of giving feedback to participants on an excellent, poor or on average performance in a previous manipulated intelligence test.

Critically, even in the absence of mood influences on behavioral performance in our study, emotional state effects arouse when examining the time-course of electrophysiological responses. In the later portion of the N400 time-window ~~(470–550 ms),~~ (470–550 ms), the ERP ~~the~~ validity effect (larger N400 for illogical than logical conclusions) only was significant under the influence of a negative compared to a neutral or positive mood. The latency of this effect falls within the period of semantic integration processes and, thus, it is in contrast with the results from the study by Blanchette and El-Deredy (2014), which found only later influences of the emotional content on conditional reasoning ~~(800–1050 ms).~~ (800–1050 ms). Our results therefore support an earlier influence of mood state (relative to the one obtained when the emotional content of the reasoning was manipulated) on how conclusions were anticipated, which goes in line with other studies showing earlier mood influences in other language comprehension processes (Chwilla et al., 2011; Federmeier et al., 2001; Pinheiro et al., 2013; Van Berkum et al., 2013).

Since the positive mood induction failed in our study, current results are unable to determine whether it might influence categorical reasoning. Thus, the hypothesis of a more flexible, heuristic-based processing style under a positive mood (Ruder and Bless, 2003), deserves future investigation in the context of reasoning tasks. With regard to a negative mood, in contrast, we found evidence to support a more analytical, rule-based cognitive style (Clore and Huntsinger, 2007), as indexed by the reduced N400 response to logical conclusions under this emotional state. We must, however, acknowledge that modulations of arousal were also present after watching video clips 1, 2 and 3, with higher arousal levels for negative relative to neutral and positive mood induction sessions. Thus, the stronger anticipation of logical conclusions occurring during this session may be driven by a negative valence increase, a higher arousal state, or a combination of both factors.

Regarding theoretical accounts on the mechanisms by virtue of which emotion might exert and influence in other cognitive tasks, an alternative interpretation of our results is that a negative mood consumed cognitive resources (Tremoliere et al., 2016, 2018) which interfered with the main reasoning task. Impaired task performance in prior studies manipulating mood has been thought to reflect a decrease in the processing capacity because cognitive resources were committed to the processing of people's own mood (Ellis, 1988; Schmeichel, 2007), or to concentration in mood regulation processes to re-establish positive mood (Mitchell and Phillips, 2007). In our view, our results do not fit well with the cognitive load hypothesis. The lack of behavioral mood effects and the fact that the larger N400 effect seemed to be driven by a specific reduction of N400 amplitude to logical conclusions under a negative mood, do not fit well with an overall memory capacity overload under emotional states.

From a slightly different view, our results could also be explained in terms of general attentional mechanisms. Negative affective states have been associated with a narrowing of attention (Derryberry, 1994; Forster et al., 2006). Under this view, drawing attentional resources away from the demands placed by the task, in conjunction with a narrowing of attention, might have led to the results. Again, the lack of behavioral mood effects and the specific reduction of N400 amplitude for logical conclusions under a negative mood, do not seem to support the hypothesis of an overall disruption of mood by a narrowing of attention.

Although attentional and cognitive capacity overload explanations are not mutually exclusive, our electrophysiological data seem to support the hypothesis that an emotional state leads to a rather specific change in cognitive style by virtue of which only the logical conclusions were more readily available in semantic memory. In the study by Federmeier ~~et al.~~ et al. (2001) a positive mood had the opposite effect, a broadening for the prediction of more distantly related semantical items. Our electrophysiological findings suggest that a more remarkable anticipation of logical conclusions was triggered under a negative mood influence, as indexed by the specific reduction in N400 in response to them. Thus, in line with the postulated association between mood and cognitive styles, a more analytical (e.g. logically valid) style seems to be prompted under the influence of a negative mood (Clore and Huntsinger, 2007). In contrast to our results, Chwilla ~~et al.~~ et al. (2011), found a less spread N400 effect under negative mood condition when high and low cloze probability items were processed within sentences. It is unclear, however, whether the later effect was driven by the differential response to the high or the low cloze probability items. Our electrophysiological data suggests a specific rather than a broad effect of mood state on language processing.

With regard to the discrepancies between the results of the current study and the ones obtained by Blanchette and El-Deredy (2014), our study differs from theirs in at least two main respects. First, our syllogism reading task includes categorical rather than conditional reasoning. In fact, rather than an N400 reduction to logical versus illogical conclusions (Rodríguez-Gómez ~~et al.,~~ et al., 2018a, 2018b), they found a larger N400 in the inference making condition relative to a baseline condition (which in their study consisted on the repetition of premises). Second, they manipulated the nature of the contents of the reasoning task (either negative or neutral) whereas we induced emotional states prior to reasoning with emotionally neutral materials. These methodological differences might explain the observation of a late ERP effects ~~(800–1050 ms)~~ (800–1050 ms) of emotional content versus an earlier influence (N400 time-window) of emotional state in reasoning with categorical syllogisms. Noteworthy, a recent study by Bago et al. (Bago et al., 2018) also reveals early effects (N2 and P300) when there is a conflict between heuristic and logic conclusions in problem solving.

Despite methodological discrepancies across ERP studies, our current findings add to the proliferating body of research that shows electrophysiological evidence on how non-linguistic aspects like emotional state exert an influence in online language comprehension tasks (Chwilla et al., 2011; Federmeier et al., 2001; Pinheiro et al., 2013; Van Berkum et al., 2013; Verhees et al., 2015; Vissers et al., 2013). From an anatomical point of view, language comprehension is suggested to involve different brain networks depending on people´s mood (Egidi and Caramazza, 2014). Thus, our results fit well with reports from recent brain imaging studies that point to the recruitment of differential mood-dependent neural networks during reasoning with semantic material (Brunetti et al., 2014; Smith et al., 2015, 2014).

In sum, the current study investigated the influence of an individuals' mood in reasoning with categorical syllogisms, using electrophysiological measures. Our results reveal that a negative mood state results in a higher capacity or an inclination to anticipate logical conclusions. In a broad sense, the results of the present study contribute to the accumulating body of evidence that highlights the importance of considering emotion as a source of modulation of other cognitive processes.~~ Uncited references(Huntsinger and Clore, 2014)~~

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Highlights

- An ERP study was conducted on the influence of mood on ~~reasoning~~reasoning.
- Compared to illogical, logical conclusions showed reduced N400 ERP ~~responses~~responses.
- Under an induced negative mood, this reduction was rather ~~extended~~extended.
- Participants anticipated logical conclusions when reading categorical ~~syllogisms~~syllogisms.
- A negative mood increased the expectation of logical ~~conclusions~~conclusions.

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