Prior Affirmative Representation Facilitates the Cognitive Processing of Compound Negation

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Abstract A mixed factorial design of 2x2x2 was applied (sequence x law x affirmation) to evaluate the effects of prior affirmative representation on the subsequent processing of compound negation. The sequence factor was defined to perform between-subjects comparisons. The other two factors, that is, logic law and prior affirmation were defined as within-subjects factors. The sequence factor was included to evaluate potential artifacts generated by the experimental design. Statistical analyses showed the absence of such artifacts. Three dependent variables were included: response type, an indirect measure of introspection quality, and a direct measure of subjective difficulty. A random sample of 130 participants were recruited for this experiment. All the participants were undergraduate students at the National University of Entre Rios, Argentina. 112 were female (86.2%). The mean age was 23.79 years old (SD = 6.452). 2 sets of 6 exercises each were given to all the participants. The classical selection paradigm was applied, that is, four response options were given in each item. Only one of them was the normative response according to logic (DeMorgan's equivalences for negated conjunctions and negated disjunctions). One set included prior relevant affirmation before requiring negation, the other set started straightforward with the negation task. The task was to find the logical meaning of such compound negation that operated on a conjunction or a disjunction. By the other side, the set of exercises without prior affirmation asked straightforward to find the equivalence for a given compound negation of a conjunction or a disjunction. After completing each set of 6 responses participants were asked to give an opinion about their own performance (introspection quality) and about the task difficulty (subjective difficulty). In consistence with the mental models theory and the relevance theory, prior affirmation increased the frequency of normative responses and the quality of introspection. However, a direct registry of task difficulty showed no difference between a prior affirmation condition and a straightforward condition in consistence with the Gricean view of negation. An unexpected result showed an incremental effect of normative responses for the negation of conjunctions in comparison with the negation of disjunctions when prior affirmation provided a pragmatically enriched context. These results are discussed in terms of working memory dynamics. In sum, our findings suggest that the processing of compound negation of conjunctions and disjunctions can be explained as a combination of explicit and implicit processes that are strongly influenced by pragmatic factors.

Keywords Mental Models, Relevance, Dual-Processes, Context, Negation

1. Introduction

Negation is a key feature of natural language [1]. The importance of negation has been extensively acknowledged by philosophers [2], linguists [3], logicians [4], and psychologists [5, 6, 7, 8, 9]. Negation has been defined in mathematical logic as an abstract function that reverses the truth value of a given sentence [10]. For example, given the sentence p: "Africa is a continent", its negation would be *not p*: "It is not the case that Africa is a continent". In this example, p is a true sentence. Therefore, *not p* is a false sentence. Conversely, the negation of a false sentence yields a true sentence.

One of the current concerns of the theories of negation is to explain the sequential relation between prior affirmation and subsequent negation. More specifically, two core questions need to be answered. First, is there an effect of prior affirmative representation on subsequent negation? Does such effect exist at all? Second, if the effect does exist, which variables shall be included in an evidence-based description and explanation? This article aims to contribute plausible answers to these questions. We aim to prove that prior affirmation representation does increase normative responses and introspection quality, but does not affect the subjective registry of difficulty for the particular case of

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compound negations. This aim is consistent with current studies that shifted their perspective from a binary view to a gradient view of the effort required to process negation [11].

This article continues as follows. First, we outline the main psychological advances in the study of the representation and inferential processing of compound negation. In particular, we highlight the theoretical and empirical contributions of the mental models theory of human thinking and a core insight of dual-process theories focused on implicit processes. Then, we comment on linguistic contributions concerned with cooperation and relevance in current pragmatics. Next, we apply the distinction between implicit and explicit processes of negation proposed by dual-process perspectives [12, 13] to the particular case of conjunctions and disjunctions. Afterwards, we derive our working hypotheses from the reviewed accounts and introduce a mixed experimental design to test them. Finally, we discuss our findings and propose further studies based on complementary measures.

1.1. Mental Models of Compound Negation

Early contributions by Wason and Johnson-Laird [14] found a psychological interaction between the polarity of a sentence, i.e. its affirmative or negative condition, and its truth value, i.e. its true or false condition. These authors found that negative sentences are harder to deal with than false sentences. They also found that the evaluation of false affirmations requires more time than true affirmations, but the evaluation of false negations is faster than the evaluation of true negations. The latter result has been described as "odd" [15, p. 436]. However, the mental models theory provided an account for this phenomenon that relates the processing times to the number of possibilities corresponding to each sentential case [15, 16, 17]. That is, humans do not reason like a universal Turing machine [18] by applying formal rules [19]. The evidence suggests that human reason proceeds by representing possibilities and using counterexamples to evaluate consistency [20, 21] and to distinguish between biconditionals, conditionals, and intention conditionals [22]. In the same line of research, the negation of compounds has been found particularly difficult to understand by individuals with no training in logic [6, 7, 8]. A compound sentence is a molecular expression that can be parsed into atomic sentences, which do not include connectives or the operator of negation. Conjunctions and disjunctions are examples of compound sentences. For instance, "Africa is a continent and London is a city" is a compound sentence because the conjunctive operator "and" connects the atomic sentence "Africa is a continent" with the atomic sentence "London is a city". In a similar manner the word "or" operates in disjunctions [10]. Recent contributions by Khemlani et al. [6, 7] postulated a novel account for the cognitive processing of sentential negation in the context of the mental models theory of human thinking [15, 16]. This theory attributes a critical role to the working memory load

during reasoning [23]. The heavier the load is, the poorer the performance in negation tasks would be. This might happen because the mental representation of the possibilities expressed in sentences would require multiple computations that include iconic representations but also an abstract representation of negation [24]. A broad prediction that can be derived from the mental models theory states that the reduction of working memory load facilitates the processing of negation [7, Prediction 4]. We suggest that one way to produce such reduction consists in presenting prior affirmative sentences before requiring the negation of the same sentences.

1.2. Relevance, Cooperation, and Pragmatics of Negation

Several contributions from cognitive pragmatics found facilitation effects when prior information is presented before requesting negation [25, 26]. In the context of the relevance theory proposed by Sperber and Wilson [27, 28] negations are not automatic, they rather require different computational demands. Furthermore, relevance is defined as a function of cognitive effort and contextual effects such that the greater the effort, the lesser the relevance [29, 30]. Consequently, the reduction of such effort would produce better performances in negation tasks. By the opposite, the pragmatic theory of Grice [31, 32] and the neo-Gricean linguists like Levinson [33] suggest that the processing of negation in conversational contexts is automatic and effortless [3]. This would particularly occur with scalar inferences, which are cognitive phenomena activated by utterances that use terms like "some" to imply "not all" [26], e.g. "Some politicians are honest". Therefore, the working memory reduction obtained through the presentation of prior affirmative sentences would produce no effect on the processing of subsequent compound negation according to the Gricean theory. This would happen because proper communication occurs only if a standard set of principles and maxims are assumed [31]. The cooperation between speaker and hearer would guarantee a sound understanding. A low effort or no effort at all would be needed. This would happen even when many inferences were required to produce a sophisticated meaning completion [30].

1.3. Explicit and Implicit Processes of Negation

From these theoretical convergences and divergences between cognitive and pragmatic theories, different patterns of introspective processing can be predicted. If the processing of negation is automatic like the Gricean perspectives suggest, then no subjective difference in difficulty should be explicitly noted between negation preceded by affirmation and straightforward negation. However, the prior affirmation condition might promote a facilitation effect based on working memory reduction. According to the mental models theory, such effect might be accessible through introspection at some degree. This would happen because subjects might notice the online load of her or his own working memory. We argue that these predictions

are not contradictory because implicit and explicit processes can be distinguished in the processing of negation [34]. An explicit measure might evidence no difference in subjective difficulty but an implicit measure might provide an introspective notice of working memory alleviation in the prior affirmation condition. Recent introspective or metacognitive studies are consistent with this conjectured relation between introspection quality and performance [35, 36]. Although some of these results have been objected after reanalysis using Bayesian methods [37], the link between performance improvement and introspection promotion has been detected in multiple domains [38]. In the field of deduction, the relevance of introspective processes has been early acknowledged [14] and recently accounted for in conditional reasoning [39, 40]. More specifically, the cognitive fluency has been understood as a metacognitive process akin to the meta-memory feeling-of-knowing phenomenon [41]. It has been found that such fluency plays a critical role in the generation of distortions like the matching bias in the Wason selection task [42]. In the field of insight problem solving a recent study conducted by Ball et al. [43] found better performances when implicit processes are facilitated.

2. Method

An experiment was conducted to study the effects of prior affirmation on the subsequent processing of compound negation. We aimed to detect such effects and to propose three dependent variables to capture important aspects of negation, i.e. normative responses, an explicit registry of subjective difficulty, and an implicit measure of introspection quality.

The compound sentences selected to achieve this aim were negations of conjunctions or disjunctions constructed according to DeMorgan's laws of logic [4, 8, 44]. DeMorgan's law 1 states that the negation of a conjunction is equivalent to a disjunction. DeMorgan's law 2 states that the negation of a disjunction is equivalent to a conjunction. Formally, for law 1 "not (p and q) is logically equivalent to (not p or not q)". For law 2 "not (p or q) is equivalent to (not p and not q)". The letters p and q represent a sentence, which is any proposition or utterance associated to a truth value (true or false, but not both) according to Suppes and Hill [10]. The use of norms like DeMorgan's laws has been recently debated [45] and considered necessary in reasoning research [46, 47].

2.1. Participants

A random sample of 130 Social Sciences students at the National University of Entre Ríos, Argentina, were recruited for this experiment. 112 were female (86.2%). The mean age was 23.79 years old (SD = 6.452). All the participants gave an informed consent before taking part in the experiment. No reward was given for participation. None of the participants received formal training in logic or mathematics as part of their university studies.

2.2. Materials and Procedure

2 sets of 6 exercises each were given to all the participants. One set included prior relevant affirmation before requiring negation, the other set started straightforward with the negation task. Tables 1 and 2 introduce examples of such tasks.

Table 1.   Task Example for Prior Affirmation before Negation

Instructions: please read carefully each sentence below. A question is presented about a daily situation. You are requested to select the option that you consider correct. Only one of the options is a better response than the others according to logic.

Helmut visited London city as a tourist. He planned for his last day in that city to visit the Buckingham Palace and the Tower of London. However, he realized that he did not have enough time to visit both places. In consistence with his situation, which possibility do you think that remained to him?

☐ a) Not visiting the Tower of London and not visiting the Buckingham Palace.

☐ b) Not visiting the Tower of London or not visiting the Buckingham Palace.*

☐ c) If he didn't visit the Tower of London, then he didn't visit the Buckingham Palace.

☐ d) Not visiting the Tower of London or else not visiting the Buckingham Palace.

Note: The symbol * shows the correct response according to DeMorgan's law 1.

Table 2.   Task Example for Straightforward Negation

Instructions: please find the sentence in small letters that is equivalent to the sentence in capital letters. Two sentences are equivalent when they have the same meaning, that is, when they express exactly the same idea. Only one of the four response options is correct according to logic.

IT IS NOT THE CASE THAT: LONDON IS A CITY AND AFRICA IS A CONTINENT

☐ a) London is not a city and Africa is not a continent.

☐ b) London is not a city or Africa is not a continent. *

☐ c) If London is not a city, then Africa is not a continent.

☐ d) London is not a city or else Africa is not a continent.

Note: The symbol * shows the correct response according to DeMorgan's law 1.

The prior affirmation set of exercises started with the description of a daily situation presented in a colloquial manner. For example, "Helmut visited London city as a tourist. He planned for his last day in that city to visit the Buckingham Palace and the Tower of London". Then, a sentence operated the negation of such prior affirmation, e.g. "However, he realized that he did not have enough time to visit both places". The task was to find the logical meaning of such negation that operated on a conjunction or a disjunction, i.e. "In consistence with his situation, which possibility do you think that remained to him?" (See Table 1 for response options).

In the other side, the set of exercises without prior affirmation asked straightforward to find the equivalence for a given compound negation of a conjunction or a disjunction

as is shown in Table 2. The straightforward set of exercises used in this experiment has been previously employed in a similar experiment that tested other predictions derived from the mental models theory [8].

The atomic truth values for both sets were TF (i.e. true and false), FT, and FF. That is, we used a trimmed truth table that excluded the TT case for both DeMorgan's laws. This exclusion was applied because in a pilot study we found that some participants evaluated only the atomic values and neglected the evaluation of connectives [8]. Such strategy was applied to reduce a potential contribution of a belief-bias-like phenomenon to the response selections [48], which was not a specific aim of this experiment and would have introduced a confound effect.

To further study possible confound learning effects two groups were defined. One group received first the prior affirmation set and then the straightforward negation set. The other group received the straightforward negation set first and then the prior affirmation set. No differences were expected between these groups, which can be interpreted as the absence of learning effects.

Each exercise in both sets included a main negation and four possible equivalences of such negation. Only one of these four options was correct according to DeMorgan's laws. The task was to evaluate the sentences and select one of them. In all the exercises the same four abstract forms were given as response options, that is: a) "not p and not q", b) "not p or not q", c) "if not p, then not q", d) "not p or else not q". The letters p and q represent atomic sentences that vary across exercises. The normative response for DeMorgan's law 1 was option b, and for law 2 was option a in this sequence. Option a is a conjunction, option b is an inclusive disjunction, option c is a conditional, and option d is an exclusive disjunction. DeMorgan's laws are normative for the inclusive disjunction, but not for the exclusive disjunction [10]. Tables 1 and 2 introduced examples for law 1. Examples and analyses for law 2 concerned with erroneous response patterns have been discussed in Macbeth et al. [8]. The sequence of exercises within each set was randomized and the response options sequence within each exercise was randomized as well. This double randomization was performed for each participant. Between both sets a distractor task was introduced. A ten items shortened version of the Big-Five Personality Inventory was administered [49].

These tasks were administered in groups of 20 to 30 students in the classroom during a regular class with the permission of the corresponding authorities. The tasks were presented in paper-and-pencil using individual booklets, which also served for collecting responses. The experiment was conducted in Spanish. For all the participants, Spanish was their mother tongue. The complete experimental sessions took around 25 minutes each.

After completing each set of 6 responses, participants were asked to give an opinion about their own performance. They answered the question: How many of your 6 last responses do you think are correct? This response provided a subjective estimation of success that was used to compare with the objective success to generate a raw index of introspection quality or calibration [36]. The objective success was the sum of normative responses according to DeMorgan's laws. The introspection quality index was calculated for each set and for each participant (introspection quality = subjective success - objective success). This indirect measure was aimed to capture a possible implicit facilitation effect in consistence with the dual-process theories or thinking [12, 13].

Two additional response vectors were generated. An explicit estimation of subjective difficulty was requested after each set of negations. Participants answered the question: How difficult was this set of 6 exercises for you? Responses were requested under the form of integers ranging from 0 to 10, being 0 the lowest difficulty and 10 the highest difficulty.

2.3. Experimental Hypotheses

Hypothesis H1 states that the frequency of normative responses for the cognitive processing of compound negations of conjunctions and disjunctions increases when prior affirmation is presented before requiring their negation. Hypothesis H2 states that introspection quality for the processing of compound negations of conjunctions and disjunctions increases when prior affirmation is presented before requiring their negation. Hypothesis H3 states that prior affirmation does not reduce the subjective difficulty when compared to straightforward negation's subjective difficulty. Hypotheses H1 and H3 are concerned with explicit registries while H2 aims to evaluate an implicit process.

2.4. Design and Analyses

A mixed factorial design of 2x2x2 was applied (sequence x law x affirmation). The sequence factor was defined to perform between-subjects comparisons. The other two factors, i.e. logic law and prior affirmation were defined as within-subjects factors. The sequence factor was included to evaluate potential artifacts generated by the experimental design. In particular, unwanted learning effect. The within-subjects factors were included to test the experimental hypotheses H1, H2, and H3.

Two conditions were defined for the sequence factor. One condition received first the prior affirmations set followed by the straightforward set (N = 61). The other condition received the prior affirmations set in second place after receiving the straightforward set (N = 69). The law factor had two conditions, one for DeMorgan's law 1 and the other for DeMorgan's law 2. The affirmation factor had two conditions, one for prior affirmation and the other for straightforward negation. If the sequence factor yields no difference, then both groups (N = 130) can be considered as stemming from the same population. In that case, the design can be reduced to a 2x2 within-subjects experiment suitable for factorial comparisons of law (law 1, law 2) and affirmation (prior affirmation, straightforward negation).

Three dependent variables were defined, i.e. normative

responses, introspection quality, and subjective difficulty to test hypotheses H1, H2, and H3 respectively. Correct or normative responses were the sum per participant of the selected options that were consistent with DeMorgan's laws. Normative responses were computed separately for law 1 and law 2. Introspection quality was defined as the difference between the subjective success and the objective success through the index introduced above [36]. The lower such difference is, the higher the quality of introspection is. This happens because the index increases when the distance between the subjective registry and the objective registry becomes greater. Subjective difficulty was the direct response given by each participant to the question concerned with difficulty that followed each set of exercises. .

2.5. Results and Discussion

Before testing the experimental hypotheses, two evaluations were performed to study the reliability of the experimental design and procedure. The first evaluation was concerned with possible gender differences. The second evaluation was needed to reject a possible learning effect that could bring unwanted variability to the dependent variables. Dependent variables' vectors resulted incompatible with the normality assumption according to the Shapiro-Wilk test and the Kolmogorov-Smirnov test. For both laws, normative

responses, introspection quality, and difficulty yielded p values close to zero for the mentioned tests. Therefore, robust statistics were applied both for significance testing and effect size estimation [50, 51].

No gender differences were found for the negations tasks. We performed separate tests between female and male participants for each law and for each affirmation condition within each law (Mann-Whitney U test ps above .41 with effect sizes close to zero using Cliff's Delta). Consequently, female and male participants were further pooled as stemming from the same population for statistical analyses. As expected, we neither found sequence differences using the same strategy (ps above .101, Cliff's Deltas close to zero for separate Mann-Whitney U tests). This result suggests that no learning effect was generated. Accordingly, both groups were further treated as stemming from the same population to test the experimental hypotheses.

Hypothesis H1 resulted consistent with the evidence. The introduction of prior affirmation before negation increased the frequency of normative responses. Figure 1 presents a visual representation of this result and Table 3 summarizes the corresponding statistical tests. The prior affirmation effect size resulted large for law 1 and about medium for law 2.
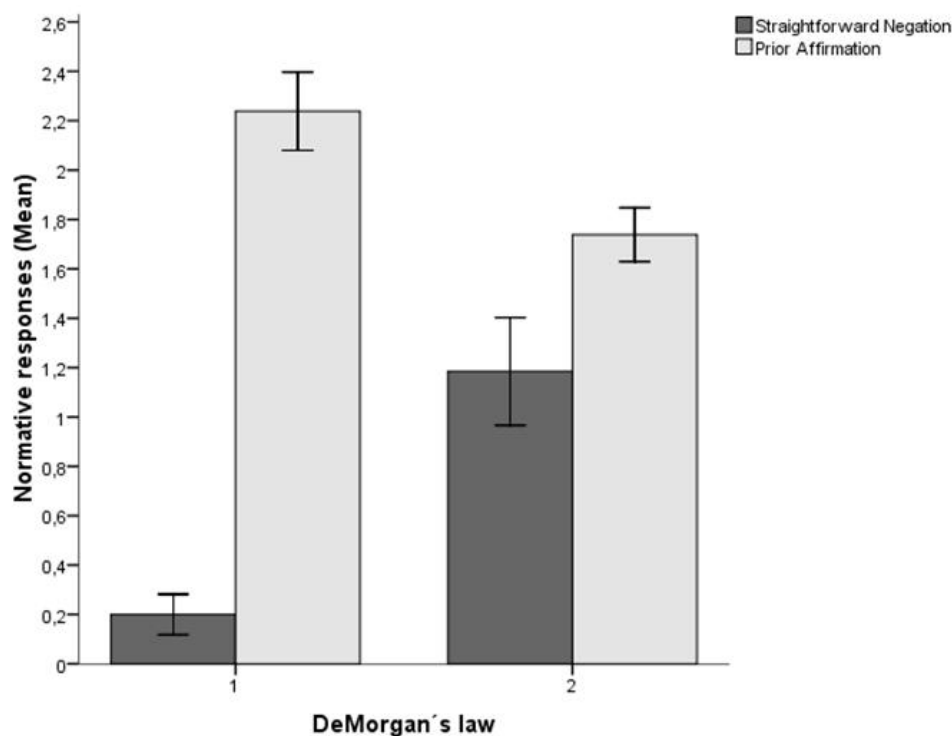
Note: Error bars represent a 95% confidence interval for the mean of normative responses. N = 130.

Figure 1. Prior affirmation versus straightforward negation

Table 3. Statistical Tests of Prior Affirmation Effect

	Law 1		Law 2	
	Straightforward Negation	Prior Affirmation	Straightforward Negation	Prior Affirmation
Mean (*SD*)	0.20 (0.472)	2.24 (0.913)	1.18 (1.256)	1.74 (0.629)
z	-10.148		-2.948	
p	<.001		.003	
$|\delta|$	.896		.278	
Effect Size	large		about medium	

Note: The reported *z* statistic corresponds to the Sign test. Means and Standard Deviations (*SD*) are reported for normative responses in the first row. N = 130. The $|\delta|$ corresponds to the Cliff's Delta absolute value effect size, which is small when greater than .147, medium around .33 and large around .474 [52].

Hypothesis H2 resulted compatible with the evidence. A raw calibration paradigm was applied for the evaluation of the introspection quality [53]. Calibration is here understood as the relation between the subjective success (i.e. experimental subject's opinion about her or his own performance) and the objective success (i.e. her or his actual performance). Calibration was computed as the difference between the former and the latter for each subject in each set of exercises. When calibration came close to zero, the subject was considered as well calibrated. In the contrary, when calibration departed from zero the subject was considered as not well calibrated. When such departures generated significant differences between the subjective success and the objective success, the presence of a calibration bias was operationally defined. In calibration research the overconfidence bias occurs when the subjective success results greater than the objective success [53, 54]. That is, the subject performed poorer than she or he thinks. To obtain more fine-grained comparisons between these biases, the estimation of robust effect sizes was applied using the absolute value of Cliff's Delta [50, 51]. As expected, a reduction in effect size for the overconfidence bias was observed for the prior affirmation condition as it is shown in Table 4 (from large to small effect sizes). A statistical test was further applied to compare calibration between these conditions. The difference in calibration resulted significant between prior affirmation and straightforward conditions (Sign test, *z* (130) = -9.037, *p* < .001, |Cliff's δ| = .769, large effect size). These results are consistent with hypothesis H2 because subjects increased their introspection quality when prior affirmative mental models were constructed before their negation.

In consistence with H3 the subjective estimation of difficulty yielded no difference (Wilcoxon Signed rank test, *V* (130) = 3595, *p* = .576, |Cliff's δ| = .008, close to null effect size) between the prior affirmation set (mean = 5.708, *SD* = 2.304) and the straightforward set (mean = 5.485, *SD* = 2.286). This result suggests that the overall reasoning process was perceived as equally difficult in both sets of exercises independently from the introspective quality increase generated in the prior affirmation condition captured by hypothesis H2. Taken together, these results suggest that the observed facilitation effect activates different cognitive processes with different degrees of

introspective accessibility. A working memory load reduction might be implicitly noticed according to H2. However, an explicit registry of the corresponding difficulty reduction was not available according to H3. This result is consistent with current views of negation as a complex set of cognitive and linguistic processes that can be placed in a theoretical gradient of effort [11] rather than being all-or-nothing phenomena.

Table 4. Statistical Tests of Introspective Quality Increase

	Straighforward Negation	Prior-Affirmation
Subjective Success	4.75 (1.448)	4.55 (1.324)
Objective Success	1.38 (1.338)	3.98 (1.229)
Calibration	3.36 (1.826)	0.58 (1.446)
p	<.001	<.001
|Cliff's δ|	.871	.25
Effect size	large	small

Note: The quality of the introspective monitoring increases when calibration approaches to zero. The robust *z* tests and effect sizes reported here correspond to the comparison between subjective and objective success within subjects. The first three rows report Means and Standard Deviations, the latter in parenthesis. N = 130.

One unexpected result was observed in the prior affirmation condition. For the straightforward negation, law 1 resulted harder than law 2 in consistence with previous findings [7, 44]. That is, the negation of a conjunction is usually harder to process than the negation of a disjunction when no prior affirmation is presented [6]. However, the introduction of prior affirmation reversed the frequency of normative responses between DeMorgan's laws. This novel result cannot be explained with the evidence collected in this experiment, nor has been specifically predicted by the accounts of negation introduced in the first section. Further research is needed to evaluate why such reversal effect occurs. One possible line of exploration might consider the working memory dynamics [15, 16, 20]. That is, the affirmative representation of one mental model in law 1demands less memory consumption than the affirmative representation of three mental models in law 2. The remaining working memory would arrive more relieved to the subsequent negation step in law 1 than in law 2. Consequently, more normative responses can be expected

for the former than for the latter as can be seen between grey bars in Figure 1 (Sign test, z (130) = -5.661, p < .001, |Cliff's δ| = .378, medium effect size).

3. General Discussion

Several theories of negation suggest that working memory modulates the representation and inference of negative sentences [6]. This conjecture has been proposed by the mental models theory [7, 8, 9, 21], and the relevance theory [25, 26, 27, 28]. In the opposite, the pragmatic theory of Grice [31, 32] and similar views proposed by neo-Gricean linguists like Levinson [33] suggest that negations in some conversational contexts are processed automatically and without effort. The experimental evidence obtained in our study suggests that working memory load actually modulates the processing of compound negations for conjunctions and disjunctions. Our evidence also supports a cognitive view that includes implicit and explicit processes. The introduction of prior affirmation promoted better performances in a negation task constructed according to DeMorgan's laws. Introspection quality also improved when prior affirmation was presented before negation according to an implicit measure that captured an overconfidence bias reduction. However, the subjective difficulty did not significantly decrease when such facilitation effect occurred. This facilitation effect promoted by implicit processes has been described as a robust phenomenon in insight problem solving tasks [43].

Concerning H1, the frequency increase in normative responses generated in our experiment by prior affirmation can be considered consistent with several studies that alleviated the working memory load by prior presentation of relevant utterances. Bott and Noveck [25] found that such procedure promoted the generation of correct inferences in scalar implicatures. Similarly, Orenes et al. [9] generated eye-tracking evidence supporting a facilitation effect for the processing of sentential negation introduced after prior affirmation in the context of the visual world paradigm. Two different processes of negation were identified in the latter study conducted by Orenes and colleagues, one for bipolar alternatives contexts, and one for multiple alternatives contexts. Gaze fixations focused on the alternative item in bipolar contexts but focused on the denied item in contexts that provided several options. This result that extends previous behavioural findings [55] has been interpreted as an avoidance strategy of working memory overload in consistence with the mental models theory [15, 56]. The evidence obtained in the present study is consistent with such view.

The formalist theories of reasoning like the Psychology of Proof or PSYCOP [57] do not provide specific predictions for the effects of prior affirmation on the subsequent processing of negation. Generally, the formalist theories suggest that sentences are first translated into a mental logic or formal code, then operated according to abstract rules, and finally translated back to words to construct new sentences

[58]. The mental models theory, by contrast, suggests that reasoning depends heavily on the representation of possibilities consistent with a given set of sentences and the further search of counterexamples [15, 16, 17]. Such representation processing requires the active participation of working memory [8]. Furthermore, for the particular case of DeMorgan's laws the mental models account predicts that law 1 should be harder than law 2 for the straightforward negation condition [6]. PSYCOP predicts the opposite asymmetry or no difference at all between law 1 and law 2 [57]. In our experiment, normative responses for law 1 (mean = 0.20, SD = 0.472) resulted less frequent (Sign test, z (130) = -6.154, p < .001, |Cliff's δ| = .438, about large effect size) than normative responses for law 2 (mean = 1.18, SD = 1.256) when no prior affirmation was presented. This result (see Figure 1) replicates previous findings in consistence with the mental models theory of negation [7, 8] and contradicts the predictions of PSYCOP.

Concerning H2, the improvement of introspection quality observed in our experiment can be considered consistent with previous studies that generated more adjusted calibration through the introduction of prior relevant information in decision making tasks [59] or training in specific-domain tasks that involve prior affirmations and feedback [36]. The fluency, i.e. acceleration of response times [40, 60], under prior affirmation versus straightforward negation conditions needs to be inspected deeper in future experiments. Particularly, more evidence is needed to account for the implicit improvement of introspection quality through alternative metacognitive measures [39].

Concerning H3, we applied a classic distinction between implicit and explicit processes of negation. Such distinction follows the dual-process theories of thinking that describe the implicit processes as autonomous and typically correlated to automaticity. By the opposite, the explicit processes are described as requiring working memory consumption and being partially conscious [12, 13]. In the field of pragmatics, one of the main differences between the relevance theory [27, 28] and the Gricean theories [31, 32, 33] is concerned with the processing effort required to the hearer when interpreting an utterance produced by the speaker [61]. The intended meaning is inferred by default in the Gricean perspective. This would happen because an adequate communication is regulated by a principle of cooperation and several maxims that guarantee the understanding between speaker and hearer [32]. Grice's maxim of manner states that the hearer expects clarity and "reasonable dispatch" [31, page 47] from the speaker. Therefore, the interpretation facilitation for the hearer stems from the cooperative setting itself. Otherwise, the communication is rejected according to the Gricean view. By the opposite, the inference of meaning might require different levels of effort from the hearer in the relevance theory [11, 27, 28]. Our results support the relevance theory for implicit processes and the Gricean theory for explicit processes of negation. Although the facilitation effect in normative responses did occur (H1) and the overconfidence bias reduction did also occur (H2), no

explicit difference was found for the subjective difficulty between prior affirmation and straightforward negation (H3). Therefore, we found an *unnoticed* facilitation effect. This phenomenon is consistent with the dual-process view that differentiates between explicit and implicit processes according to the working memory demands [12, 13]. A higher demand triggers explicit and effortful processes while a lower demand correlates with automaticity, that is, implicit and effortless processing [62].

Our findings are consistent with the production of negation heuristics as was predicted by Khemlani et al. [6] and with the occurrence of reasoning biases as was extensively accounted for by dual-process theories [12, 13, 29, 63]. Similarly, the cognitive processing of straightforward compound negation has been recently described as shallow and akin to a matching-bias-like phenomenon [64] as was discovered and explained by Evans and colleagues [65, 66, 67, 68, 69, 70]. Furthermore, Evans et al. [34] provided strong evidence for the distinction between implicit and explicit processes of negation in the context of conditional reasoning. Our results with compound negation tasks support the same distinction for biconditionals constructed according to DeMorgan's laws.

Further studies are needed to evaluate the unexpected reversal effect observed in our experiment (see Figure 1). We suggest that this result is consistent with a working memory dynamics conjecture. However, more experiments are required to test this hypothesis. One strategy that can be applied with this aim is to manipulate the concurrent working memory load [71].

One limitation of our study is concerned with the lack of response time records to obtain complementary evidence. More time would be needed to process DeMorgan's law 1 than DeMorgan's law 2. However, other critical modulatory factors like meaning, reference, and context shall be taken into account [6]. A further exploration of our findings can be performed through eye-tracking methods [72, 73]. Inspection times, fixations, and revisits to areas of interest are dependent variables that might provide complementary evidence for our findings. A previous eye-tracking experiment that collected both eye-tracking measures and ERPs obtained results that can be considered consistent with such strategy [74]. Greater pupil dilation can be expected for the straightforward condition than for the prior affirmation condition because memory load contributes to such dilation [75].

Several studies conducted in the general field of reasoning [37] and in the specific field of sentential reasoning [74] found thematic effects that may also be present in our study. The robust phenomenon of belief bias can be understood as the tendency to select responses that are consistent with the world knowledge or beliefs of the experimental subjects [48, 68]. This tendency has been observed independently of the experimental instructions [60]. In other words, factual sentences are more frequently selected than counterfactual sentences in reasoning tasks regardless of the requested task. To evaluate the possible presence of this effect in our study we examined factuality in the straightforward condition. By the other side, the prior affirmation condition employed a set of hypothetical situations for which the factual versus counterfactual distinction cannot be applied (e.g. "Helmut visited London as a tourist" is a hypothetical or fictional rather than a factual utterance). The straightforward condition included 6 negations, among which 3 were conjunctions and 3 were disjunctions. All the conjunctions were true compound sentences. The set of disjunctions included 2 counterfactual sentences and 1 factual. No significant differences (Sign test, z (130) = -1.784, p = .074, |Cliff's δ| = .007, close to null effect size) in normative responses were found between the 2 pooled counterfactuals (mean = 0.37, SD = 0.439) and the factual (mean = 0.45, SD = 0.50). This finding suggests that removing TT cases from our experimental materials was an adequate strategy to reduce or avoid the belief bias effect. This is noteworthy because the study of belief bias was not aimed. The trimmed truth table that we used in our experiment promoted response patterns that can be attributed to the processes of negation rather than promoting confound effects between negation and belief. No statistical comparisons were performed between factual and counterfactual sentences pooling conjunctions and disjunctions in the same test because DeMorgan's laws 1 and 2 have shown different normative response patterns in previous studies [7, 8]. Taken together, these results suggest that belief bias did not occur in our experiment. The same phenomenon was observed in a recent experiment that tested other mental models' hypotheses but applied similar materials [8].

In sum, our study suggests that the introduction of prior affirmative representation before negation facilitates the cognitive processing of negative compound sentences constructed according to DeMorgan's laws. phenomenon has been accounted for by the mental models theory in psychology [6, 7], and by the relevance theory in pragmatics [27, 28]. The proposed distinction between implicit and explicit processes of negation follows the dual-process theories of thinking [12, 13, 34, 43, 76]. The explicit evaluation of subjective difficulty resulted consistent with the Gricean pragmatics [31, 32]. More research is needed to achieve a stronger evaluation of these findings. Particularly, more experimental evidence is required to understand the unexpected reversion effect between normative responses for DeMorgan's laws triggered by prior affirmative representation.

4. Conclusions

To conclude, our findings suggest that the processing of compound negation of conjunctions and disjunctions can be explained as a combination of explicit and implicit processes that are strongly influenced by pragmatic factors.

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REFERENCES

[1] Horn, L. T., 1989, A natural history of negation. Vasa, Chicago, IL: University of Chicago Press.

[2] Aristotle. In: J. Barnes, Ed., The complete works of Aristotle, Vols. 1 and 2, Princeton, NJ: Princeton University Press, 1984.

[3] Horn, L. T., and Ward,G., 2005, The handbook of pragmatics. Oxford, UK: Blackwell.

[4] DeMorgan, A., 1847, Formal logic or the calculus of inference necessary and probable. London, UK: Taylor & Walton.

[5] Evans, J. S. B. T., and Handley, S., 1999, The role of negation in conditional inference. The Quarterly Journal of Experimental Psychology; 52A(3): 739-769, 1999. doi: 10.1080/027249899391034.

[6] Khemlani, S. S., Orenes,I, and Johnson-Laird, P. N., 2012, Negation: A theory of its meaning, representation, and use. Journal of Cognitive Psychology; 24(5): 541–559. doi: 10.1080/20445911.2012.660913.

[7] Khemlani, S. S., Orenes, I., and Johnson-Laird, P. N., 2014, The negations of conjunctions, conditionals, and disjunctions. Acta Psychologica; 151: 1-7.doi: 10.1016/j.actpsy.2014.05.004.

[8] Macbeth, G., Razumiejczyk, E., Crivello, M., Bolzán, C., Pereyra Girardi, C., and Campitelli, G.,2014, Mental Models for the Negation of Conjunctions and Disjunctions. Europe's Journal of Psychology; 10(1): 135–149. doi:10.5964/ejop.v10i1.696.

[9] Orenes, I., Beltrán, D., and Santamaría, C., 2014, How negation is understood: Evidence from the visual world paradigm. Journal of Memory and Language; 74: 36-45. doi: 10.1016/j.jml.2014.04.001.

[10] Suppes, P., and Hill, S., 1992, First course in mathematical logic. Mineola, NY: Dover Publications.

[11] Politzer-Ahles, S., and Gwilliams, L., 2015, Involvement of prefrontal cortex in scalar implicatures: evidence from magnetoencephalography. Language, Cognition, and Neuroscience; 1-14. doi: 10.1080/23273798.2015.1027235

[12] Evans, J. S. B. T., and Stanovich, K. E.,2013a, Dual-process theories of higher cognition: Advancing the debate. Perspectives on Psychological Science; 8(3): 223-241. doi: 10.1177/1745691612460685.

[13] Evans, J. S. B. T., and Stanovich, K. E., 2013b, Theory and metatheory in the study of dual processing: Reply to comments. Perspectives on Psychological Science; 8(3): 263-271. doi: 10.1177/1745691613483774.

[14] Wason, P. C., and Johnson-Laird, P. N., 1972, Psychology of reasoning: Structure and content. Cambridge, MA: Harvard University Press.

[15] Johnson-Laird, P. N., 2006, How we reason. New York, NY: Oxford University Press.

[16] Johnson-Laird, P. N., 1983, Mental models: Towards a cognitive science of language, inference, and consciousness. Cambridge, NA: Harvard University Press.

[17] Johnson-Laird, P. N., 2010a, Mental models and human reasoning. Proceedings of the National Academy of Sciences; 107(43):18243-18250. doi:10.1073/pnas.1012933107.

[18] Turing, A. M., 1937, On cumputable numbers, with an application to the Entscheidungs problem. Proceedings of the London Mathematical Society; s2-42(1): 230-265. doi: 10.1112/plms/s2-42.1.230.

[19] Johnson-Laird, P. N., 2010b, Against logical form. Psychologia Belgica; 50(3&4): 193-221. doi: 10.5334/pb-50-3-4-193.

[20] Johnson-Laird, P. N., & Byrne, R. M. J., 1991, Deduction. Hillsdale, NJ: Lawrence Erlbaum Associates.

[21] Johnson-Laird, P. N., Khemlani, S. S., and Goodwin, G. P., 2015, Logic, probability, and human reasoning. Trends in Cognitive Sciences; 19(4): 201-214. doi: 10.1016/j.tics.2015.02.006.

[22] Juhos, C., Quelhas, A. C., and Byrne, R. M. J., 2015, Reasoning about intentions: Counterexamples to reasons for actions. Journal of Experimental Psychology: Learning, Memory, and Cognition; 41(5): 55-76. doi:10.1037/a0037274.

[23] Valiña, M. D., Seoane, G., Ferraces, M. J.,and Martín , M., 1999, The importance of pragmatic aspects in conditional reasoning. The Spanish Journal of Psychology; 2(1): 20-31. doi: 10.1017/S1138741600005424.

[24] Orenes, I., and Santamaría, C., 2014, Visual content of words delays negation. Acta Psychologica; 153:107-112. doi: 10.1016/j.actpsy.2014.09.013.

[25] Bott, L., and Noveck, I. A., 2004, Some utterances are underinformative: The onset and time course of scalar inferences. Journal of Memory and Language; 51(3): 437–457. doi: 10.1016/j.jml.2004.05.006.

[26] Tomlinson, J. M., Bailey, T. M., and Bott, L., 2013, Possibly all of that and then some: Scalar implicatures are understood in two steps. Journal of Memory and Language; 69(1): 18-35. doi: 10.1016/j.jml.2013.02.003.

[27] Sperber, D., and Wilson, D., 1986, Relevance: Communication and cognition. Oxford, UK: Basil Blackwell.

[28] Sperber, D., and Wilson, D., 1987, Précis of relevance: Communication and cognition. Behavioral and Brain Sciences; 10(4):697-754.doi: 10.1017/S0140525X00055345.

[29] Evans, J. S. B. T., and Over, D. E., 1996, Rationality and reasoning. Hove, UK: Psychology Press.

[30] Wilson, D., and Sperber, D., 1994, Outline of relevance theory. Links & Letters; 1: 85-106.

[31] Grice, H. P., Logic and conversation in Syntax and semantics 3: Speech acts. In P. Cole & J. L. Morgan, Eds. New York, NY: Academic Press, pp. 41-58, 1975.

[32] Grice, H. P., 1989, Studies in the way of words. Cambridge, MA: Harvard University Press.

[33] Levinson, S., 2000, Presumptive meanings: The theory of generalized conversational implicatura. Cambridge, MA: MIT Press.

[34] Evans, J. S. B. T., Clibbens, J., and Rood, B.,1996, The role of implicit and explicit negation in conditional reasoning bias. Journal of Memory and Language; 35(3): 392-409. doi: 10.1006/jmla.1996.0022.

[35] De Neys, W., Cromheeke, S., and Osman, M., 2011, Biased but in doubt: Conflict and decision confidence. Plos One; 6(1): e15954. doi: 10.1371/journal.pone.0015954.

[36] Rinne, L. F., and Mazzocco, M. M. M., 2014, Knowing wright from wrong in mental arithmetic judgments: Calibration of confidence predicts the development of accuracy. Plos One; 9(7): e98663. doi: 10.1371/journal.pone. 0098663.

[37] Singmann, H., Klauer, C. K., and Kellen, D., 2014, Intuitive logic revisited: New data and Bayesian mixed model meta-analysis. Plos One; 9(4): e94223. doi: 10.1371/journal. pone.0094223.

[38] Fox, K. C. R., Zakarauskas, P., Dixon, M., Ellamil, M., Thompson, E., and Christoff, K., 2012, Meditation experience predicts introspective accuracy. Plos One; 7(9): e45370. doi: 10.1371/journal.pone.0045370.

[39] Ackerman, R., and Thompson, V., Meta-reasoning: What can we learn from meta-memory. In: A. Feeney & V. Thompson, Eds., Reasoning as memory, Hove, UK: Psychology Press, pp. 164, 182., 2014.

[40] Thompson, V., Prowse-Turner, J., Pennycook, G., Ball, L. J., Brack, H., Ophir Y., and Ackerman, R., 2013, The role of answer fluency and perceptual fluency as metacognitive cues for initiating analytic thinking. Cognition; 128(2): 237-251. doi: 10.1016/j.cognition.2012.09.012.

[41] Metcalfe, J., 1986, Feeling of knowing in memory and problem solving. Journal of Experimental Psychology: Learning, Memory, and Cognition; 12(2): 288-194. doi: 10.1037/0278-7393.12.2.288.

[42] Thompson, V., Evans, J. S. B. T., and Campbell, J. I. D., 2013, Matching bias on the selection task: It's fast and feels good. Thinking and Reasoning; 19(3-4): 431-452. doi: 10.1080/13546783.2013.820220.

[43] Ball, L. J., Marsh, J. E., Litchfield, D., Cook, R. L., and Booth, N., 2015, When distraction helps: Evidence that concurrent articulation and irrelevant speech can facilitate insight problem solving. Thinking & Reasoning; 21(1): 79-96. doi: 10.1080/13546783.2014.934399.

[44] Macbeth, G., Razumiejczyk, E., and Campitelli, G., 2013, The abstraction effect on logic rules application. Education Sciences and Psychology; 2(24): 85-96.

[45] Schurz, G., 2014, Cognitive success: Instrumental justification of normative systems of reasoning. Frontiers in Psychology; 5(625): 1-16. doi: 10.3389/fpsyg.2014.00625.

[46] Markovits, H., 2014, Development and necessary norms of reasoning. Frontiers in Psychology; 5(488): 1-10. doi: 10.3389/fpsyg.2014.00488.

[47] Stupple, E. J. N., and Ball, L. J., 2014, The intersection between Descriptivism and Meliorism in reasoning research: further proposals in support of 'soft normativism'. Frontiers in Psychology; 5(1269): 1-13. doi: 10.3389/fpsyg.2014.0126 9.

[48] Stupple, E. J. N., Ball, L. J., Evans, J. S. B. T., and Kamal-Smith, E., 2011, When logic and belief collide: Individual differences in reasoning times support a selective processing model. Thinking & Reasoning; 23(8): 931-941. doi: 10.1080/20445911.2011.589381.

[49] Rammstedt, B., and John, O. P., 2007, Measuring personality in one minute or less: A 10-item short version of the Big Five Inventory in English and German. Journal of Research in Personality; 41: 203-212.doi: 10.1016/j.jrp.2006.02.001.

[50] Cliff, N., 1993, Dominance statistics: Ordinal analyses to answer ordinal questions. Psychological Bulletin; 114(3): 494-509. doi: 10.1037/0033-2909.114.3.494.

[51] Macbeth, G., Razumiejczyk, E., and Ledesma, R., 2011, Cliff's Delta Calculator: A non-parametric effect size program for two groups of observations. Universitas Psychologica; 10(2): 545-555.

[52] Romano, J., Kromrey, J. D., Coraggio, J., Skowronek, J., and Devine, L., 2006, Exploring methods for evaluating group differences in the NSSE and other surveys: Are the t-test and Cohen's d indices the most appropriate choices?, Paper presented at the Southern Association for Institutional Research, Arlington, VA.

[53] Kahneman, D., and Tversky, A., 2000, Choices, values, and frames. Cambridge, MA: Cambridge University Press.

[54] Macbeth, G., and Razumiejczyk, E., 2008, Debiasing overconfidence bias in verbal tasks. Anales de Psicología; 24(1): 143-149.

[55] Beltrán, D., Orenes, I., and Santamaría, C. , 2008, Context effects on the sponteneous production of negation. Intercultural Pragmatics; 5(4): 409-419. doi: 10.1515/IPRG. 2008.020.

[56] Johnson-Laird, P. N., 2001, Mental models and deduction. Trends in Cognitive Sciences; 5(10): 434-442. doi: 10.1016/S1364-6613(00)01751-4.

[57] Rips, L. J., 1994, The psychology of proof. Cambridge, MA: MIT Press.

[58] Rips, L. J., 2011, Lines of thought: Central concepts in cognitive psychology. New York, NY: Oxford University Press.

[59] Macbeth, G., and Morán, V., 2009, Underconfidence bias as a specific-domain phenomenon. Revista Latinoamericana de Psicología; 41(1): 47-57.

[60] Trippas, D., Handley, S. J., and Verde, M. F., 2014, Fluency and belief bias in deductive reasoning: new indices for old effects. Frontiers in Psychology; 5(631): 1-7. doi: 10.3389/fpsyg.2014.00631.

[61] Politzer-Ahles, S. and Fiorentino, R., 2013, The realization of

scalar inferences: Context sensitivity without processing cost., Plos One; 8(5): e63943. doi:10.1371/journal.pone.0063943.

[62] Kahneman, D., 2001, Thinking, fast and slow. New York, NY: Farrar, Straus, and Giroux.

[63] Elqayam, S., and Over, D. E., 2013, New paradigm psychology of reasoning: An introduction to the special issue edited by Elqayam, Bonnefon, and Over. Thinking & Reasoning; 19(3): 249-265. doi: 10.1080/13546783.2013.841 591.

[64] Macbeth, G., Razumiejczyk, E., Crivello, M., Fioramonti, M., and Pereyra Girardi, C., 2013, The shallow processing of logical negation. Psychology and Behavioral Sciences; 2(5): 196-201. doi: 10.11648/j.pbs.20130205.15.

[65] Evans, J. S. B. T., 1972, Interpretation and matching bias in a reasoning task. British Journal of Psychology; 24(2): 193–199. doi: 10.1080/00335557243000067.

[66] Evans, J. S. B. T., 1996, Decide before you think: Relevance and reasoning in the selection task. British Journal of Psychology; 87: 223-240.

[67] Evans, J. S. B. T. , 1998, Matching bias in conditional reasoning: Do we understand it after 25 years?. Thinking & Reasoning; 4(1): 45-82. doi: 10.1080/135467898394247.

[68] Evans, J. S. B. T., and Curtis-Holmes, J., 2005, Rapid responding increases belief bias: Evidence for the dual-process theory of reasoning. Thinking & Reasoning; 11(4): 382-389. doi: 10.1080/13546780542000005.

[69] Evans, J. S. B. T., and Lynch, J. S., 1973, Matching bias in the selection task. British Journal of Psychology; 64(3): 391-397. doi: 10.1111/j.2044-8295.1973.tb01365.x.

[70] Stupple, E. J. N., Ball, L. J., and Ellis, D., 2013, Matching bias in syllogistic reasoning: Evidence for a dual-process account from response times and confidence ratings. Thinking & Reasoning; 19(1): 54-77. doi: 10.1080/13546783 .2012.735622.

[71] Sevenants, A., Dieussaert, K., and Schaeken, W., 2011, Truth table tasks: Irrelevance and cognitive ability. Thinking & Reasoning; 17(3): 213-246. doi: 10.1080/13546783.2011.569 153.

[72] Ball, L. J., Lucas, E. J., Miles, J, N, V., and Gale, A. G., 2003, Inspection times and the selection task: What do eye-movements reveal about relevance effects? Quarterly Journal of Experimental Psychology; 56A: 1053–1077. doi: 10.1080/02724980244000729.

[73] Evans, J. S. B. T., and Ball, L. J., 2010, Do people reason on the Wason selection task? A new look at the data of Ball et al. (2003). The Quarterly Journal of Experimental Psychology; 63(3): 434-411. doi: 10.1080/17470210903398147.

[74] Ferguson, H. J., Sanford, A. J., and Leuthold, H., 2008, Eye-movements and ERPs reveal the time course processing negation and remitting counterfactual worlds. Brain Research; 1236: 113-125. doi: 10.1016/j.brainres.2008.07.099.

[75] van Rejn, H., Dalenberg, J. R., Borst, J. P., and Sprenger, S. A., 2012, Pupil dilation co-variates with memory strength of individual traces in a delayed response paired-associate task. Plos One; 7(12): e51134. doi: 10.1371/journal.pone.0051134.

[76] Wilkinson, M., Ball, L. J., and Alford, D., 2015, Counterfactual reasoning for regretted situations involving controllable versus uncontrollable events: The modulating role of contingent self-esteem. Advances in Cognitive Psychology; 11(1): 22-30. doi: 10.5709/acp-0168-4.