

On the non-incremental processing of negation: A pragmatically licensed sentence-picture verification study with Italian (dyslexic) adults

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Abstract

This paper reports the results of two ERP studies that have been conducted with the following aims: (i) the aim of assessing the evidence for non-incremental models of negation processing (Kaup et al. (2006), (2007)), particularly in the version based on the Two Step Simulation Hypothesis (Lüdtke et al. (2008)), and (ii) the aim of assessing possible differences in the processing of negation between normally-developed and dyslexic adults. The results that emerge from the behavioral data and from the statistical elaboration of the collected EEG data concerning normally-developed adults provide substantial confirmation for the existence of a first stage of processing in which negation is still not integrated (thus for a non-incremental model of negation processing), though they also suggest that the mental representations created at the different stages of processing are dynamically compared in the course of the whole process rather than being sequentially produced and suppressed. Though no well-known ERP effect emerges with adult dyslexics, the EEG data strongly suggest that negation processing by adult dyslexics follow a completely independent route with respect to normally-developed adults, which dispenses with sentence-picture priming effects but finally results in a functionally less effective processing strategy, as also confirmed by the behavioral data (i.e. higher reaction times and lower accuracy rates).

Mots clés: *Non-incremental processing of negation, sentence-picture matching effects, ERP correlates of polarity and truth-value, non-sequential interpretation of negation, dyslexia and negation*

1. Background and Rationale of Our Two Studies

The Two Step Simulation Hypothesis (TSSH) is a specific implementation of the experiential/simulation view of language comprehension, according to which language processing recruits non-linguistic cognitive processes, based on the increasing evidence that there is substantial neural pathway overlap between the verbal representation of a situation and the perception or the motor

enactment of the same situation (cf. a.o. Pulvermüller 2002, Ghio & Tettamanti 2010, Tettamanti & Buccino 2005). This hypothesis is particularly interesting when considered from the perspective of the long-standing debate on the *dual code theory of mental representations* (Paivio 1991), which puts a special emphasis on the similarities between *pictorial* and *verbal* encoding of thought. On the other hand, the view that concepts are mental pictures of things has been heavily criticized (Fodor & Pylyshyn 2015). The criticism concerns the fact that certain things cannot be pictured, the fact that the semantics of perceptions and beliefs cannot be expressed in images (cf. particularly discussion of the so-called 'black swan argument'), and the fact that the topography of images and concepts is different (images can be decomposed into parts but not into constituents, warranting recursive rules for the expression of more complex constituents).

In Kaup et al. (2006, 2007), the view is that the processing of negation involves the commitment to two distinct temporal stages, one corresponding to constructing the mental representation of the negated situation, the second corresponding to the simulation of the actual meaning of the negative sentence. This immediately provides an account for the more costly processing of negative sentences and also, perhaps more significantly, for the difference in behavioral measures (accuracy rates and reaction times) which has been regularly found between true negative and false negative sentences in sentence-picture verification tasks, whereby true negatives turn out as more difficult to process (Kaup & Ludtke 2008 and Vender & Delfitto 2010). A first potential criticism of the TSSH is based on the suppressive effect of negation on the accessibility of the concepts in the scope of negation (MacDonald & Just 1989, Giora et al. 2004). However, in absence of precise data concerning the dynamics of suppression effects, it is not clear that suppression represents direct counter-evidence for the two-stage model of interpretation advocated by the TSSH. Another important objection to the TSSH is that negative sentences are not more costly to process than corresponding affirmatives whenever they are uttered in a supportive context, that is, when pragmatic felicity conditions are met (cf. the literature on plausible denial). Even in this case, however, it may be claimed that less costly processing in supportive contexts is in fact a predictable consequence of the TSSH, since a supportive context easily translates into facilitating conditions for the simulation of the negated state of affairs, which is somehow made perceptually or verbally salient in supportive contexts.

In Lüdtke et al. (2008) the search for evidence for a non-incremental analysis of negation is based on a sentence-picture verification task used to investigate ERP correlates during and after

sentence reading. The sentence-picture verification task involved 17 normally-developed German undergraduates, who were presented 320 experimental items organized in 4 conditions: True Affirmative (TA), False Affirmative (FA), True Negative (TN) and False Negative (FN). On each trial, the sentences were visually presented to the subject, followed by the visual presentation of the picture, with a varying Stimulus Onset Asynchrony (SOA): 160 items were presented according to a short-delay condition (SOA=250 ms) and 160 items according to a long-delay condition (SOA=1500 ms). In this setting, the truth-value of the sentence can only be determined in relation to the following picture. To briefly exemplify on the negative conditions, in the case of a FN sentence, the subject was visually presented the image of a tower in front of which there is a ghost and the sentence "In front of the tower there is no ghost".

In the case of a TN sentence, the image portrayed a lion in front of a tower and the subject read the sentence "In front of the tower there is no ghost". The ERP measures highlighted 3 main EEG effects. First, the authors interpret the enhanced negativity starting 250ms after the onset of negation (i.e. the negated noun in their German protocol) as evidence that negation is recorded very early by the subject. Second, they interpret the posterior late positive shift starting 550ms after the picture onset as a P600 effect, roughly reflecting the process associated with the planning of the verification task, i.e. the computation of the truth-value associated with the sentence, with an enhanced late positivity observed with negative sentences. However, the really important (and by far less controversial) result concerns a robust association of N400 effects with both truth-value and polarity, that is, a significant Negation-by-Truth value interaction. With affirmative sentences, N400 effects were enhanced in the false condition ("In front of the tower there is a ghost", associated with an image in which there is a lion in front of the tower), whereas with negative sentences, the N400 amplitude was larger in the true condition ("In front of the tower, there is no ghost", associated with an image where there is a lion in front of the tower).

These results are easily amenable to an interpretation according to which the picture processing is primed in true positive and false negative sentences (in which the referent of the noun in the sentence matches the entity represented in the picture), whereas the absence of this priming effect slows down processing in the other two conditions. In turn, this squares with the hypothesis that there exists a stage of interpretation of negative sentences in which negation is still not integrated: the matching effect between sentence and picture observed in false negatives is predicted only under the condition that it is the negated state of affairs (i.e. the semantic content of the sentence

without negation) that primes the processing of the picture, providing a plausible confirmation of the non-incremental analysis of negation endorsed by the TSSH.

Lüdtke et al.'s study has some evident limits. The first shortcoming concerns the fact that a full interpretation of the sentence is actually not required, since, as we already observed above, the priming effects (and the associated N400 amplitudes) may be simply triggered by a noun/entity (a)symmetry (the referent of the last word in the sentence vs. the entity depicted in the image). More importantly, we should notice that the N400 effect, initially found in cases of anomalous sentence completion (as in "The pizza was too hot to eat" vs. *drink), is reported to be sensitive to predictive processing and is generally interpreted as a measure of the effort required for accessing and integrating the meaning of the processed stimulus within the current semantic context.

Unfortunately, this entails that the larger N400 amplitudes detected with true negatives might simply reflect the pragmatic infelicity of the two conditions that give rise to larger N400 amplitudes, since both false affirmatives and true negatives can be analyzed as the denial of a state of affairs that is neither introduced by previous linguistic stimuli nor recovered by the following picture (cf. Nieuwland & Kuperberg 2008). This is thus a typically unresponsive context for negation, that is, a context in which the conditions for plausible denial are not satisfied. Clearly, the methodological issue that arises here is whether the experiment can be replicated in a form that makes pragmatic infelicity a less straightforward candidate for the detected N400 effects, favoring thus an interpretation of the ERP results in terms of a compelling two-stage interpretation of negative sentences.

Nieuwland & Kuperberg (2008) conducted an ERP study that is intended to investigate the difference between supportive and unresponsive contexts in the processing of negation. Their protocol is a sentence-verification task based on the construction of pragmatically felicitous and pragmatically infelicitous sentences, regularly preceded by a uniform introductory statement. For instance, in the case of the TN condition, the felicitous sentence could be something as "With proper equipment, scuba-diving isn't very dangerous and often good fun", whereas the infelicitous sentence could take the form of "With proper equipment, bulletproof vests aren't very dangerous and used worldwide for security". In a nutshell, the result showed that for pragmatically felicitous sentences, only truth-value, and not polarity, plays a role in the modulation of the N400 effects. In other words, false sentences were found to enhance the N400 amplitude irrespective of whether they were affirmative or negative.

Conversely, pragmatic infelicity was found to give rise to a generalized enhancement of the N400 amplitude with negative sentences, both true and false. As a conclusion, the authors claim that the Polarity by Truth-value effects that have been taken by Lüdtke et al. (2008) as showing that the modulation of N400 in negative sentences supports a non-incremental analysis of negation simply are not found in supportive contexts. They claim that the enhanced N400 amplitude found with true negatives in Lüdtke et al.'s experiment was a consequence of difficult semantic integration due to the presence of an unresponsive context rather than a consequence of the absence of priming of the sentence on the picture.

We contend that Nieuwland & Kuperberg's criticism is not conclusive, for the very reason that their experimental protocol has as strong methodological flaws as Lüdtke et al.'s. First of all, the experimental paradigm is by far less rich than Lüdtke et al.'s: in particular, the recourse to a sentence verification task, based on the truth-value of world-related statements, makes it impossible, by definition, to temporally distinguish between the processing of the linguistic stimuli (crucially including negation) and the phase of sentence verification. More importantly, the attempt at attaining pragmatic felicity by means of an introductory statement strongly influences the predictability of false sentences, inducing thus a bias towards true sentences. This asymmetry in the naturalness of the experimental conditions might have been an important determinant of the ERP measures.

2. Our First Study: Negation Processing in a Sentence-Picture Verification Task with Normally-Developed Adults

Our first experimental design was intended to replicate Lüdtke et al.'s (2008) while overcoming the major limitations of the original experimental paradigm. In particular, we opted for a complex visual scene in order to establish on a more solid methodological basis if the ERP correlates of the activation of the negated state of affairs persists even (i) in absence of simple lexical level priming effects and (ii) in a more pragmatically felicitous situation. The sentence-picture verification task comprises a group of normally-developed Italian adults (mean age 27:6), who were presented 240 stimuli, organized in the usual 4 conditions (60 items each condition), giving rise to 4 counterbalanced lists.

The paradigm involves the use of 30 transitive verbs and 30 pairs of characters. The visual stimulus was presented on the screen for 350ms, 250ms after presentation of the verbal stimulus. Subjects were instructed to evaluate the semantic coherence between the sentence

and the picture with a yes/no answer. Each participant was tested individually in the *Brain Vision Lab* of the *Dipartimento di Scienze Neurologiche e del Movimento* of the University of Verona. Here is an illustration of the way in which the selected visual scene determines the assignment of different truth-values to the 4 sentences (corresponding to the 4 conditions):


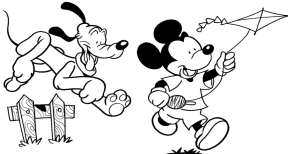
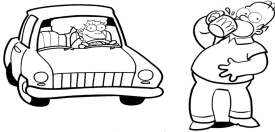

<i>Sentence</i>	<i>Picture</i>
<p><i>True affirmative (TA)</i> <i>Minnie sta tagliando delle carote.</i> 'Minnie is cutting carrots'.</p>	
<p><i>False affirmative (FA)</i> <i>Topolino sta saltando un recinto.</i> 'Micky Mouse is jumping a fence'.</p>	
<p><i>True negative (TN)</i> <i>Homer non sta guidando la macchina.</i> 'Homer is not driving the car'.</p>	
<p><i>False negative (FA)</i> <i>Aladdin non sta chiudendo la porta.</i> 'Aladdin is not closing the door'.</p>	

Figure 1 : Experimental conditions

2.1. Results

The behavioral results confirm the Polarity by Truth-value effect detected in Lüdtke et al.'s study. More particularly, accuracy rates

were differently affected by sentence truth-value depending on polarity, with false affirmatives and true negatives giving rise to higher error rates, as seen above. A comparable effect was detected for the average reaction times, though this effect presented a clear asymmetry between positive and negative sentences, being extremely tiny for the negative condition.

ERP extraction was performed through the *Fieldtrip* software (Oostenveld and Fries 2011). Three major effects were calculated: (i) A *match/mismatch* effect (NT+AF)-(NF+AT), based on the difference between (a) the sum of the wave averages of the true negative and the false affirmative sentences and (b) the sum of the averages of the negative false and affirmative true sentences; (ii) A *polarity effect*, based on the differential waves between negative and affirmative conditions: (NT+NF)-(AT+AF); (iii) A *truth-value effect*, calculated as the differential waves between the true and false conditions: (AT+NT)-(AF+NF). The EEG data provide a rather solid confirmation of the behavioral data. In fact, the negative deflections that were observed at posterior sites in the time interval between 400 ms and 600ms after the sentence were actually modulated by the match/mismatch effect, resulting in a larger negative shift for false affirmative and true negative sentences.

Quite significantly, the negative shift was not simply modulated by the presence/absence of negation, confirming thus one of the major insights in Lüdtke et al.'s study. On the basis of the qualitative analysis of grand averages and effects, the following three time-windows were selected: TW1: 400-600ms, characterized, as just seen, by the polarity by truth-value interaction (*match-mismatch* effect); TW 2: 600-1000ms, showing a negative deflection for negative sentences (*polarity* effect), together with the emergence of a truth-value related left anterior-negativity; TW3: 1000-1400ms, characterized by a more sustained left-anterior negativity for true sentences in comparison with false sentences (*truth-value* effect).

2.2. Discussion

A first difference between our results and those in Lüdtke et al. 2008 concerns the negligible difference in reaction times (though not in accuracy rates) between false and true negative sentences that emerged from the behavioral data derived from our study. We suggest that this result might be an artifact of the adopted experimental design. On one side the richer visual scene, containing two distinct characters and two distinct activities, arguably ensures that priming between sentence and picture be not reduced to lexical priming or to non-linguistic shortcut strategies, and also prevents

pragmatic infelicity (roughly due to the relevance of asserting or denying something about one character or activity with respect to the other visually salient character or activity).

On the other side, however, the complex visual scene creates a perceptual complexity that is not present in Lüdtke et al.'s design. Though a split of the character and activity mentioned in the sentence into two separated elements within the following picture is only a property of true negative sentences, and not of false negative sentences, the perceptual assessment necessary for a global felicitous evaluation of the verbal stimulus remains fairly complex also for false negatives. It is thus possible that the difference in reaction times between TN and FN that is predicted under the TSSH as an effect of the sentence/picture matching be simply obliterated under these experimental conditions, given to the intervention of independent factors of processing difficulty. If this line of analysis is correct, we might conclude that what is required in order to obtain relevant ERP data necessarily translates, methodologically, in a more complex experimental setting that complicates the assessment of the behavioral data.

The data emerging from the EEG analysis, though not exactly replicating Lüdtke et al.'s findings, can be fairly taken to confirm a two-stage based processing of negation. Firstly, the negative amplitudes measured at the first stage of sentence processing (400-600ms) clearly represent a Polarity by Truth-value effect. More exactly, the fact that FA and TN pattern together (as in Lüdtke et al.'s study) can be interpreted as a signature of the first step in processing hypothesized by Kaup and colleagues, during which subjects engage in the simulation of the non-negative state of affairs, i.e. as a rough equivalent of the N400 effect that was assumed to support the TSSH. On the other hand, the persistence of this Polarity by Truth-value effect across the following time-window (600-1000ms), during which this effect was accompanied by the emergence of an anterior left truth-value effect, might be taken as evidence for a slightly different model of processing of negation, in which the activation of the non-negative state of affairs is not suppressed right away after the first-stage is completed, but is maintained while processing proceeds to integrate negation. In other words, though our EEG data confirm the presence of a stage of interpretation preceding the integration of negation into the structure, they seem to support a model in which the interpretation of negative sentences does not rely on a strictly sequential two-stage process but rather consists in the progressive simulation of the two stages envisaged by the TSSH, which become simultaneously available starting from 600ms after picture onset.

A further confirmation for this model is provided by the observation that the negative deflection observed in the first time-window (400-600ms) is accompanied, within the same time interval, by the emergence of a polarity effect, characterized by a different topographic distribution than N400, clearly distinguishing between sentences of different polarity in spite of the relevance of the same pattern registered in Lüdtke et al.'s study, according to which the negative deflection is larger with FA and TN, independently of polarity. It should also be emphasized that we did not find any parietal late-positivity deflection, which was taken by Lüdtke et al. as a signature of the process of integration of negation corresponding to the second stage envisaged by the TSSH. However, we can fairly say that evidence for the late integration of negation is provided in our study by the emergence of a polarity effect, in terms of a truth-value related negativity at the left anterior electrodes, within the second time-window (600-1000ms), a process that starts manifesting itself within the first time-window, as just emphasized.

To sum up, our study can be considered a successful replication of Lüdtke et al.'s findings. Its main result consists in the observation that, even when the priming effects envisaged by the TSSH are controlled for (non-linguistic) task-specific shortcut strategies and the experimental conditions are controlled for pragmatic infelicity, negative sentences seem to require a costly non-incremental two-stage processing. Contra Nieuwland & Kuperberg (2008), we have provided some confirmation that the N400 deflection detected in sentence-picture verification tasks stems from a robust Polarity by Truth-value effect, as predicted by the TSSH, thus indirectly corroborating the TSSH.

3. Our Second Study: Negation Processing in a Sentence-Picture Verification Task with Adult Dyslexics

Our second experimental design was intended to provide at least some preliminary results on the processing of negation in communicatively impaired subjects, in particular adult dyslexics. Due to space limitations, we will limit ourselves to a sketchy presentation. The choice of dyslexic subjects is motivated by the interplay between two distinct hypotheses: (i) the TSSH entails that sentential negation is based on a relatively complex processing strategy, based on the evaluation and comparison of two different representations (corresponding to the simulation of the negated state of affairs and of the actual state of affairs); (ii) dyslexics suffer either from a deficit affecting the procedural memory system (as in Fiorin 2010, adopting Ullman's Declarative/Procedural Model, cf. Ullman 2001) or from

serious limitations in their working memory, hampering both their phonological competence and their executive functions (as in Vender 2011).

Our experimental hypothesis was that these deficits in procedural memory or in phonological and executive working memory exert a significant influence on the way dyslexics process negative sentences. More particularly, we predict that the TSSH involves the application of working memory resources that might not be available to dyslexics, who may thus interpret negative sentences according to alternative less demanding processing strategies. A group of 15 adults took part in the study (mean age 22;4), which consisted of two sessions, one including a series of behavioral tests concerning subjects' writing and reading skills and working memory capacity, the other designed to test the subjects' comprehension of negative sentences through the same sentence-picture verification task used in our first study. More particularly, the writing and reading skills were tested by means of the *Battery for the Assessment of Reading and Writing in Adulthood* (Re et al. 2011), whereas working memory was assessed through five tests evaluating the functionality of the three components in which the working memory capacity is most commonly analyzed: phonological short-term memory, visuo-spatial short-term memory, and central executive functions. The group of normally-developed adults that participated in the first study was used as a control group in the second study.

3.1. Results

As for the behavioral measures, both accuracy and reaction times were submitted to a 2 (polarity) \times 2 (truth-value) analysis of variance (ANOVA). What is particularly significant, from the perspective of the results obtained in the first study, is the observation that the Polarity by Truth-value interaction had a significant influence on both accuracy [$F(1, 12) = 11.108, p \leq .01$] and reaction times [$F(1, 12) = 7.679, p \leq .05$], reflecting the well-known gradient of difficulty between our four conditions: TA > FA > FN > TN. However, dyslexics showed slower response times and higher error rates in all conditions in comparison with control subjects, indicating that the former experienced more difficulty in the execution of the experimental task as a whole with respect to the latter, and not only in the verification of the negative sentences.

In order to verify the influence of working memory on negative sentence processing hypothesized by Vender & Delfitto (2010) and Vender (2011), we carried out a linear regression analysis with working memory measures as independent variables and the behavioral performance (accuracy, reaction times) in the picture-

sentence verification task as dependent variables. We found that both accuracy and reaction times (for all four experimental conditions) significantly relate, to some extent, to phonological working memory (predictors: *digit span forward*, *digit span backward*). The relevant results are reported in the table below. However, as shown by the very low R^2 values, we can fairly conclude that working memory accounts only for a limited amount of the variance in the subjects' behavioral performance.

Dependent Variable		R^2	t	p-value
Accuracy	True Aff	.180	20.504	$\leq .001^*$
	False Aff	.223	18.683	$\leq .001^*$
	True Neg	.207	11.159	$\leq .001^*$
	False Neg	.305	15.718	$\leq .001^*$
RT	True Aff	.172	6.496	$\leq .001^*$
	False Aff	.149	6.460	$\leq .001^*$
	True Neg	.163	5.719	$\leq .001^*$
	False Neg	.292	6.760	$\leq .001^*$

Table 1: Linear regression analysis with phonological working memory (*digit span forward and backward*) as predictor.

As for the EEG analysis, we adopted the same method used for EEG extraction, epoch rejection and grand averages calculation used in the first study. The visual inspection of the grand averages was driven by the comparison with the three main effects observed with non-dyslexic subjects in our first study: the *match-mismatch* effect, the *polarity* effect, and the *truth-value* effect. The most evident ERP effect consists in the early emergence of a *polarity* effect in the dyslexic group, starting from about 400ms after the onset of the picture and reflecting the large and sustained negativity elicited by the negative true condition with respect to all the other three conditions. This effect appears to have a rather frontal focus, maximal on anterior left sites, but it is also evident over posterior sites where, for the control group, the N400-like effect developed in the same time window, but with a more posterior and bilateral distribution.

3.2. Discussion

As already mentioned, the statistical analysis of the behavioral data showed that dyslexics, though reflecting the same hierarchy of

difficulty among the four conditions that was detected for normally-developed subjects, had a significantly worse performance in all conditions, not only in the negative conditions. This suggests that our results cannot provide any direct confirmation of Vender & Delfitto (2010) and Vender (2011) claim that negation constitutes a specific source of processing difficulty for dyslexic children, though it should be emphasized that our study concerns dyslexic adults and not dyslexic children. The analysis of the ERPs elicited in the dyslexic subjects by the sentence-picture verification task, though not able to provide direct information on the processing of negation in dyslexics, clearly pointed to some major differences between dyslexics and normally-developed subjects. In particular, while in the control group the first processing stages appeared to be determined by the match-mismatch effect between the sentence and the picture, eliciting a negative deflection whose specific modulation (a larger effect with FA and TN conditions) is clearly reminiscent of the N400 component that was taken in Lüdtke et al.'s study as a confirmation of the predictions made by the TSSH, the dyslexic group manifested different ERP effects for affirmative and negative conditions already in the very first stage of processing.

More precisely, true negative sentences were found to elicit a long standing broadly distributed negativity (emerging about 400ms after picture onset and presenting its maximal amplitude at frontal sites) in comparison with false negative sentences, whereas no similar effects were found when the picture followed affirmative sentences. Though this effect is hard to qualify in terms of well-known ERP components, the complete absence of the N400 match-mismatch effect for affirmative sentences, as well as the anterior distribution of the effect and its sustained latency, suggests that the effect may represent an instance of the *anterior sustained negativity* typically associated, in the ERP literature, to interpretive difficulties, conceptual violations and, more in general, to discourse model elaboration. Both the early difference between affirmative and negative sentences and the difference between true and false negative conditions may be taken to suggest that dyslexic subjects interpret negative sentences by relying on completely different cognitive processes with respect to those predicted by the TSSH.

This confirms the insight that ERP techniques can sometimes not only improve but also correct behavioral results (cf. a.o. Poeppel & Omaki 2008): in our case, though behavioral results do not warrant the conclusion that negative sentences represent a really significant source of processing difficulty for dyslexics, the ERP findings show that this might be due to the choice of some compensatory processing strategy, by means of which dyslexics try to reduce the working

memory load required by keeping distinct representations/simulations of the sentence in their working memory buffer, as the TSSH would force them to do. In fact, the emergence of a *truth-value* effect in the second and third time windows indicates that the dyslexic participants did actually manage to process the truth-value of the sentence (as indeed confirmed by the above-chance accuracy level). However, the significant difference in both accuracy and reaction times between dyslexic and normally-developed subjects may be reasonably taken to imply that the alternative strategy adopted by the dyslexic group in the interpretation of negative sentences is functionally less effective than the one used by the control group and does not suffice to compensate for the working memory deficit underlying dyslexia.

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