UNIVERSITA' DEGLI STUDI DI VERONA
Dipartimento di Filologia, Letteratura e Linguistica
Scuola di Dottorato in Studi Umanistici
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On the processing of sentential negation in dyslexic adults. An ERP study.

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Coordinatore:
Prof.ssa Birgit ALBER

Tutor:
Prof. Denis DELFITTO

Co-tutor:
Prof.ssa Silvia SAVAZZI
Prof. Francesco VESPIGNANI

Dottorando:
Maria SCAPPINI

A tutte le persone per cui vorrei avere più tempo

Contents

Part 2: The present study

Abstract

The present work aimed at dealing with two main issues: (a) to contribute to the broad debate on the processing of negation trough an ERP investigation of negative sentences processing in Italian adults, still lacking in the literature on the topic; and (b) to provide further evidence and deepen analysis of dyslexics' difficulty in the comprehension of orally presented negative sentences. To these purposes, the results of two behavioral preliminary studies and two main EEG-ERP studies (STUDY 1 and STUDY 2) are presented.

The two preliminary studies involved a group of 10 adults (mean age 27;9) and a group of 33 Italian children (mean age 9;4). These two studies were principally intended to assess the experimental settings of the protocol and to evaluate its suitability for the performance of an EEG study with the two different populations. Besides having led to important adjustments in the experimental design, the results of the preliminary studies showed the difficulty of involving children in an EEG study of the type planned. As a consequence, the two EEG studies subsequently performed exclusively involved adult participants.

As mentioned, STUDY 1 aimed at contributing to the broad debate on the interpretation on negation. In particular, it was intended to provide further confirmation to the non-incremental account, according to which the interpretation of negative sentences (e.g. *The boy is not running*) inherently differs from the interpretation of other linguistic structures, in that it requires the comprehender to construct two different, subsequent mental simulations: a first representation corresponding to the negated state affairs (i.e., a boy who is running), and a second referring to the actual, negative meaning of the sentence. This latter proposal is in contrast with alternative incremental approaches, according to which the processing of negative sentences does not intrinsically differ from that of affirmative sentences, except than for higher pragmatic sensitivity, which would determine longer processing times in all cases in which the negative sentence to be interpreted is not presented in adequately supportive linguistic contexts – as it mostly happens in experimental paradigms. Recently, two main EEG studies have been performed with the purpose of providing a more precise insight into the temporal dynamics of negation processing. Lüdtke, Friedrich, Filippis, & Kaup (2008) analyzed ERP effects associated with the execution of a sentence-picture verification task including both true and false affirmative and negative sentences. The results showed that the early stages of negative sentences verification are not influenced by the actual meaning of the sentence, but rather by the matching/mismatching between the picture content (e.g., a ghost in front of a tower) and the entity mentioned in the preceding sentence, resulting in larger N400 amplitudes for non-priming conditions (i.e., false affirmative and true negative sentences, e.g., *In front of the tower there is a lion/there is no lion*) than for priming conditions (i.e., true affirmative and false negative sentences, e.g., *In front*

of the tower there is a ghost/there is no ghost). The fact that the entity mentioned in the sentence was not always depicted in the picture, however, determined a sense of pragmatic infelicity, possibly affecting event-related potentials in all cases in which the sentences involved predication about an entity not relevant to the following picture. To avoid this kind of influence, Nieuwland & Kuperberg (2008)'s ERP study focused on the interpretation of pragmatically licensed sentences, that is, affirmative and negative sentences introduced by a simple proposition restricting the conditions of validity of the target statement (e.g., *With proper equipment, scuba diving is/is not very dangerous and often good fun*). In this latter study, N400 amplitudes reflected the actual sentences' truth-value, reporting larger N400 amplitudes for false conditions than for true conditions, regardless of sentence polarity. Far from constituting a neutral discourse context, however, the short propositions inserted with the aim of ensuring pragmatic licensing determined a strong expectation for true sentences and, consequently, a sense of unnaturalness for false sentences that might represent the main cause of N400 amplitudes. In addition, the use of sentences related to general world-knowledge did not allow the experimenters to temporally and functionally distinguish the cognitive activity connected with the processing of the strictly linguistic material from that determined by truth-value evaluation, both crucially associated to N400 component. On the basis of these considerations, STUDY 1 aimed at replicating Lüdtke et al. (2008)'s findings through a sentence-picture verification task arguably free from the pragmatic infelicity characterizing that previous study. A group of 27 Italian adults (mean age 27;6) took part in STUDY 1. The behavioral and EEG results are mainly consistent with the non-incremental models of negation processing. In particular, the first stages of sentence verification were characterized by a N400 modulations very similar to that observed by Lüdtke and colleagues, revealing no initial sensitivity to negation. Importantly, the adoption of a pragmatically controlled design prevented the effect from being influenced by the simple priming between the picture and the sentence. In the following time windows, in addition, the emergence of electrophysiological components reflecting the *truth-value* and *polarity* effects provided important evidence of the successful integration of the negative meaning into the interpretative process.

The STUDY 2 extended the investigation to a group of Italian dyslexic adults (15 subjects, mean age 22;4). The non-dyslexic participants of the STUDY 1 were included as control group. The rationale for the involvement of dyslexic subjects was provided by previous behavioral studies reporting increased difficulty in the interpretation of negative sentences by Italian dyslexic children (Vender & Delfitto, 2010) and adults (Rizzato, Scappini, Cardinaletti, 2014) in comparison with non-dyslexic peers. In order to verify Vender (2011) hypothesis, according to which the dyslexics' difficulties in the spoken language comprehension may depend on their poor working memory capacity, a series of working memory tests were also included in the experimental protocol for this second study. The results of these latter tests highlighted significantly weaker phonological working memory in the dyslexic subjects in comparison with non-dyslexic controls. The analysis of the sentence-picture task performance showed an overall slowdown and poorer accuracy for dyslexic subjects in comparison with controls, suggesting that the dyslexics experienced more troubles in all conditions, most likely deriving from the working memory load associated with the execution of the experimental task. Although the negative sentences were characterized by slower response times and higher error rates than affirmative sentences, the performance resembled that observed in the control group. Therefore, no confirmation of specific difficulty in the interpretation of negative sentences by dyslexic subjects was reported. Contrary to Vender (2011), in addition, no clear evidence of working memory involvement in negative sentences interpretation was found. The analysis of the ERPs and, in particular, the observation in the dyslexic group of (a) a crucial lack of the N400 effect characterizing the first stage of sentence verification in the control group, and (b) the emergence of an early *polarity* effect, unreported in the control group, suggests that dyslexic adults may rely on different cognitive strategies for the interpretation of affirmative and negative sentences in comparison with non-dyslexic subjects. Worth noting, however, this latter hypothesis is at variance with the predictions of the *two-step simulation hypothesis* by Kaup and colleagues, according to which the interpretation of the negative sentences necessarily requires the initial simulation of the negated state of affairs.

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General overview

The present work investigates two main issues. On one side, it deals with the broad debate about the processing of linguistic negation by providing novel electrophysiological data on the interpretation of negative sentences by a group of Italian healthy subjects, still lacking in the literature on the topic. On the other side, it deepens the relationship between working memory resources, negative sentences interpretation and developmental dyslexia, in the line of research initiated by Vender and Delfitto (2010).

The dissertation is constituted by two main sections. In the first section (PART 1), the theoretical background of the main experimental studies presented in PART 2, involving both typically developed and dyslexic Italian students, is provided. In particular, Chapter 1 includes a short introduction to the most relevant issues addressed by the strictly linguistic studies on negation (§ 1.1) and a detailed overview and evaluation of the most important evidence and models reported in the psycholinguistic and neurolinguistic investigation on negative sentences (§ 1.2 and 1.3). Chapter 2 is devoted to a discussion of the use of the sentence-picture verification paradigm in the study of sentential negation (§ 2.3.1), to the presentation of the EEG-ERP technique (§ 2.3.2) and to the consideration of the main ERP components reported in language comprehension studies in general, and in negative sentences interpretation in particular (§ 2.3.1.2). To conclude, Chapter 3 offers a brief introduction to developmental dyslexia (§ 3.1), followed by a short overview of the linguistic and working memory deficits reported in both children and adults with dyslexia (§ 3.2 and § 3.3, respectively)

The second part (PART 2) of the dissertation is devoted to the presentation and discussion of the experimental studies performed during my PhD. After the consideration of the evidence emerged in two behavioral preliminary studies involving a group of Italian children and a group of Italian adults (Chapter 2), the methods and results of STUDY 1 (Chapter 3) and STUDY 2 (Chapter 4) are reported. STUDY 1 made use of a pragmatically balanced sentence-picture verification task to test the comprehension of affirmative and negative sentences in a group of Italian typically developed young adults. As we will see, the results of this first study provided behavioral and electrophysiological evidence in support of non-incremental processing of negation. The STUDY 2 performed the same experimental protocol to a group of Italian undergraduate dyslexic students. A battery of working memory and writing and reading tasks was also included. The results of these latter tests highlighted significant differences between adult dyslexics and control subjects both in the phonological component of working memory and in most writing and reading tasks. The analysis of the performance in the sentence-picture verification task showed that, though the execution of the sentence picture-verification tasks was characterized by an overall slowdown and poorer accuracy in the dyslexic group in comparison with the control group, adult dyslexics do not seem to present a specific impairment for negative sentences interpretation.

Part 1
Theoretical Background

1 LINGUISTIC ISSUES IN THE STUDY OF NEGATION

The existence of a linguistic entity for the expression of negation represents a universal feature in human languages (Greenberg, 1966). Interestingly, beyond being universal, negation is also specific to human languages as, as far as it is known, "no animal communication system includes negative utterances, and consequently none possesses a means for assigning truth value, for lying, for irony, or for coping with false or contradictory statements" (Horn, 1989: xiii). What human languages all have in common is not only the possibility of expressing a negative meaning, but the fact that it is always linked to the presence of an *overt* expression.[1] This means also that, in all languages, a sentence is considered positive by default, unless an overtly expressed linguistic operator marks it as negative; in other words, therefore, negative sentences are always considered marked in comparison with the unmarked positive sentences. The nature of the linguistic elements used for expressing negation has a wide variation across languages, ranging from specific verbs to negative participles or affixes.[2] In most languages, in addition, negation is not strictly associated to a single element but, rather, to a very large (and, in some cases, redundant) set of linguistic expressions. To exemplify, Italian negative sentences can be characterized either by the presence of the negative participle *non* (corresponding to the English *not*); by negative quantifiers such as *niente* e *nessuno* (broadly corresponding to the English *nothing* and *none*); by the so called negative concord, that is, the concurrent use of *non* with a negative quantifier or with a negative polarity item (such as *alcuno* in sentences like 'Non c'è alcun problema', *There isn't any problem*);[3] or by negative

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[1] No human language makes exception, including sign languages, in which negation can be either expressed by the use of a manual negative sign combined with a non-manual marking (a head movement) or by head-movement alone. A cross-linguistic overview of negation in sign languages is provided by Zeshan (2004).

[2] See Miestamo (2007) for a typological review.

[3] Negative concord and negative polarity items represent two very interesting forms of negation. Negative concord expressions, present with different forms in many languages, are negative sentences characterized by the presence of two negative elements which do not yield to each other cancelation (as it would be expected from a logical point of view), but result in one semantic negation, e.g., Italian <u>*Non*</u> *è venuto* <u>*nessuno*</u>, (Neg) - nobody - has - come, 'Nobody has come'. The term Negative Polarity Items refers to a large and categorically varied class of linguistic elements (as, for example, verbs, adverbs, quantifiers, etc.), whose common feature is the need of being licensed by negation, e.g., English *any*, which is well-formed in negative sentences (*I didn't see any student*), but ill-formed in positives (e.g., **I saw any student*); Italian *niente* ('nothing'), which is only

connective adjuncts (such as *nè*, *nemmeno*). It is also possible, however, that the negative meaning of a sentence is encoded directly within the single lexical items used, as shown by the large number of substantives, adjectives, and adverbs formed trough the affixation of the very prolific negative prefixes *im*-, *s*-, *ir*- (e.g., *impossibile* 'impossible', *sfortuna* 'unlucky', *irrimediabilmente* 'irremediably'). All in all, therefore, negation represents a multifaceted and complex linguistic phenomenon. Given the applicative nature of the present work, we will not address all the theoretical issues which have occupied linguistic investigation on negation; rather, we will offer a very preliminary and mainly descriptive introduction to the most relevant interpretative and structural features of negation. As a consequence, we will not provide much attention to any specific theoretical account, neither we will try to solve (and not even to exhaustively mention) those aspects which still remain controversial in the linguistic investigation on negation. Among all the possible kinds of negative structures, moreover, particular consideration will be devoted to the case of Italian sentential negation (that is, the negation of a standard declarative verbal main clause), which is the object of the experimental studies presented in Part 2.

1.1 The interpretation of negation

At a first sight, speaking about the semantics of negation may sounds trivial, as one could be tempted to solve the question very hastily by saying that negation 'simply' reverses the polarity of the sentence and, consequently, its truth-conditions.[4] Consider, for example, the following sentences as uttered in a situation in which John is happy:

(1) John is happy.
(2) John is not happy.

In such a situation, the positive sentence (1) is true, whereas the negative sentence (2) is false, as a consequence of truth-conditions reversal operated by the presence of the negative marker *not*. The truth-conditional semantics notion of negation,

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licensed in negative concord constructions (e.g., *Non ho capito niente,* 'I didn't understood anything'). Both negative concord and Negative Polarity Items phenomena have received huge attention in the linguistic investigation on negation in the past decades. For brevity convenience, however, we will not deal with these two topics. For a more detailed introduction to negative concord see Zeijlstra (2004); for an introduction to negative polarity items see Ladusaw (1997) and Giannakidou (2008).

[4] Truth-conditions are defines as the conditions the world must meet for a sentence to be true. The consideration of truth-conditions is at the basis of truth-conditional semantics, according to which the meaning of a sentence is equivalent to its true-conditions. The major objection to this approach is represented by the fact that two sentences can have equivalent true conditions though having different meaning. As a consequence, true-conditions are generally considered to be only a part of the meaning of a sentence.

according to which negation is defined as a truth-reversal propositional operator, is based exactly on this idea.[5] A similar idea is present, however, in all theoretical accounts – logical, philosophical and linguistic – which have dealt with negation. As we will consider more in detail in the next paragraphs, however, the semantics of negation is not only limited to this most apparent meaning.

1.1.1 The scope of negation

As briefly mentioned above, negation reverses the polarity of the sentence in which it occurs and, as a consequence, its truth-value. In many cases, however, this reversal does not involve the whole sentence, but only a sub-sentential component. For this reason, the *scope* of negation assumes a crucial importance in the interpretation of the negative operator, that is, the part of the meaning to which it refers – or, more formally, the part of the sentence which is under the domain of the negation. Languages such as English and Italian, in which sentential negation is expressed through the use of a preverbal negative participle (e.g., English *not*; Italian *non*), offer clear examples of how the difference in the scopal domain of negation yields to difference interpretations of the same sentence. Consider the following sentences with regard to a scenario in which a boy, called John, is drinking an orange juice:

(3) John is not cooking.
(4) John is not drinking.
(5) John is not drinking some beer.

Sentence (3) is true as, in fact, John is not cooking, but he is drinking the orange juice. For the same reason, on the contrary, sentence (4) is false. Though sharing the same portion of sentence *John is not drinking*, sentence (5) is true. As easily recognizable, what makes the difference between the two sentences is the domain of the negative participle *not*: the falsity of (4) is given by the fact that the negation has *wide scope*, that is, it scopes over the predicate of the sentence, as indicated in (6), while the truth of (5) depends upon the fact that negation has *narrow scope* and, therefore, does not scope over the predicate, but only over the complement *some beer*, as illustrated in (7):

(6) ¬ [John is drinking].

[5] Interestingly, negative elements do not only reverse truth-conditions of a certain sentence, but also the direction of their entailment. While affirmative sentences are upwards entailing (which means that the truth of a proposition about an element, say, an apple, implies the same proposition to be true for the superset of that element, e.g., fruit), negation is downward entailing, that is, the truth of a negative propositions (e.g., about apples) the same will old for the subset of apples (e.g., Granny Smith) but not for the superset of the fruit in general. We will not, however, deal with this issue further.

(7) [John is drinking ¬ (some beer)].[6]

Importantly, however, sentence (5) is not prevented from receiving wide scope interpretation, as illustrated in (8), sharing the same truth-value conditions of sentence (6) above:

(8) ¬ [John is drinking some beer].

The distinction between narrow and wide scope of negation is also at the basis of Klima (1964)'s definition of *constituent* and *sentential negation*, according to which if the entire proposition falls under the scope of the negative operator, the negation yields sentential negation; if the negation only applies to a particular constituent, there is no sentential negation, but only constituent negation. Worth noting, in most cases both narrow and wide scope interpretations are equally plausible. As consequence, the choice between the two can only be determined by contextual cues.

The sharp contrast between wide and narrow scope interpretation of a same sentence has became very popular through Russell (1905)'s example about the king of France baldness:

(9) The king of France is bald.
(10) The king of France is not bald.

As explained by Russell, sentence (9) assumes that there is an entity which is the king of France and that this entity has the property of being bald, as expressed trough the logical form (11):

(11) $\exists$ x [K (x) $\wedge$ $\neg\exists$ y[(y$\neq$x) $\wedge$ K(y)] $\wedge$ B(x)].
'There is an x such that x is king and there is no y such that y is different of x and king, and x is bald.'

The negative sentence (10), on the other hand, allows two interpretations. If the description 'the king of France' has a *primary occurrence*, that is, stands outside the scope of negation, the sentence share the existential presupposition of sentence (9), that is, the fact that there is a entity which is a king of France, but it claims that this entity does not have the property of being bald (12):

[6] More formally, wide scope and narrow scope of negation can be defined as follows:
a. In wide scope, negation logically dominates propositional material: ¬ [… φ…];
b. In narrow scope, negation logically dominates a less than full-propositional material, for instance a propositional function: […¬ φ…].
(definition from Moeschler, 2010: 32).

(12) $\exists$ x [K(x) $\wedge$ $\neg\exists$ y[(y $\neq$x) $\wedge$ K(y)] $\wedge$ $\neg$B(x)]
'There is an x such that x is king and there is no y such that y is different of x and king, and x is not bald'.

If, on the contrary, the definite description 'the king of France' has a *secondary occurrence* within the scope of negation, the falsity of the sentence is not necessarily determined by the un-baldness of the king of France, but it may be determined by the fact that there is not an entity corresponding to the definite description 'the king of France' (13):

(13) $\neg$ $\exists$ x [K(x) $\wedge$ $\neg\exists$ y[(y $\neq$x) $\wedge$ K(y)] $\wedge$ B(x)]
'There is not an x such that x is king and there is no such that y is different of x and king, and x is bald'.

In this second case, negation cancels the existential presupposition of the entity 'the king of France'.[7] As it has been noted by Horn (1989), though not representing the most intuitive interpretation of a negative sentence in isolation, the wide scope interpretation becomes the only possible when the presupposition rejection becomes explicit:

(14) The king of France is not bald – there isn't any king of France!

Currently, Russell terminology have been replaced by the distinction between *internal* and *external negation*, corresponding, respectively, to Russell's primary and secondary occurrence of definite descriptions: external negation has its scope over a full logical proposition containing no free variables (e.g., the whole proposition 'The king is not bald'), whereas internal negation has its scope over a propositional function, such as a non-propositional form containing free variables (e.g., the description of the predicate 'is bald').[8] As could be easily observed,

[7] For simplicity convenience, we have by now omit to say that, as the king of France example clearly shows, negative sentence always carry an implicit positive meaning, that is the presupposition of the existence of the entity to which the predicate refers to. Saying, for example, that *John is drinking* presupposed, in fact, at least the existence of an entity corresponding to the definite description 'John'. The presupposition, however, can also be extended to the predicate of the sentence. If, for example, one says that *John is not drinking some beer*, she can be presupposing both there is an entity corresponding to John and that that entity has the propriety of being drinking something: [John is drinking $\neg$ (some beer)]. As observed by Russell (1905), wide scope interpretation always yields presupposition cancelling, while the same does not happen in the case of narrow scope interpretation since the negative meaning does scope over the whole sentence.

[8] This definition is taken from Moeschler (2010). As explained by the same author, "a propositional function is a logical form containing at least one free variable, that is, a

therefore, internal negation has narrow scope, while external negation has wide scope:

(15) Internal negation = primary occurrence = narrow scope.
(16) External negation = secondary occurrence = wide scope.

The consideration of the different scopal domains of negation is also useful in drawing a distinction between different kinds of sentential negation. In most cases, as we have seen, the presence of negation modifies the truth-conditions of the sentence. These cases are considered cases of *descriptive negation*, as negation modifies the propositional meaning of the sentence. There are cases, however, in which the semantic contribute of negation seems to be different. Consider, for example, the following sentences:

(17) Chris didn't manage to solve some of the problems – he managed to solve all of them.[9]
(18) He didn't call the [pólis], he called the [polís].
(19) Grandpa isn't feeling lousy, Johnny, he's just a tad indisposed.
(20) No, he's not meeting a woman this evening - he's meeting his wife! [10]

As firstly highlighted by Horn (1989), in these latter examples negation does not modify the propositional meaning of the sentence (e.g., claiming that a certain entity does not have a particular property), but it is used to communicate an objection to the way in which the same propositional meaning had been previously expressed. This latter use of negation has been therefore named *metalinguistic negation*, as the scope of negation is not the propositional meaning of the sentence, but rather the speech act itself.

Another example of non-standard negation scope is represented by *illocutionary negation*, that is, the cases in which negation scopes over the illocutionary force of a certain sentence. Consider the sentences below:

(21) I don't promise I will come.
(22) I promise I will not come.

As explained by Moeschler (2010), which in turn follows Searle (1969)'s theory of speech acts, (21) is an example of illocutionary negation as the presence of negation determines the sentence not being a promise. In (22), on the contrary,

variable that is bound by a quantifier. Taken individually, $K(x)$, $\neg \exists y[(y \neq x) \wedge K(y)]$ and $B(x)$ are propositional functions" (Moeschler, 2010: 31, note 3).
[9] Worth nothing, in this sentence negation cancels the universal implicature associated with the quantifier *some*.
[10] Examples taken from Horn (1989: 370-372).

negation does not scopes over the illocutionary marker of the sentence (the verb *to promise*), but over the propositional meaning of the subordinate (*I will come*). The difference between the two sentences is formalized in (23) and (24), where F indicates the illocutionary force associated with the predicate *to promise* and P the propositional meaning (*to come*):

(23) ¬ F (P)
(24) F (¬P)

The identification of the scope of negation becomes even more intriguing in the cases in which the negative element enters in combination with that other scope-bearing elements, such as universal quantifiers:

(25) All that glitters is not gold.
(26) All vegetarians do not eat meat.

While in the former sentence negation scopes over the universal quantifier *all* yielding the meaning that is not the cases that all that glitters is gold (26), in the second sentence, it is conversely the universal quantifier which have scope over the negative operator *not* (27):

(27) ¬ (All that glitters is gold).
(28) All vegetarians ¬ (eat meat).

To conclude, the scope of negation can be further marked by *focus*, generally defined as the part of the scope that is most prominently negated and indicated by the speaker through the assignment of a particularly marked stress on the word/the constituent at issue (underlined in the examples below). Although the relationship between focus and scope is in some cases quite intricate, the recognition of the focus helps in understanding the intuition that in a sentence like (29) it is in some sense only *Mary* that is negated, although negation scopes over the whole sentence. Similarly, in sentence (30) the negative marker *-n't* scopes over the whole constituent *intentionally delete the backup file*, but it has clear focus on *intentionally*:

(29) I didn't get that book from <u>Mary.</u>
(30) Liz didn't <u>intentionally</u> delete the backup file.[11]

As it has been observed, negation focus can absolve different communicative functions, the most frequent of which is rendering negative sentences more informative by indicating which of the sets of conditions that determines the truth

[11] Example (29) is taken from Partee (1993: 1), example (30) from Huddleston and Pullum (2002: 799).

of a sentence has necessarily to hold for that clause to be true. In sentence (29), for instance, the indication of Mary as the focus of negation allows the comprehender to understand that what is false is not the fact that the speaker received a book, but only the indication of the person from which she has received it: the condition which has to hold for the sentence to be true is, therefore, that the book was not given by Mary, not that the speaker didn't received any book.[12] Another communicative purpose of negation focus, identified by Rooth (1997: 294), is that of evoking alternatives without commitment to any alternative being true:

(31) A: Is anyone going to the dinner with the colloquium speaker?
B: I don't know. I'm not going.

1.1.2 Contrariety, contradiction and uninformativeness of negation

The consideration of the meaning of negation has a very long tradition, dating back – at least – to the ancient philosophers Plato and Aristotle. Aristotle formulated two laws governing negation from a strictly logical point of view, the *Law of Contradiction* and the *Law of the Excluded Middle*. The first law demands that two opposite propositions cannot be true simultaneously; the Law of the Excluded Middle requires that of any two opposite propositions, one is true:

(32) Law of Contradiction: $\neg$ (p and $\neg$ p).
(33) Law of the Excluded Middle: $\neg p \vee p$.

The applicability of the two laws has traditionally constituted the basis for the distinction between *contradictory negation* and *contrary negation*, exemplified in (34) b and (35) b respectively:

(34) a. John is older than 18.
b. John is not older than 18.
(35) a. John is friendly.
b. John is not friendly.

Contradictory negation obeys both laws: as expected from the *Law of the Excluded Middle,* in fact, it is not possible that John is contemporary older and younger than 18; as asserted by the *Law of Contradiction*, at the same time, one of the two sentences in (34) has to be necessarily true. In the case of contrary negation, on the

[12] As this example clearly shows, in some cases the focus of negation simply overlaps the narrow scope domain of negation. Due to time and space limitations, however, we will not deal with this topic in all its complexity, limiting our consideration to the fact that negation is a focus-sensitive operator.

other hand, only the *Law of the Excluded Middle* holds, as the two sentences cannot be simultaneously true in the same situation. The *Law of Contradiction*, however, is contradicted by the fact that John could be neither friendly nor unfriendly, but something in the middle. Horn (1989) gives to similar cases the name of *scalar predicates*, indicating that they denote a scale from one extreme (e.g., friendly) to the other (e.g., unfriendly). When used in scalar contexts, therefore, negation seems to express either a 'in between' or a 'less than' meaning, as shown by sentence (36), which probably means that John has one or two children:

(36) John does not have three children.

As it can be noted, in many cases negative statements declare what it is *not* without precisely expressing what it is. This fact has been formalized by the *Principle of Negative Uninformativeness* proposed by Leech (1981), according to which "negatives, all things been equal, are less informative than their positive counterpart". Consider, for instance:

(37) Bogotá isn't the capital of Peru.
(38) Bogotá is the capital of Colombia.

Even though both sentences are true, (37) is far less informative than (38), as it does not provide any information about the actual capital of Peru, apart from excluding one of many possibilities, the city of Bogotá. The contrast between positive sentences' informativeness and negative sentences' uninformativeness is also very evident in negative sentences containing quantifiers:

(39) Many people saw the movie.
(40) Not many people saw the movie.

Interestingly, while in (39) the quantifier *many* can receive specific reference, this is not possible for (40):

(41) Many people (namely, John, Bill, Mary, etc.) saw the movie.
(42) Not many people (*namely….) saw the movie.[13]

According to Leech (1981), the under informativeness of the negative sentences is due to the fact that "the population of negative facts in the world is far greater that of positive facts" and, therefore, "we must assume a context in which the negation of X is precisely as informative as it is required".[14] Worth noting, the only cases in which negative sentences give an equally informative meaning as their positive

[13] Examples (39)-(42) and relative considerations are taken from Lasnik (1975: 22-23).
[14] The important role of the linguistic context for the interpretation of negative sentences will be the object of § 1.1.3.

counterparts are represented by the sentences containing contrary predicates (such as *open*/*close*, *of*/*on*, etc.), which cannot receive the scalar interpretation in the sense of Horn (1989), that is, situations in which the population of negative facts and that of positive facts can be considered equal, as exemplified in the sentences below:

(43) The radio is on.
(44) The radio is not off.

If the radio is not off, in fact, there are not other possibilities that being on. Very differently, if one says that Bogotá is not the capital of Peru, she gives very little information for the identification of which of the many alternatives represents the true one.

1.1.3 Notes on the pragmatic sensitivity of negative sentences

As we have seen, Leech (1981) attributes negative sentences uninformativeness to the fact they need to be uttered in appropriate contexts. According to Horn (1989: 198), such contexts are those in which the negation of X is motivated by previous assertions about X. Consider, for example, the two sentences we have presented below:

(45) Bogotá isn't the capital of Peru.
(46) Not many people saw the movie.

Though being not very informative in isolation, the two sentences become much more informative if uttered in an appropriate context, e.g., to correct a previous believe or assertion stating that Bogotá is the capital of Peru, for sentence (45), or that many people had saw the movie, for sentence (46). This observation stays at the basis of Horn (1978)'s definition of the *markedness implicature* for canonical negation, stating that "there should be reason to utter a sentence and, for a negative sentence, that reason (…) is generally the earlier consideration of its affirmative counterpart" (Horn 1978: 203).[15] In other words, canonical negative sentences are not used for simply conveying a piece of information, as it is the case for positive sentences, but they are expected to be uttered with the purpose of expressing an additional communicative effect.

A very similar intuition has been captured by Wason (1965)'s notion of the *context of plausible denial*, according to which the plausibility of a negative sentence is indissolubly connected to (a) the presence of a prior expectation that has to be denied, and (b) the plausibility of the prior statement itself.[16] To

[15] As explained by the same author, this implicature derives from Grice's Maxim of Relation, according to which speaker utterances are asked to be relevant to what is at issue in the conversational context (Grice, 1975: 45-46).
[16] Wason focuses more on the second of the two constrains, observing that the sense of appropriateness of a negative sentence is strongly dependent on the plausibility of its

exemplify, none would reasonably utter a sentence like "I did not eat all the cake" out of the bleu, without the presupposition that there was a cake which has been eaten by someone. As a consequence, negative sentences are not only marked from a structural point of view (by the presence, as we said, of an overt linguistic operator), but also interpretatively.[17] It might be worth noting that the prior expectation can be either explicitly manifested (for instance, by making the question "Who did eat the cake?" or "Did everyone had the cake?") or only implicitly present (by the simple presence of a cake partially devoured, or by the well known greediness of a certain person, which is once again suspected of having eaten a massive part of the cake). In both cases, however, contextual information provides felicitous discourse context for the utterance and the interpretation of a sentence like *I did not eat the cake*. On the contrary, the use of a negative sentence in absence of any contextual informational determinates an inevitable effect of strangeness and burdens the interpretation with the necessity of solving the pragmatic infelicity by 'filling the gap' of the missing presupposition.[18] As Wason's second constrains underlines, however, the plausibility of the positive counterpart which is implicitly presupposed by a negative sentence also represents a very important condition for the sense of appropriateness of the negative statement itself. The importance of this concept can be easily observed in the consideration of the two sentences below:

(47) The whale is not a fish.
(48) The whale is not a bird.

While the appropriateness of sentence (47) is determined by the fact that it is perfectly plausible to wonder whether a whale is a fish or not, the oddness of (48) is provoked by the 'nonsense' of its affirmative counterpart or, in other words, by the fact that it does not have any sense to wonder whether the whale is a bird and thus, to negate this possibility. As we will see more in detail in § 2.1.2, the consideration of the pragmatic felicity of negative sentences has played a crucial role in first psycholinguistic studies on the processing of negation and still represents a very debated issue in experimental studies' design on negation.

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affirmative counterpart: while a sentence like *The whale is not a fish* do not determinates any effect of inappropriateness, as it seems perfectly plausible to wonder whether a whale is a fish, the oddness a sentence like *The whale is not a bird* it is indeed provoked by the fact that it does not have any sense to wonder whether the whale is a bird (or, in other words, by the 'nonsense' of its affirmative counterpart).

[17] The use of negation in combination with scalar predicates seems to be an exception to this generalization. Saying that "John is not older than 18", in fact, may not presuppose that John is older than 18; rather, in adequate circumstances, negation seems to be use to provide information *for exclusion*, meaning something like "I don't know exactly how many years John has, but I can exclude that he is older than 18".

[18] A similar idea is found in Givón (1978), who argues that negative sentences require a particular pragmatic context within which been processed to encounter the presuppositions held by the listener.

1.2 Structural properties of sentential negation

As we have said, the expression of negation is always associated with the presence of an overt linguistic element, whose nature largely varies across human languages. The possible forms sentential negation can present have been distinguished in three main groups: I) languages which have special verbs that deny a sentence (e.g., Evenki language, spoken in Siberia); II) languages which have negative verbs taking an entire clause as their complement (e.g., Tongan, spoken in Polynesia); III) languages which use participles or affixes (either prefixes, affixes or infixes. e.g., Romance and Germanic languages). Within this latter group, two further differences can be observed. First of all, in some languages sentential negation is expressed by a single negative marker (e.g., Italian *non*), while in some others it has a bipartite structure, either including a pre-verbal negative clitic and a free standing negative marker (e.g., French participles *ne….pas*) or a combination of negative particles/affixes (e.g., Afrikaans). Secondly, while in some languages negation markers behave like free standing elements either occupying the preverbal (e.g., Italian) and the post-verbal position (e.g., Dutch), in some others it can optionally cliticize on the main verb or on the auxiliary (e.g., English).[19] Whatever the way of expressing sentential negation, negative sentences are characterized by more syntactic structure than affirmatives since there is a part of the syntactic structure dedicated to negation. A first issue for any syntactic approach to negative sentences is, therefore, that of identifying the nature of this part of the sentence, the syntactic status of the elements from which it is composed and the position they occupy within the syntactic structure. A second important issue is represented by the fact that, in some cases, negative elements surface in a structural position different from the one where they are expected to be syntactically generated. A third issue, concerning the syntax-semantic interface level, is represented by the fact that, as we have seen in the consideration of the scopal domain of negation, in some sentences negation occupies a position different from that in which it is interpreted by the semantic component. In the next paragraphs, we will endeavor to offer a brief consideration of these three main issues within the tradition of the generative studies on negation.

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[19] Worth noting, the way of expressing negation is not only cross-linguistically different, but it also varies diachronically within the same language. More specifically, as observed by Jespersen (1917), the evolution of the ways in which negation is expressed seem to follow a general tendency, known as *Jespersen Cycle*, according to which in all languages the expression of negation would be characterized by a first phase in which a single negative adverb is used, after which, as a consequence of the weakening of it, sentential negation would be concurrently associated to some other additional word. Further on, this latter would become the only way of expressing negation, until when it would undergone the same development of the original word it was originally intended to be used in combination with, that is, it would start to be felt, in turn, as too weak and, therefore, to be accompanied by another negative marker, which would then follow the same destiny. Although having found support from the analysis of the evolution of Latin, French, and English negative expressions, Jespersen’s proposal has never being compared to a larger sample of languages and is still taken, therefore, with some caution.

1.2.1 *The syntactic status of negative markers*

Zanuttini (2001) and Merchant (2001) have elaborated a series of tests to determine the syntactic status of negative elements. Zanuttini (2001)'s work focus on the blocking effect of negative elements to provide evidence in favor of the head status of preverbal negative markers.

The first interesting observation made by Zanuttini (2001) concerns cliting-climbing, the movement phenomenon as a consequence of which the pronominal object of an embedded infinitive appears attached to the main verb, as frequently happens in Romance languages (49). As French examples below clearly show, clitic-climbing is not possible in presence of a negative marker (50), requiring the clitic object to remain in its canonical position (51):

(49) Jean la fait manger à Paul.
Jean - it - makes - eat - to - Paul.
'Jean makes Paul eat it'.
(50) *Jean l'a fait *ne pas* manger à Paul.
Jean - it - has - made - *neg* - *neg* - eat – to - Paul.
'Jean has made Paul not eat it'
(51) Jean *ne* l'a *pas* fait manger à Paul.
Jean - *neg* - it - has - *neg* - made - eat - to - Paul.
'Jean has made Paul not eat it'.[20]

Another cue in favor of the assignment of head status to preverbal negative markers is represented by the blocking effect negative elements exercise to long clitic-climbing, a phenomenon which is allowed, for example, in Italian, where the object can move from the complement position of an infinitive to the position in front of the finite verb (52). As shown in (53), however, such a movement is prevented by the presence of the negative marker *non*:

(52) Gianni li vuole vedere.
Gianni - them - wants - to see.
'Gianni wants to see them'.
(53) *Gianni li vuole non vedere.
Gianni - them - wants - *neg* - to see.
'Gianni does not want to see them.[21]

A third syntactic movement which has been found to be sensitive to negative elements is verb movement, a phenomenon characteristic, for example, of Paduan dialect.[22] In this Northern Italian variety, yes/no interrogatives require the C^0 head to be overtly filled; as a consequence, therefore, the verb moves from V^0 to C^0, as

[20] Examples taken from Zanuttini (2001: 524), cited in Zeijlstra (2004: 153).
[21] The observation of this phenomenon goes back to Rizzi (1982).
[22] See Poletto (2000).

exemplified in (54). If, however, the verb has to cross over another head, verb movement is made illicit by the Head Movement Constrain.[23] Precisely this latter case is found in negative interrogatives, where the negative marker intervenes as blocking element (55), allowing only the negative construction without verb movement (56):

(54) Vien lo?
Comes - he?
'Is he coming?'
(55) *Vien lo no?
Come - he - *neg*?
'Isn't he coming?'
(56) No vien lo?
Come - he - *neg*?
'Isn't he coming?'

To conclude, the application of Merchant (2001)'s *why not* test provides final confirmation for the head status of preverbal negative markers.[24] Given that the *why not* construction is considered to be a form a phrasal adjunction, it is expected not to be allowed in those languages in which negative markers are syntactic heads as it happens, in fact, e.g., in Italian (57) and in Greek (58):

(57) *Perchè *non*?
'Why not?'
(58) *Giati *dhen*?
'Why not?'[25]

The tests we have just considered have been successfully applied for the diagnosis of the head status of the negative markers which are syntactic words. According to Zanuttini (2001) and Zeijlstra (2004), nevertheless, the same syntactic status has to be assigned to all non-adverbial negative markers, including weak negative markers (that is, negative markers that need to be accompanied by another negative element)[26] and negative affixes. Leaving a host of the details of their

[23] The *Head Movement Constraint*, firstly formulated by Travis (1984: 131), states that "an X^0 may only move into the Y^0 which properly governs it". In other words, head movement is limited in distance by the prohibition of skipping another governing head position.
[24] Rowlett (1998) presents two main possible contra-arguments to the assignment of the head status to preverbal negative markers; Zeijlstra (2004), however, provides convincing analysis in favor of the fact that this arguments are in real opposition with the treatment of negative elements as syntactic heads. The reader who is interested to a discussion of this latter issue is referred to the original works.
[25] Notice that, as observed by Merchant (2001), in these languages the same meaning can be grammatically expressed by using the *no* word, as exemplified by the grammaticality of the Italian question 'Perchè *no*?' (= Why *no*?) and of its Greek correspondent 'Giati *oxi*?'.
[26] Most Slavic languages, for example, express negation by means of a negative marker attached to V_{fin}, in a very similar fashion to weak preverbal negative markers. The main

argumentations aside, we limit our consideration to the observation that, in fact, though the application of the head movement tests is made impossible by the fact that weak negative markers as affixes are attached to the finite verb (and therefore cannot block any head movement themselves), the application of the *why not* test support this conclusion. As shown by the Russian (59) and West Flemish (60) examples, in fact, the adjunction of weak negative marker or of a negative affix to XP is forbidden, giving evidence in favor of their head status:

(59) *Pochemu*ne*?
Why-*neg*
'Why not?'
(60) *Waarom *en*?
Why-*neg*
'Why not?'

Zeijlstra (2004) makes use of the same head movement and *why not* test we have already considered in the assessment of the head status of non adverbial negative elements (be it strong, weak or affixal elements) to show that adverbial negative markers do not belong to the same syntactic category, but to that of maximal projections. A first support to this classification is provided by verb movement analysis in V2 languages, whose main clause structures are characterized by the fact that the verb has to occupy the second position in the clause. As exemplified by Swedish (61) and Dutch (60), adverbial negative markers do not exercise the verb movement blocking effect which would be expected in the case in which they were syntactic heads:

(61) Jan köpte *inte* boken.
Jan - bought - *neg* - books.
'Jan didn't buy books'.
(62) Jan liep *niet*.
Jan - walked - *neg*.
'Jan didn't walk'.[27]

A further confirmation of the non-syntactic head status of adverbial negative words comes from the application of the *why not* test, which is allowed in all languages which have adverbial negative marker:

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difference between weak and strong negative markers concerns the occurrence of clitics and other functional markers that are attached to the verb (as the so-called weak markers) and occupy a lower position in the clause than strong negative markers. We will not deep into this distinction, but we will assume Zanuttini (2001) and Zeijlstra (2004)'s classifications, referring the interested reader to these latter works for a more detailed analysis.

[27] Examples taken from Zeijlstra (2004: 161).

(63) a. Why *not*? (English)[28]
b. Warum *nicht*? (German)
c. Waarom *niet*? (Dutch)
d. Varför *inte*? (Swedish)

1.2.2 The syntactic position of negative markers and phrase

As we said, in all world languages the expression of negation requires an overt negative element, whose presence determines the existence of more syntactic structure in negative sentences with respect to affirmative sentences. The piece of syntactic structure that is unique to negative clauses has been traditionally labeled Negation Phrase (NegP for short). The position it occupies within the clause, however, is far from receiving general consensus, and is currently object of a larger number of works, an ordinate review of which will lead us far from our main interests. We will thus limit our consideration to most generally accepted conclusions on both the position of negative markers and the position of NegP within the clause, without entering in too many details.

As observed by Haegeman (1995), a first aspect to be considered in relation whit the position negative elements occupy within the syntactic structure is that languages differ with respect to the place of origin of the negative marker: strong preverbal negative markers are base-generated in Neg^0, whereas negative markers that require a second negative marker are generated in the lower position V_{fin}, as a V-adjoined clitic or as verbal inflection. The distinction between strong preverbal negative markers and weak preverbal negative markers/negative affixes we have outlined above, therefore, might be simply the result of the position in which they generated. Negative adverbs, differently, are generally assumed to originate in Spec,NegP, but this assumption is not uncontroversial: accordingly to Rowlett (1998), for example, the French negative adverb *pas* is base-generated in a *v*P adjunct position and then moved overtly to Spec,NegP. As underlined by Zeijlstra (2004), however, though it is seems plausible that negative adverbs are base-generated in a *v*P adjunct position and only then moved to Spec,NegP position, this latter movement is a characteristic of all languages with adverbial negative markers.

The second important issue concerns NegP's position within the clause. Three main hypotheses have been advanced in this respect. The first proposal, outlined by Ouhalla (2003), assumes that the position of NegP is the result of a single parameter, as a consequence of which NegP can either occupy the top of TP or the top of VP. The second hypothesis, put forward by Zanuttini (1998), is based on the

[28] Worth noting, the adverbial status of the English *not* does not hold for the weaker form of *not*, *n't*. According to Haegeman (1995), while *not* is a specifier, *n't* is a syntactic head. Though widening the class of preverbal negative markers – as *n't* is strictly speaking not preverbal –, this classification is compatible with the distinction between XP negative markers (corresponding to adverbial negative markers) and X^0 negative markers (including all the non-adverbial forms of negative markers).

idea that there are multiple NegP's in the clausal domain which potentially could all host a negative marker. The third hypothesis, to conclude, has been developed by Zeijlstra (2004) on the ground of two main other works: (a) Nilsen (2003)'s suggestion that functional categories in the clause are not syntactically but semantically driven; (b) Ramchand (2004)'s observation that sentential negation introduces an operator which binds free variables, the nature of which varies across languages, but also intra-language.[29] As a consequence, Zeijlstra (2004) suggests that the positions of NegP are derived from the semantic properties of the negative operator and, in particular, from the nature of the variables it binds: in those languages in which NegP dominates TP, the negative operator binds temporal variables; in languages in which NegP is below TP, the negative operator binds event variables. Though a deep consideration of the two hypothesis goes beyond the scope of the present study, it is worth noting that Zeijlstra (2004)'s assumption of the semantic derivation of the NegP position has the advantage of accounting for the variety of the negative markers positions without presupposing multiple syntactic positions for the NegP, as every NegP in the syntactic clause is assumed to be derived by exactly one semantic negation.[30]

1.2.2.1 The concept of Negation Raising

As we have said, the negative marker can occupy a position different from that where it is generated, as it happens, for example, in those languages in which the negative adverb is generated in a *v*P adjunct position and then moved overtly to Spec, NegP. Another case of overt movement of negation is represented by the case of *negation raising* (alternatively termed *attraction of negative*), indicating all the cases in which the negation in the matrix clause of a sentence it is interpreted as negating the complement clause. This peculiarity has been observed, in particular, in negative sentences including psychological verbs (such as believe, *believe, want, seem, suppose, likely, ought to*; but not *know*), exemplified in sentence (64), whose meaning is considered equivalent to that expressed by (65):

(64) I don't think he will come.
(65) I think he will not come.

This phenomenon has been object of a large number of works, providing both syntactic and pragmatic analysis, a detailed (though not extremely updated) consideration of which can be found in Horn (1989: 308-330).

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[29] Ramchand illustrates the case of Bengali language, which has two different negative markers, *ni* and *na*, the first one binding event variables, the second binding time variables.
[30] Prior to introduce its own proposal, Zeijlstra (2004: 176-180) provides a quite detailed consideration of Ouhalla (2003)'s and Zanuttini (1998)'s suggestions as well. The reader which is interested is referred to this latter review, together with the original works.

2 THE PROCESSING OF NEGATION: EVIDENCE AND MODELS

In the previous paragraphs, we have tried to define the linguistic features of negative elements. Much more intricate is defining how the presence of a negative marker affects language processing and comprehension processes. In this second part of the chapter, we will extend our consideration to this very fascinating and debated issue. In doing that, we will firstly provide an overview of cross-linguistic studies on the processing of negative sentences (§ 2.1); secondly, we will offer an overview of the main psycholinguistic models proposed for negative sentences processing (§ 2.2).[31] To conclude, in the final paragraphs of this section we will discuss the advantages of the use of the picture-sentence verification paradigm (§ 2.3.3) and of EEG technique (§ 2.4.4) in the investigation of negative sentences processing to motivate their adoption for the present research on the processing of negation (see STUDY 1 and STUDY 2 in the second part of this dissertation).

2.1 Psycholinguistic and neurolinguistic studies

Among the many directions an overview of current evidence on negation processing may take, we choose to organize the studies according to three broad classes of evidence: 1) studies which report that interpretation of negative sentences requires extra time and extra effort (in comparison with that of affirmative sentences); 2) studies which show that the processing of negation is highly sensitive to prior (and late) contextual information; 3) studies demonstrating that negative elements act as accessibility-reducing operators on the terms within their scopes.

2.1.1 Negation processing requires extra time and extra 'effort'

Since the very first studies on negation processing, the interpretation of negative sentences has been largely reported to induce longer processing times and higher error rates in comparison with non-negated sentences, independently from the experimental task used. Early studies employed different kinds of sentence verification tasks to investigate the impact of negation on simple sentences interpretation. The results consistently showed that the execution of the task at

[31] As we said before, we will restrict our consideration to sentential negation, intended as the negation of a standard declarative verbal main clause. From this moment on, therefore, unless otherwise specified, we will use the expression 'negative sentences' to refer to this specific kind of sentence, thus excluding negative polarity items expressions, negative concord sentences and all the other non-standard negative structures.

issue was slowed down and more error prone for negative sentences in comparison with structurally similar affirmative sentences (Clark and Chase, 1972; Carpenter and Just, 1975; Trabasso et al., 1971, Carpenter et al., 1999). Wason (1961), in addition, showed that not sentence polarity, but also its truth-value determines important effects on response latencies. Participants were asked to judge the truth-value of four kinds of world-knowledge related sentences: true affirmatives (e.g., *24 is an even number*), false affirmatives (e.g., 25 *is an even number*), true negatives (e.g., 27 *is not an even number*), and false negatives (e.g., *26 is not an even number*). The results showed that while the evaluation of an affirmative sentence took longer when the sentence was false in comparison with when it was true, negative sentences verification followed the inverse pattern, with true negative sentences reporting slower response times than false negative sentences:

(66) True Aff < False Aff < False Neg<True Neg.

Though Wason (1961)'s work has been object of many methodological criticisms,[32] subsequent studies have nevertheless confirmed both that negative sentences are processed significantly slower than affirmative sentences (Carpenter et al., 1999; Kaup et al., 2006; Kaup et al. 2007) and true negative sentences require more time to be interpreted than false negative sentences (Vender and Delfitto, 2010; Kaup et al. 2005; Dale and Duran, 2011).[33]

Longer reaction times for negatives in comparison with affirmative sentences have also been reported in studies employing other kinds of experimental tasks. Hasegawa et al. (2002) developed a target-to-probe matching study to test affirmative and negative sentences comprehension in a group of Japanese subjects speakers of both Japanese and English. The stimuli consisted in both English and Japanese target sentences of the form *The worker read a magazine and showed some pictures to the brothe*r (target), each of which followed by a mono-clausal probe sentence, affirmative or negative, of the type *The worker read/does not read a magazine*. The participants' task was to judge the truth-value of the probe sentence. The results showed that subjects had longer response times with negative than with affirmative negative probes, independently from the language used. Christensen (2009)'s very similar designed study with a group of Danish speakers - tested with Swedish materials only – provided further evidence that the evaluation of negative probe sentences requires significantly more time than that of affirmative probes, regardless of whether the target sentence was affirmative or negative.[34] Paradis and Willners (2006) presented their participants with

[32] Main criticisms of this study are discusses in Horn (1989: 172-176).
[33] As we will discuss later, these counterintuitive data have been accounted for within the Two-Step Simulation hypothesis formulated by Kaup and colleagues (see, for example, Kaup et al., 2007).
[34] Both Hasegawa et al. (2002) and Christensen (2009)'s studies also included neuroimaging recordings through fMRI. We will consider fMRI evidence in the next paragraphs.

affirmative and negative statements involving scalar adjectives (e.g., *narrow*, in a sentence like *The road along the coast is/is not narrow)* and, then, to mark the position of the target noun presented in the sentence (e.g., *road*) on an 11 point scale (e.g., with *path* and *motorway* as extreme terms). Also in this study, the time needed for executing the task, i.e. scaling the items, was longer when the target noun to be evaluated had been previously defined by a negated adjective (e.g., *not narrow*) than in the case in which it had been presented in association with a non-negated adjective (e.g., *narrow*).

2.1.1.1 Negation late integration

Another important class of data is constituted by studies indicating that negation is not immediately incorporated during sentence interpretation, but only some thousands of milliseconds after sentence presentation. An extensive number of studies have shown, in fact, that initial processing of a negated sentence is not influenced by the presence of negation. Giora (2005)'s study, for example, reported that reading affirmative (e.g., *This dress is pretty*) or structurally similar negative (e.g., *This dress is not pretty*) sentences equally primed related concept (*e.g.*, nice), independently from sentence polarity. This result thus suggests that – at very early stages of sentence interpretation – negative markers do not have any effect on the accessibility of lexical items under their scope. Giora (2005)'s findings have been confirmed and extended by Hasson and Glucksberg (2006)'s study focusing on the interpretation of affirmative and negative metaphors. In this latter study, participants had to read affirmative and negated metaphors such as *This lawyer is/is not a shark* and to make lexical decisions to terms related either to the meaning of the affirmative sentence (e.g., *vicious*), or to that of the negative sentence (e.g., *gentle*), or completely unrelated from both of them. Three different conditions were created with respect to the delay between the onset of the metaphorical sentence and the presentation of the target word, which thus differentiated the participant within three groups: participants who were presented the target word 150ms after sentence onset; participants who were presented the target words 500ms after sentence onset; and participant who were presented the target word 1000ms after sentence onset. The results of the participants who performed the lexical decision task in the very early stages of the interpretation of the metaphorical sentence (i.e., 150ms/500ms conditions) replicated Giora (2005)'s observations, reporting no effect of negation. After both affirmative and negative sentences, in fact, lexical decisions were facilitated in case of affirmative-related terms in comparison with negative-related terms, suggesting that negative sentences are still processed 'as' affirmatives at this stage. The participants who were presented to the target word 1000ms sentence onset, on the contrary, reported no facilitation for affirmative-related terms when they followed negative metaphors, but only when they were presented after affirmative metaphors, indicating that negation has been meanwhile processed and interpreted.

The different sensitivity to negation between early and later stages of sentence processing has been object also of a series of studies by Kaup and colleagues. Kaup et al. (2005) developed a sentence-picture verification task in which participants were presented with affirmative and negative sentences describing the spatial arrangement of two entities, e.g., *The elephant is/is not above the giraffe* and, subsequently, with a picture of two cards, standing one above the other and illustrating the two mentioned objects. Their task was to decide as quickly as possible whether both the objects illustrated had been mentioned in the sentence or not. Though the two depicted objects always corresponded to those mentioned in previous sentences (and thus the expected answer was always *yes*), the spatial arrangement of the two entities could not respond to participants expectations, contradicting the state of affairs described by the sentence, as in the case in which a picture of a card illustrating a elephant placed above a card depicting a giraffe was presented after the affirmative sentence *The elephant is above the giraffe* or after the negative sentence *The elephant is not below the giraffe*. Also in this study, the time of presentation of the second stimulus (i.e., the picture) was manipulated between subjects: half of the participants saw the picture with a delay of 750ms after the sentence; the other half with a delay of 1500ms. The results of the intermediate-delay group (750ms) were characterized by shorted response times for pictures matching the entities disposition described by sentence than for mismatching ones in the case of affirmative sentences, but by the inverse pattern in the case of negative sentences, after which pictures matching the actual spatial arrangement expressed by the sentence elicited longer response times than pictures corresponding to the negated state of affairs. Participants of the 1ong-delay group (1500ms), on the contrary, showed a main effect of picture-sentence match for both affirmative (as it was also in the intermediate-delay) and negative sentences, the processing of which at this stage appeared more facilitated by the presentation of a matching picture than by a picture corresponding to the negated state of affairs (as it happened in the intermediate-delay condition). Very similar evidence has been reported in Kaup et al. (2006)'s study investigating the interpretation of sentences with contradictory predicates. Participants read affirmative and negative sentences containing a contradictory predicate (e.g., *The door was/was not open)* and subsequently, after a delay of either 750ms or 1500ms, saw matching or mismatching pictures. All the pictures illustrated the entity mentioned in the corresponding sentence, but their properties could differ from that described in the sentence (e.g., an open door instead of a closed door). The results confirmed Kaup et al. (2005)'s findings: while in the 750ms condition response times for negative sentences were shorter in the cases in which the picture illustrated the negated state of affairs (e.g., a closed door following the sentence *The door is not closed*) than in those in which the actual state of affairs was depicted (e.g., an open door), in the 1500ms condition response times for negative sentence were shorter when the picture matched the actual state of affairs. Very comparable results have been reported in Kaup et al. (2007)'s sentence-picture verification task. After having read a definite (e.g., *The eagle is not in the sky*) or an indefinite sentence (e.g., *There is no eagle in the sky*), participants of this latter study were shown pictures of the entity mentioned in the sentence (e.g., an eagle), whose shape could either reflect the described state of affairs (e.g., a crouching eagle) or the negated state of affairs (e.g., an flying eagle). Participants' task was then to judge whether the depicted entity had been mentioned in the sentence or not. Since the picture always depicted the entity mentioned in the previous sentence, experimental items always predicted *yes* response. As in Kaup et al. (2005), however, the two picture could differ from the sentence with respect to the shape and position of the entity. Again, shorter response times in the recognition task were reported in the cases in which the picture corresponded to the non-negated meaning of the target sentence than in the cases in which it matched the actual, negated meaning.[35] As observed by the authors, the otherwise unexplainable facilitation effect produced by the matching between a negative sentence and the pictorial representation of its opposite, non-negated meaning can be accounted for only by assuming that, at the initial stages of negative sentence interpretation, the comprehended has not yet integrated the meaning of negation and is still committed in mentally simulating the affirmative counterpart of the negative sentences under interpretation.

Leaving aside the theoretical implications of these latter assumptions (to which we will return in more details in § 2.1), it is sufficient for the present purpose to note that the findings reported so far clearly speak in favor of a late, non incremental integration of negation, which might be by itself sufficient for explaining the slowness of negative sentences interpretation in comparison with affirmative sentences.

Initial insensitivity to negation has been also confirmed by EEG-ERP studies, which reported no early differences in brain potentials characterizing first stages of affirmative and negative sentences interpretation (Fischler et al., 1983; Lüdtke et al., 2008; Ferguson et al., 2008). However, we postpone the presentation of these studies to § 2.3.3, which will be entirely dedicated to the use of the EEG technique in the investigation of negation processing.

2.1.1.2 On-line measures of negative sentences interpretation processing cost

Though the long-tradition association of longer response latencies and/or reaction times with negative sentences interpretation has been largely as an indication of the higher processing cost associated with negative sentences in comparison with non-negated sentences, the recent use of on-line techniques has allowed more direct evidence. Dale and Duran (2011) employed an action-dynamic paradigm based on the assumption that mouse-tracking trajectories performed during the execution of a specific task represent an immediate reflection of the its cognitive cost. Participants were asked to silently read some affirmative and negative sentences, which could either be world-knowledge congruent (e.g., *Elephants are large/Elephants are not small)* or not (e.g., *Elephants are small/Elephants are not*

[35] No difference was reported between the definite and the indefinite conditions.

large), and to judge each sentence's correctness by clicking the corresponding *true*/*false* circle on the screen. Computer mouse movements towards the chosen answer have then been analyzed in terms of number of deviations (technically, *x*-flips) and acceleration/deceleration alternation in course, two parameters which have been found to strictly correlate with processing difficulty.[36] As expected, the interpretation of negative sentences was characterized by more discreteness and acceleration/deceleration changes in the mouse course than was observed for affirmative sentences. Among negative sentences, moreover, true sentences were found to determine higher increase of *x*-flips and speed alternations than false sentences, confirming the polarity by truth-value interaction firstly outlined by Wason (1961, see pag. 30 above).

Neuroimaging studies have also provided important – though not uncontroversial – information on the cognitive processes associated with negative sentences interpretation. In particular, the use of fMRI technique[37] has allowed identifying which brain areas are more significantly involved in affirmative and negative sentences interpretation. The first fMRI study on negation processing was developed by Carpenter et al. (1999) and based on a sentence-picture verification task: participants were presented with sentences of the type *It is true/it is not true that the star is above the plus*, followed by a picture illustrating a plus sign '+' standing above or below an asterisk sign '*', and were asked to judge sentence congruency against the picture. The behavioral results showed that, as said, subjects responded slower after negative sentences than after affirmative ones. Neuroimaging data, on the other hand, revealed increased activation in the left temporal and biparietal regions for negative sentences than for affirmative sentences, an effect which the authors take to reflect the higher linguistic and visuo-spatial processing associated with negation. In a posterior study, Hasegawa et al. (2002) investigated the interpretation of English and Japanese negative sentences by a group of Japanese subjects who were also moderately-fluent speakers of English. Participants were presented with bi-clausal target sentences of the type *The worker read a magazine and showed some pictures to the brothe*r (target), each of which was followed by an affirmative or negative mono-clausal probe sentence such as *The worker read/does not read a magazine,* and were asked to judge the truth-value of each probe with respect to the preceding target sentence.[38] In line with previous studies, the analysis of behavioral data revealed

[36] For more information on this experimental method see Dale and Duran (2011: 984-985).
[37] fMRI procedure (short for functional Magnetic Resonance Imaging) employs magnetic resonance imaging technology to measure hemodynamic response of the brain to specific stimuli and cognitive activities. As increased neuronal activity of a specific brain area determines enhanced blow flow in the same area, fMRI allows to identify the different involvement of brain areas in specific cognitive processes (e.g., negative *vs*. affirmative sentences comprehension). fMRI studies specifically investigating sentence comprehension processes, in addition, reported that the amount of activation in a network of areas increased as a function of the structural and lexical complexity of the sentence (Just et al., 1996; Keller et al., 2001).
[38] We already mentioned this study in § 2.1.1.

higher difficulty for negatives in comparison with affirmative sentences, resulting in longer reaction times and higher error rates, independently from the language used. In contrast, fMRI data showed effects for negation only with subjects' second language stimuli (i.e., English), the processing of which was characterized by enhanced left hemisphere activation. Worth noting, in addition, differently from Carpenter et al. (1999), Hasegawa and colleagues observed that increased activation for negative sentences was significant only in left hemisphere regions (and, in particular, in the posterior temporal cortex, in the supramarginal gyrus, and in the precentral cortex).

A very similar target-to-probe experimental task was adopted by Christensen (2009) with a group of monolingual Danish subjects. Participants were first asked to read a target sentence, which could either be affirmative (e.g., *De sejeste mænd kender og bruger også sæbe*, 'The toughest men know and also use soap') or negative (e.g., *De sejeste mænd kender men bruger ikke sæbe*, 'The toughest men know but don't soap'). The sentence was immediately followed by an arrow, appearing in the centre on the screen, which they were instructed to interpret as something like "from this it follows that...". Afterwards, a probe sentence, which could be, in turn, either affirmative (e.g., *De sejeste mænd kender sæbe*, 'The toughest men know soap') or negative (e.g., *De sejeste mænd kender ikke sæbe*, 'The toughest men know not soap') was presented. Participants' task was to judge the correctness of the probe sentence. Again, behavioral data were characterized by significantly longer reaction times for negative probes in comparison with affirmative probes. Similarly to Hasegawa et al. (2002), imaging results showed increased activation for negative sentences in the left premotor cortex, even though Christensen (2009)'s subjects were tested exclusively in their native tongue. In addition, previously unreported enhanced activation in the right supramarginal gyrus for affirmatives sentences was observed. These apparently puzzling results have been explained by the author as a consequence of the distinct cognitive resources involved in the processing of the two types of sentences: while left premotor cortex greater activation during negative sentences interpretation would reflect the increased syntactic processing required by the presence of the negative phrase, right supramarginal gyrus activation detected during affirmative sentences processing would represent the response of the higher semantic processing derived from affirmative sentences' upward entailing nature.[39] Regardless the validity of this latter interpretation, it is easily notable that the fMRI data of the three studies presented so far are only partially convergent: Carpenter et al. (1999) report greater activation in the parietal region bilaterally and in left posterior temporal cortex for negative sentences and no effect for affirmatives; Hasegawa et al. (2002) found enhanced activation only in left hemisphere regions (posterior temporal cortex, the supramarginal gyrus, and the precentral cortex), and limited to subjects' second language processing; Christensen (2009) observed a similar activation of the left

[39] We mentioned this aspect in note 5. The reader interested in further explanations of this data and on the relative hypothesis is referred to Christensen (2009)'s paper.

premotor cortex during the interpretation of subjects' native language stimuli. As noted by Christensen (2009), however, most of these divergences are likely to be the consequence of differences in design and procedure, on the one hand, and of methodological limits of the three studies, on the other. Carpenter et al. (1999), for example, considered a very narrower region, leaving aside some of the areas observed in Hasegawa et al. (2002)'s and Christensen (2009)'s study. Carpenter et al. (1999) and Hasegawa et al. (2002)'s results, on the other side, might have been biased by the relatively low number of participants (8 and 10 subjects, respectively). Even if, therefore, no definitive conclusions can be drawn from current fMRI findings, it is worth noting that all the three studies mentioned associated negative sentences interpretation with enhanced brain areas activation and that, in at least two of them, left premotor cortex (B6) has been reported as most directly involved in the processing of negation (Hasegawa et al., 2002; Christensen, 2009).

Completely different results have been reported by Tettamanti et al. (2008), Tomasino, Weiss, and Fink (2010), Liuzza, Candidi, and Aglioti (2011), Aravena et al. (2012), and Foroni and Semin (2013), which conversely found activation decrease for negative sentences in comparison with affirmative sentences. For clarity convenience, we postpone the consideration of these studies to § 2.1.3.1, dedicated to the consideration of the evidence suggesting that negative elements are not responsible of an enhancement of brain areas activation, but rather of their inhibition.

2.1.1.3 Negation processing is working memory dependent

As observed by Deutsch et al. (2009), the fact that negation determines slower processing of verbal materials and higher error rates in language-related tasks suggests that its computation relies on relatively non-automatic processes. This observation has lead to the construction of an experimental study specifically designed to determine the involvement of working memory resources in negation processing. Although not strictly focusing on sentential negation, but rather on the computation of single words, Deutsch et al. (2009)'s study deserve some attention as it provides first evidence of working memory involvement in negation processing, an issue particularly relevant to the experimental study presented in the second part of this dissertation. More precisely, Deutsch et al. (2009) investigated the effects of the concurrent performance of a working memory task on the evaluative priming of negated and non-negated words. Participants were presented with negative and positive words (e.g., *friends*), some of which accompanied by negation (e.g., *no friends*). Each word was followed by a Chinese ideograph, which participants were asked to judge as above or below visually pleasant. While half of the participants were limited to the execution of this unique task, the other half was distracted by the concurrent memorization of 8 number digits. Interestingly, the results of the 'non-distracted' group showed that subjects' responses were affected by both words valence (positive vs. negative) and negation: negated positive primes, in fact, were judged less positively than non-negated positive primes, while negated negative primes received slightly more positive responses than non-negated negative primes. The responses of the group who concurrently performed the digit memory task, on the contrary, reported no effect of negation, but a still significant effect of word valence. This latter evidence, therefore, indicates that the cognitive loads determined by the simultaneous performance of the working memory task specifically interfered only with the possibility of quickly interpreting negation, but not with the execution of the evaluative priming task *per se*, neither with those aspects which are not working memory dependent (e.g., word valence). The results of the 'non-distracted' group, on the other hand, showed that, if working memory resources are not otherwise taxed, negation can be processed very quickly and almost automatically, as it mostly happens in everyday language usage.

The observation that, under particularly demanding conditions, negation is not computed automatically but depends on 'conscious', effortful processing constitutes a central findings of Herbert and Kübler (2011)'s study as well. In this latter study, participants were presented with both semantically congruent (e.g. *no summer-winter*) and incongruent words-pairs (e.g., *no summer-sun*) and sentences (e.g., *Dogs cannot fly* vs. *Dogs cannot bark*), and were asked to mentally evaluated the truth-value of each statement on the basis of their factual knowledge. During the execution of the task, event-related potentials were recorded trough EEG.[40] Brain potentials analysis showed that the detection of the incongruence between the stimuli and subject's factual knowledge associated with the raising of the P600 brainwave, which have been connected with memory-based stimulus encoding and post-semantic reintegration processes. P600 amplitudes, in addition, were larger when the words were preceded by semantically congruent negated primes (e.g. *no summer-sun*) than when they were accompanied by semantically incongruent nouns (e.g., *no summer-winter*) and, correspondingly, in the cases in wich false sentences contained two related words (e.g., *<u>Dogs</u> cannot <u>bark</u>*) than in the case of true sentences constituted by unrelated words (e.g., *<u>Dogs</u> cannot <u>fly</u>*). This latter observation, therefore, shows that P600 was not determined by the simple automatic priming of the verbal materials, but rather by higher-order processing determined by the interpretation of negation, as demonstrated by its sensitivity to sentence truth-value.

Implicit evidence of memory resources involvement in negative sentence interpretation comes from Christensen (2009)'s fMRI study. As said, the study reports negative sentence interpretation to be characterized by a greater activation of by left premotor cortex than that of affirmative sentences, a data which may reflect the major syntactic processing required by the presence of negation. As observed by the author himself, however, left premotor cortex is not only

[40] We do not provide an introduction to the EEG technique at this point as we will devote § 2.3.1 to this purpose. The reader in need of information about event-related potentials, therefore, is referred to dedicated section below.

responsible for the execution of structure-dependant non-motor mental tasks (such as syntactic processing), but it has also been found to be highly involved in high-ruled governed working memory processes. In this latter view, therefore, left premotor enhanced activation during negative sentences processing would be clearly in line with Deutsch et al. (2009)'s and Herbert and Kübler (2011)'s observations.

2.1.2 Negation processing context sensitivity

While easily recognizable in experimental studies, the processing difficulty of negation appears much less evident in everyday communication, where negative sentences are used with almost the same frequency than affirmatives and seem to be processed with the same easiness. This asymmetry is determined, as we will see, by the different contexts in which the sentences are uttered. In natural language situations, in fact, independently from their truth-value, negative sentence are generally used – as we said – to correct an expectation (Wason, 1965; Givón, 1978), or to deny an information already presented in the discourse context (Horn, 1989). In most experimental studies, on the contrary, the use of negative sentences is not pragmatically justified and determines a sense of strangeness which burdens the 'normal' process of interpretation. Moving from this observation, numerous studies have shown that the processing cost associated with the negative sentences may be extremely reduced if they are uttered in a context of plausible denial.

Wason (1965) investigated a corollary hypothesis of the notion of plausible denial,[41] the *exceptionality hypothesis*, according to which – if it is true that the plausibility of a negative sentence depend upon both the presence of a prior expectation and the plausibility of its positive counterpart – negation might be most naturally used to predicate about a dissimilar item set off against a class of similar items, rather than about one of the items similar to all the others. To test this hypothesis, he presented the participants with a picture of eight numbered circles, of which seven colored red and one colored blue (circle 7), and asked them to complete a series of fragments concerning the circles' properties. The results showed that, although completing negative fragments (e.g., *Circle 4 is not…*) took generally longer than completing affirmative fragments (e.g., *Circle 4 is...*), the difference was significantly smaller when the negative sentences referred to the circle with the exceptional color (e.g., *Circle 7 is not red*) than when they referred to one of the seven other circles (e.g., *Circle 4 was not blue)*. The results, therefore, reflected the predictions of Wason's notion of plausible denial: while the seven vs. one proportion of red and blue circles, in fact, could give the participants the expectation of circle 7 to be red and make it plausible to use negation for correcting it, the context provided no expectation of circle 4 to blue, a correction of which

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[41] As we said, the notion of *context of plausible denial* recognizes the plausibility of a negative sentence in (a) the presence of a prior expectation that has to be denied, and (b) the plausibility of the prior statement itself.

resulted, therefore, pragmatically inappropriate. Similarly, while the plausibility of the sentence *Circle 7 is not red* relied in the plausibility of its affirmative counterpart (i.e., *Circle 7 is red*), the implausibility of *Circle 4 is not blue* was an effect of the implausibility of its affirmative correspondence. Wason (1965)'s results have been confirmed by Villiers and Flusberg (1975)'study on the interpretation of negative sentences by children between 2 and 4 years. Children were presented with a stimulus set of seven cars and one bottle and were asked to judge the correctness of related sentences. As expected, participants needed more time and made more errors in the verification of the implausible negative sentence *This is not a bottle* in comparison with the more plausible *This is not a car*.

Many studies, on the other hand, focus on Wason's first constrain, showing that the processing difficulty traditionally associated with negative sentence interpretation disappears when there are accompanied by an adequately informative context, instead of being presented in isolation. Glenberg and Robertson (1999) compared the time needed for reading affirmative and negative sentences following a supportive (e.g. sentences like *The couch was/wasn't black* after a context discussing the choice of color for a new couch,) and a non supportive context (similar sentences preceded by context lacking relevant information). The results showed that, when sentences were accompanied by an adequately informative context, affirmative and negative versions took equally long to be read; when the same sentences were presented in a non-supportive context, on the contrary, negative sentences were read more slowly than affirmative sentences. Such findings, therefore, confirm the different pragmatic requirements of affirmative and negative sentences, showing that the absence of an adequately supportive context represents an impediment for negative sentence interpretation, but not for affirmative sentences interpretation. Glenberg and Robertson (1999)'s observation has been confirmed and extended in two experiments by Lüdtke and Kaup (2006). In the first experiment, participants were asked to read affirmative and negative sentences (e.g., *The water was/was not warm*) concerning a target entity (e.g., water) which had been previously introduced in a prior text that provided – in all cases – in an adequate context for sentence interpretation. Nevertheless, the text introducing the target entity could differ along two directions: first, the proposition that was affirmed or negated by the experimental sentence could be explicitly mentioned or not (e.g., *She wondered whether the water would be warm* vs. *She wondered what the water would be like*); second, the same characteristic could presented as the only possibility or as one of two alternatives (e.g., *She wondered whether the water would be warm* vs. *She wondered whether the water would be warm or cold*). The results of this first experiment replicated Glenberg and Robertson (1999)'s findings showing that the reading time of negative sentences benefits from the prior explicit mention of the negated proposition, independently of whether it was presented as the only possibility or as one of two possibilities, whereas the reading times of the affirmative sentences were not affected by context manipulations. In the second experiment, the experimental sentences were also introduced by a short narrative story aiming at constituting a felicitous pragmatic context for the negative sentences interpretation, but the property concerning the target entity (e.g., a boy's T-shirt dirtiness after he played outside in the backyard) was never explicitly mentioned, and could only be inferred – more or less strongly – by the text. Experimental sentences, then, represented a correction of this inference either by means of an affirmative statement (e.g. *The T-shirt was clean*) or by means of an explicit negation (e.g., *The T-shirt was not dirty*). Interestingly, the results of this second study showed that contexts strongly implying a prior expectation facilitate the interpretation of negative sentences correcting that expectation exactly as it happened in the cases in which the prior context explicitly mentioned the relevant property of the target entity (Exp.1). When the context did not strongly suggest the negated proposition, however, negative sentences required more processing time than their affirmative counterparts. As explained by the authors, therefore, the results of the two experiments further confirm that the presence of a prior expectation to be denied makes negative sentences pragmatically even more adequate than affirmative and, thus, very much easily interpretable.

Similar evidence of the facilitative effect of contextual information have been reported in two action-dynamic follow-up studies by Dale and Duran (2011), which compared the mouse-trajectories associated with the interpretation of affirmative and negative sentences presented out of the context (Experiment 1, see § 2.1.1) with those connected to the interpretation of sentences inserted in a context of plausible denial. In Experiment 2, the same sentences used in Experiment 1 (e.g., *Elephants are/are not small*) were tentatively made more plausible through the insertion of a preceding simple question (e.g., *You want to lift an elephant? Elephants are not small*). In Experiment 3, richer contextual information are provided, as both the question introducing the experimental sentence and the sentence itself were described as a statement of an adult correcting a child. In both experiments, participants were asked to judge whether they consider the final statements to be sensible or nonsense by clicking a circle corresponding to *yes*/*no* appearing on the screen. As in Experiment 1, mouse-trajectories were analyzed in terms of discreetness and acceleration/deceleration patterns and interpreted as measures of the processing difficulty. Unexpectedly, Experiment 2 reported higher discreetness in the mouse-trajectories for negatives than for affirmative sentences, indicating that the sentences were still perceived as pragmatically implausible. In Experiment 3, on the contrary, sentences' pragmatic felicity determined by richer contextual information was reflected in a significant reduction of mouse-trajectories' discreetness and speed alternations.

Tian, Breheny, and Ferguson (2010) investigated negative sentences contextual sensitivity from a completely different perspective by comparing the interpretation of simple negative sentences (e.g., *Jane didn't cook the spaghetti*) and cleft sentences with negative clauses (e.g., *It was Jane who didn't cook the spaghetti*). The choice for this latter kind of sentences was motivated by the fact that, differently from simple sentences, cleft sentences are considered to be presupposition triggers. In this view, therefore, while the interpretation of simple negative sentence in isolation is expected to be burdened by the need of resolving the sense of inappropriateness determined by the lack of contextual information, the use of negative cleft sentences interpretation in isolation should result in effortless comprehension processes. To illustrate, while a sentence like *Mike didn't hire his shirt* presented out of an adequate context (e.g., a discourse yielding the presupposition that Mike should have hire his shirt) is inevitably perceived as inappropriate to some extent, a sentence like *It was Mike who didn't iron his shirt* brings by itself the implicit presupposition that someone did not hire his/her shirt, resulting pragmatically more appropriate even when presented out of any supportive context. To test this hypothesis, the authors designed an experiment very similar to Kaup et al. (2007): 250ms after having read a sentence of the type *Mike didn't hire his shirt*/*It was Mike who didn't iron his shirt*, participants saw a picture either matching the actual meaning (e.g., a crumpled shirt) or the negated meaning of the sentence (e.g., an ironed shirt), and were asked to decide whether the depicted item (i.e., the shirt) had been mentioned in the sentence they read or not. Response times after simple negative sentence were longer when the picture matched the negated state of affairs than when it matched the actual state of affairs, indicating that the comprehenders have not yet integrated negation into the interpretation process. Response times with cleft sentences, on the contrary, were characterized by the inverse pattern, with shorter reaction times when the image matched the actual meaning of the sentence than when it mismatched it, indicating that the interpretation process was faster in this condition in comparison with simple negative statements. As expected by the authors, the pragmatic properties of cleft sentences had a significant facilitative effect on the interpretation of negative statements in isolation.

As we will discuss more extensively in § 2.1.3, to conclude, a large extent of studies have shown that contextual consideration have an important influence on the possible suppression or retention of the concepts under the scope of negation (see, for example, Giora et al., 2007).

Studies employing neuroimaging techniques and, in particular, EEG-ERP recording, however, have only partially confirmed previous behavioral findings. Fischler et al. (1983) analyzed the event-related potentials associated with the interpretation of affirmative and negative sentences predicating the membership of a concrete noun (e.g., *bird*) to a superordinary category name (e.g., *bird*/*vehicle*). Contrary to Fischler and colleagues' predictions, N400 potential (generally associated to the detection of semantic anomalies and violations) resulted more sensitive to the relationship between the concrete noun and the category name, than to sentences' effective meaning. To exemplify, N400 was larger for true negative sentences containing two incongruent nouns (e.g., *The robin is a vehicle*), than for false negative sentences predicating about two semantically proximal nouns (e.g., *The robin is not a bird*). In the subsequent literature on the pragmatics of negation, Fischler et al. (1983)'s data have been taken as a confirmation of Wason (1965)'s constrains on the context of plausible denial, according to which the plausibility of a negative statement is strictly connected to both its relevance to the prior linguistic context and the plausibility of its affirmative counterpart. As explained by Staab et al. (2008), since sentences were presented in isolation, participants' expectations were inevitably related with the semantic category of the concrete noun opening each sentence; as a consequence, statements which involved a category with no semantic relationship with the concrete noun mentioned were therefore perceived pragmatically more infelicitous than those predicating about a semantically related class of entities. Regardless of the appropriateness of this latter explanation, Fischler et al. (1983)'s results provided important confirmation that pragmatic aspects have strong effects on negative sentences interpretation, at the point of exercising – when not controlled – an even major influence than sentences' truth-value. As clearly demonstrated by Staab et al. (2008)'s and Nieuwland and Kuperberg (2008)'s subsequent studies, however, when negative sentences are presented in appropriate linguistic contexts, sentences truth-value has also an influence on N400 component. Staab et al. (2008) recorded even-related potentials during the verification of both affirmative and negative sentences (e.g., *... so he bought/he didn't bought the pretzels/the cookies*), which had been previously introduced by a short story (e.g., *During his long flight Joe needed a snack. The flight attendant could only offer him pretzels and cookies*) and by a bias sentence which had the purpose of orienting participants' expectations (e.g., *Joe wanted something salty.../Joe wanted something sweet....*). To simplify, a whole story ending by a true negative sentence would be constituted as follows (the target sentence is underlined): "*During his long flight Joe needed a snack. The flight attendant could only offer him pretzels and cookie. Joe wanted something salt, <u>so he didn't bought cookies</u>".* N400 analysis showed that false sentence endings elicited larger negativities than true ones, although the effect reached significance only for affirmative sentences. Nieuwland and Kuperberg (2008) compared event-related potential elicited by the interpretation of pragmatically licensed and pragmatically unlicensed sentences. Pragmatically felicitous sentences were introduced by a single statement (e.g., *With proper equipments...*) relevant to the target affirmative or negative sentence, which could be either true (e.g., *With proper equipments, scuba-diving isn't very dangerous/scuba-diving is very safe*) or false (e.g., *With proper equipments, scuba-diving isn't very safe/scuba diving is very dangerous*). Pragmatically infelicitous sentences were introduced by the same statements used for the pragmatically felicitous sentences, although in these cases the introductive statement was almost irrelevant to the meaning of the following sentence (e.g., *With proper equipments, bullet-proof vest are/aren't very dangerous/safe*). The results showed that, when sentences had been appropriately introduced, N400 activation was modulated by the truth-value of the final word of each sentence for both affirmative and negative sentences, with false words enhancing larger N400 than true words. When sentences were not presented in a pragmatically felicitous context, very differently, N400 increased activation was observed after false words in affirmative sentences, but also after true words in negative sentences (e.g., *With proper equipments, bullet-proof vest aren't very safe*). Ferguson et al. (2008), nevertheless, reported evidence indicating that, in sharp contrast with Staab et al. (2008) and Nieuwland and Kuperberg (2008), event-related potentials are not immediately affected by prior contextual information's manipulation. Ferguson et al. (2008) investigated the interpretation of sentences introduced by a negated-world context (e.g., *If cats were not carnivores they would be cheaper for owners to look after*). Subsequent sentences could represent a congruous continuation (e.g., *If cats were not carnivores, they would be cheaper for owners to look after. Families could feed their cats a bowl of carrots and listen to it purr happily*) or an incongruent continuation of the negated-world prior assumption (e.g., *If cats were not carnivores, they would be cheaper for owners to look after. Families could feed their cat a bowl of fish and listen to it purr happily*). The results showed that inconsistent continuations elicited a more negative-going N400 potential (typically revealing semantic and pragmatic anomalies) than context-consistent sentences. Despite the prior negated-world context, therefore, brain potentials were modulated on the basis of subjects' real-world knowledge, suggesting that the interpretation process was not immediately updated with the contrafactual context introduced by the *if* sentence. Given the complexity of the issue, however, we postpone a more detailed discussion of these conflicting ERP results to § 2.3.3, specifically dedicated to the consideration of the EEG in the investigation of negation processing.

Taken all together, the available evidence speaks in favor of important differences in the processing of negative sentences when presented in isolation/irrelevant context and in supportive contexts, mostly confirming Wason (1965)'s predictions on the plausibility of negative sentences. It remains unclear, however, whether the context provides a facilitation of the processing of linguistic structures which are, *per se*, difficult, or whether, on the contrary, presentation of negative sentences in isolation induces difficulty on an otherwise smooth linguistic operation. Ferguson et al. (2008) have provided interesting observations in this regard. Beyond the EGG study we considered above, the same authors performed a eye-tracking experiment to compare the processing of sentence either introduced by a real-world congruent utterance (e.g., *If cats are hungry…*) or by a statement contradicting general world-knowledge (e.g., *If cats were not carnivores…*). In both cases, the first sentence was followed by a sentence which could be either consistent or inconsistent with the given context yielding four possible situations: real-world consistent sentences (e.g., *If cats are hungry, they usually pester their owners until they get fed. Families could feed their cat a bowl of fish and listen to it purr happily*); real-world inconsistent sentences (e.g., *If cats are hungry, they usually pester their owners until they get fed. Families could feed their cat a bowl of carrots and listen to it purr happily*); negated-world consistent sentences (e.g., *If cats were not carnivores, they would be cheaper for owners to look after. Families could feed their cat a bowl of carrots and listen to it purr happily*); negated-world inconsistent sentences (e.g., *If cats were not carnivores, they would be cheaper for owners to look after. Families could feed their cat a bowl of fish and listen to it purr happily*). The analysis of eye-movements showed that sentences incongruent with real-world based contexts had longer reading times, more fixations and a higher incidence of regressions to the critical noun (namely, the words which determined sentence congruency or incongruence with the previous context, i.e., *carrots*/*fish*) than real-world congruent sentences. Sentence introduced by a negated-world context, on the other hand, were characterized by a delayed integration of the critical word (i.e., *carrots*/*fish*), reflecting subject's need to resolve the conflict between her factual knowledge and the prior-context information. According to the authors, precisely this need would induce the comprehender to override automatic language processing and to activate a reflective, memory-based component, resulting in delayed inconsistency detection. Very similarly, it could be argued that, when negative sentences are interpreted in isolation, the comprehender has to resort to non-automatic, working memory based processes to compensate for the lack of contextual information, taxing working memory resources of an extra effort beside that of processing negation (with an effect very similar to that induced by Deutsch and collegues trough the insertion of a secondary, concurrent task during sentence processing, § 2.1.1.3). The interpretation of negative sentences in isolation, therefore, would simply highlight the nature of negation processing, showing its non-full automaticity.

To conclude, therefore, while it seems fundamental that experimental studies provide sufficient contextual information to make the utterance of a negative sentences pragmatically not completely implausible, it seems equally important that the embedding context does not produce a stronger expectation for a negative sentence than for a positive one, thus having the effect of overriding eventual differences between the two types of sentences.[42]

2.1.3 Negation effects on negated concepts accessibility

A last issue which has been extensively investigated since very early studies on negative elements concerns the consideration of negation as an operator that shifts attention away from the information mentioned within its scope, reducing the accessibility of this information. First data in this direction have been reported in MacDonald and Just (1989)'s probe-recognition task, in which subjects were asked to decide whether a certain probe (e.g., *cookies*) was present in a previously read sentence or not (e.g., *Almost every weekend Mary bakes some bread but no cookies*). The results showed that subjects were significantly slower in recognizing the probes which had appeared under the scope of a negative element (e.g.,

[42] From the methodological point of view, it must also be pointed out that, as Dale and Duran (2011)'s second experiment clearly shows, some attempts of creating adequate linguistic contexts for the utterance of negative sentences in experimental studies produce the contrary effect, rendering the use of some sentences even more absurd, e.g., *Flying cars? - Cars have no wings!* (Dale and Duran, 2011, Experiment 2). As the third experiment performed by the same authors suggests, therefore, it seems easier to give to the experiment a completely 'artificial' setting (e.g., presenting the statements as pronounced by an adult to a child), rather than attempting to make natural the elicitation of true negative sentences based on world-knowledge in experimental settings.

cookies), in comparison with non negated probes (e.g., *bread*), a fact that which have been traditionally interpreted as an effect of the reduced lexical accessibility of negated terms.[43] Subsequent studies, however, have better clarified this observation, showing that the inhibition power associated with negation is also strongly influenced by the situational context in which the negative sentences are presented. This latter aspect have been made particular evident by two studies by Kaup (1997; 2001), partially replicating MacDonald and Just (1989)'s conditions. More precisely, Kaup suggested that the different accessibility of negated and non-negated terms may also be determined by the fact that, while the non-negated words (e.g., *bread*) corresponded to concepts which were present in the described situation, the negated words did not (e.g., *cookies*). To demonstrate this hypothesis, Kaup (1997; 2001) developed two target-to-probe recognition tasks involving both negative sentences referring to constructing actions (e.g., *Every weekend Mary <u>bakes</u> some bread but no cookies baking*) and negative sentences based on deconstructing actions (e.g., *Peter <u>burns</u> the old bed but not the big cupboard*). The choice of these verbs permitted a control of the effects of the probes' presence in the described situation: while, in fact, the lexical properties of constructing verbs determined the presence in the situation of the non-negated objects of the predicate, but not that of the negated terms, deconstructing verbs allowed the presence in discourse of the negated terms (e.g., *the big cupboard*), but not that of non negated concepts (e.g., *the old bed*). The results confirmed the author's expectations. In the cases of constructing verbs sentences, in which the presence/absence of negation was the only variable influencing words accessibility, negated probes were recognized slower than non-negated ones. When, however, the lexical properties of the verb also had an effect on the representation on the entities in the described situation, as it happened with deconstructing verbs, no differences in the accessibility of negated and non-negated term were observed, reflecting the fact that, in this latter condition, the two variables counter acted each other.[44]

Similarly, Giora and colleagues (2007) reported various evidence indicating that the suppressing effect of negation is inhibited when the retention of the negated meaning it is functional to global discourse considerations. The first experiment investigated the influence of late contextual information on the possible suppression/retention of previous negated information. The same metaphorical expression used in Hasson and Glucksberg (2006)'s study (e.g., *The train was no rocket*) were followed by wither congruent (e.g., *The trip to the city was fast*

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[43] Correspondingly, studies investigating the interpretation of quantifiers reported that negative quantifiers determine a similar inhibitory effect (Sanford, Moxey, and Paterson, 1996).

[44] Kaup and Zwaan (2003) further examined the influence of the presence of the negated concepts in the described situation on the processing of negative sentences, reporting results mainly in line with the two previous studies mentioned above. As recognized by the authors themselves, however, important differences in the lexical properties of the verbs used and in the resulting inferences make it difficult to draw definitive conclusions from this study. The reader interested in more information is therefore referred to the original work.

though) and or incongruent continuation strings (e.g., *The old man in the film spoke fast*). The results showed that, when negative metaphors were followed by coherent strings, the negated concept (e.g. *fast*) was non suppressed, but it primed the next discourse segment even when the second fragment was presented with a delay of 1,000ms. On the contrary, when the sentences were continued by an incongruent continuation, no facilitation of the related concepts (e.g., *fast*) was observed, suggesting that the irrelevant late context invited the suppression of the preceding negated concept (e.g. *rocket*). A second experiment performed by the same authors showed that, similarly, prior relevant contextual information (e.g., *I live in the neighborhood of millionaires who like only their own kind. Nonetheless on Saturday night, I also invited to the party at my place a woman who is not wealthy*) allowed retention of the negated concept (e.g., *wealthy*) even as long as 750ms following the sentence onset. The third experiment reported within the same study showed that negated information relevant to prior concept, however, loses accessibility between 750 and 1000ms after the sentence onset. These latter findings confirm previous studies' results showing that, even when no contextual cues invite to the retention of the negated concept, accessibility-reduction is not immediately observable, but it occurs in later stages of sentence comprehension. Hasson and Glucksberg (2006), for example, demonstrated that, when subjects were asked to perform a lexical decision task either 150 or 500ms after the onset of a negative sentence (e.g., *The train to Boston was no rocket*), lexical decisions on incompatible concepts (e.g., *fast*) were easier than those on compatible concepts (e.g., *slow*), reflecting – as we already said – initial insensitivity to negation. When, however, the execution of the task was postponed at 1000ms after sentence onset, this facilitative effect disappeared, since negation had now prompted the inhibition of the term under it scope. When the task was performed with affirmative sentences, on the contrary, the facilitation effect associated with compatible concepts was maintained even in the 1000ms condition. Interestingly, in addition, Kaup et al. (2006), suggested that, in the case in which the alternative meaning it is clearly deducible from the negative sentence (as it happens, for example, in the case of contradictory predicates) the negated term is suppressed around 1500ms after the sentence onset in favor of the activation of the alternative meaning. This observation was made clear by the result of a study in which participants had to silently read affirmative and negative sentences in which a target entity and a contradictory predicate were being mentioned (e.g., *The door was open/not open*) and to name out as quick as possible the name of the entity appearing in the subsequent picture. The pictures, which could match or mismatch the entity's properties, were presented at two different delays: 750ms or 1500ms after sentence onset. The result showed that, when the picture was presented after a delay of 1500ms, participants had shorter response times when the picture matched the actual meaning of the sentence (e.g., a close door after having read the sentence *The door was not open*) then when it matched the negate term (e.g., an open door), reflecting the suppression of the negated meaning and the activation of actual one.

Very similarly, Mayo, Schul, and Burnstein (2004) and, more recently, Orenes, Beltrán, and Santamaría (2014) showed that the availability of a complement term facilitates the rejection of a negated term. In Mayo, Schul, and Burnstein (2004)'s study, participants were asked to judge whether a character's description (e.g., *Tom's clothes are folded neatly in his closet*) was either congruent or incongruent with a previous description (e.g., *Tom is not a tidy person*). The results indicated that participants were faster to judge a description congruent with the complement meaning of a previous bipolar description (e.g. *Tom forgets where he left his car keys*, compatible with the 'messy', after having read the sentence *Tom is not a tidy person*) rather than descriptions incongruent with it (e.g., *Tom's clothes are folded neatly in his closet*), suggesting that they had suppressed the meaning of the negated term and activated its alternative antonym. The evaluation of sentences referring to unipolar descriptions (e.g., *Rosy is not an adventurous person*), on the contrary, was facilitated when the statement to be evaluated was related with the negated term of the previous sentence, although being incongruent with the meaning of the first description (e.g., the *adventurous*-congruent description *Roy loves to travel to distant places*), than when it was congruent with the actual meaning of the sentence (e.g., *Roy is stressed by any change in his life*). This difference has been interpreted as an indication that the suppressive effect of negation is strongly influenced by the nature of the term under the scope of negation: while the availability of a complement concept induces a focus shift from the negated concept to its alternative opposite (as shown by the facilitative evaluation of congruent descriptions), its unavailability invites to retention of the meaning negated. Orenes, Beltrán, and Santamaría (2014)'s visual word paradigm study reported very similar results. In this latter study, participants were firstly presented with a verbal description of a binary (e.g., *The figure could be red or green*) or multary context (e.g., *The figure could be red, or green, or blue, or yellow*). After which, they listened an affirmative or negative target sentence (e.g., *The figure was/was not red*) while four figures of different colors were presented on the screen. Eye movements were recorded to control for subjects' attention shifts. The analysis of the data showed an increased fixation on the mentioned color for affirmatives in both binary and multary contexts. Differently, negative sentences presented different pattern of eye movements in the two conditions: negative sentences following multary descriptions were characterized by an increased fixation on the mentioned colored around 400ms after the end of the sentence, similar to that observed with affirmative sentences; negative sentences introduced by multary contexts, on the contrary, reported increased fixation on the alternative color that varied with respect to the baseline around 1340ms after the end of the sentence. This difference, therefore, confirms that suppression of the negated term is not the default strategy for negative sentence interpretation, but that it is the preferred option if a complementary term is available. The significant difference in the time course of fixations in the two conditions, in addition, suggests that the suppression of a complementary negated term and the attention shift toward its alternative represent a demanding, time consuming operation.

To conclude, Giora et al. (2005) and Paradis and Willners (2006) showed that, in many circumstances – even in presence of bipolar terms – negation does not determine a suppression of the concept under its scope, but rather its *mitigation*. Evidence in this direction comes by two very comparable studies in which subjects were asked to mark the position of a target noun (e.g., *road*) on a scale ranging from two extreme points (e.g., *narrow*-*wide*).[45] All the target terms had been previously introduced within a sentence in which they could either being definite by a negated scalar adjective (e.g., *The road along the coast is not wide*) or by a non-negated one (e.g., *The road along the coast is narrow*). Interestingly, targets which were presented in negative statements were mostly marked with non-extreme positions on the scale, suggesting that an expression as ‘not wide’ was interpreted as more close to ‘less than wide’ than to ‘narrow’ (as it would be if negation had completely suppressed the meaning of *wide*). Conversely, affirmative items were most frequently assigned to scalar end positions.[46]

2.1.3.1 Negation inhibition of neuronal activation

Recent research investigating brain areas involvement in language processing has provided important neurological confirmation of the inhibitory effect of negation. In particular, a growing number of studies have shown that negative elements determine a reduction of the activation of the brain areas associated with the simulation of the linguistic concepts under the scope of negation. As we mentioned, first evidence in this direction have been reported by Tettamanti et al. (2008). This fMRI study was designed in continuity with Tettamanti and Buccino (2005), which compared cerebral activations determined by the action-related sentences (e.g., *Ora io mordo la mela*, ‘Now I bite the apple’) with that associated to abstract sentences interpretation (e.g., *Ora io apprezzo la fedeltà*, ‘Now I appreciate the loyalty’). The results of this latter study show that the different properties of the words within the sentences are also reflected in different neuronal activations: although all stimuli enhanced left premotor cortex activity, the processing of action-related words additionally involved the entire left fronto-parieto-temporal system, including the inferior parietal lobule and the posterior temporal cortex. The interpretation of sentences containing abstract content words,

[45] The examples are taken from Paradis and Willners (2006)’s study, which we mentioned also in § 2.1.1. Analogous materials have been used by Giora et al. (2005).

[46] Another piece of evidence which, according to Giora et al. (2005), speaks against the consideration of suppression as the default effect of negation is represented by the fact that, when asked to judge the global acceptability of a sentence, subjects are sensitive also to the meaning of the negated terms contained in it. To illustrate, the results of the study showed that participants consider sentence containing two items categorizable in the same set (e.g., *What I bought yesterday was not a* <u>*bottle*</u> *but a* <u>*jug*</u>) significantly more acceptable than sentences constituted by items from different sets (e.g., *What I bought yesterday was not a* <u>*bottle*</u> *but a* <u>*closet*</u>). As observed by the authors, if – on the contrary – the meaning of the negated term had been suppressed altogether, no effects of it should have been found in the evaluation task.

on the other hand, associated with the activation of the posterior cingulate cortex. On the basis of this findings, Tettamanti et al. (2008) presented their participants with both the affirmative and the negative versions of the action-related and abstract sentences employed by Tettamanti and Buccino (2005). The results of this second study show that negative sentences determine a reduction of brain activity in comparison with their affirmative counterparts. In particular, the processing of both action-related and abstract related negative sentences was characterized by a reduced activation of the pallido-cortical areas. In addition, the two types of sentences tested determines the deactivation of the representation systems correspondent to the semantic properties (concrete vs. abstract) of the concept expressed: while action-related negative sentences associated with a reduction of the hemodynamic response in the left fronto-parietal regions, abstract related sentences were accompanied by a hemodynamic deactivation of posterior cingulated cortex.

Subsequent studies further investigated the effect of negation on motor circuitry activity associated with action-related verbs and, in particular, with verbs referring to hand activities. Tomasino, Weiss, and Fink (2010) analyzed the different brain activation elicited by the interpretation of affirmative and negative imperative sentences, either composed by hand action-related verbs (e.g., *Do write/Don't write*) or by meaningless pseudo-verbs (e.g., *Do gralp*/*Don't gralp*; control condition). After having silently read each imperative statement, participants were asked to judge whether they consider the verb to make sense or not. Beside neuronal activation related to the execution of the lexical decision task (the consideration of which goes far beyond the interest of the present discussion), Tomasino et al. (2010) reported significant activation of motor areas during the processing of affirmative action-related imperatives, and decreased primary motor and premotor cortex activation for negative action-related negative imperatives, suggesting that linguistic negation exercises – as we said – an inhibitory effect on brain activations. Behavioral results of action-related verbs were similarly modulated by sentence polarity, with negative imperatives reporting longer response times to the lexical decision task than affirmative imperatives, a data that the author interpret as a consequence of the reduced lexical accessibility of the negated terms. Neuronal activity associated with non-existing verbs, on the contrary, was not influenced by sentence polarity. Importantly, even though in some cases pseudo-verbs also determined an activation of motor areas, neither this association was systematic, nor negated version of the same pseudo-verbs determined the inhibition of those areas.

Similarly to Tettamanti et al. (2008), two subsequent studies by Liuzza, Candidi, and Aglioti (2011) and Alemanno et al. (2012) further investigated motor areas activation during affirmative and negative hand action-related sentences in comparison with affirmative and negative abstract sentences. Liuzza and colleagues made use of the TMS technique (and, in particular, to the recording of motor-evoked potentials from a specific hand muscle)[47] to measure motor system excitability during sentence interpretation. The analysis of the results confirmed that while reading affirmative action-related sentences (e.g., *Io spremo il limone,* 'I squeeze the lemon') induces the activation of sensorimotor neuronal systems, affirmative abstract sentences (e.g., *Io ricordo il passato,* 'I remember the past') do not produce the same affect. Most relevant to our purpose, in addition, sensorimotor modulation were not observable when action-related verbs were accompanied by negation (e.g., *Non spremo il limone*, 'I don't squeeze the lemon'), providing further confirmation of the inhibitory effect of negation. Alemanno et al. (2012) employed EEG to record mu ERD associated to silent reading of four different types of sentences: affirmative hand-action related sentences (e.g., *Io scrivo*, 'I write'), negative hand action-related sentences (e.g., *Non scrivo*, 'I don't write'), affirmative abstract sentences (e.g., *Io penso*, 'I think'), and negative abstract sentences (e.g., *Non penso*, 'I don't think). After having read each sentence, the subjects were asked to decide whether the verb they had just read has high or low frequency in Italian. Mu ERDs are patterns of electrophysiological waves reflecting the motor cortex activity which occurs during movement execution or visualization of performing a motor action. More precisely, motor cortex areas activity can be measured in terms of mu waves suppression or desynchronization, as a consequence of the large numbers of neurons forming EEG waves and firing in synchrony.[48] In line with previous finding on motor areas involvement in action-related concepts processing, Alemanno et al. (2012) reported significant mu rhythm desynchronization over the left motor and pre-motor areas (usually involved in uni and bi-manual programming and execution) during the reading of affirmative hand-action sentences, compared with abstract sentence reading. Negative hand-action sentences, in addition, were characterized by delayed mu ERD and by mu waves of larger amplitudes, reflecting the minor involvement of cortex areas determined by sentence negative polarity.

Aravena et al. (2012) and Foroni and Semin (2013) provided even more direct measures of negative sentences motor deactivation thanks to experimental tools able to record the activity of very specific muscles. Aravena et al. (2012) analyzed the force with which participants hold a grip-force sensor while listening affirmative sentences containing hand actions (affirmative condition; e.g., *At the Gym, Fiona lift the dumbbells*), negative sentences with hand actions (negative condition; e.g., *In the plane, Laura doesn't lift her luggage*), and affirmative sentence composed by abstract verbs plus concrete nouns (control condition, e.g., *In the spring, Edmond loves the flower bush in the garden*). As explained by the authors, enhanced motor activity was expected to produce an immediate increase in

[47] TMS (short for Transcranial Magnetic Simulation) is a non-invasive method which allows the activation of specific areas of the brain through the alteration of their electromagnetic field. More precisely, short magnet pulses are administered through an electromagnetic coil held against the forehead and cause small electrical currents which stimulate the nerve cells in the specific or general parts of interest in the brain.
[48] For more information and references on mu-waves see Alemanno et al. (2012: 42).

grip-force. The results confirmed this expectation showing that action-related sentences enhanced a significant increase of the grip-force in the affirmative condition, but not in the negative condition. Interestingly, in addition, control condition sentences did not produce any modulation in grip-force modulation, confirming previous studies' observation that the processing of abstract verbs does not result in enhanced motor areas activation. Furthermore, the fact that abstract verbs were immediately followed by a concrete noun also demonstrated that motor areas activation is neither simply associated with concrete words, but only with words specifically expressing some kind of motor activity. Parallel, Foroni and Semin (2013) investigated the effect of negation on the interpretation of emotional expression either directly referring to zygomatic activity (e.g., *I'm smiling* vs. *I'm not smiling*) or not (e.g., *I'm frowning* vs. *I'm not frowning*). During sentence interpretation, zygomatic muscle activity was continuously measured on the left side of the face through Electromyography technique (EMG).[49] Again, while reading affirmative versions of zygomatic expressions lead to the activation of the zygomatic muscle, the negative versions of the same expressions determined inhibition of the same muscle already 500-700ms after stimulus onset.

To conclude, Bartoli et al. (2013) hypothesized that, if it is true that processing of linguistic expressions describing motor activity depends upon the same neuronal circuits employed for its actual execution, the concurrent interpretation of a sentence describing a specific activity and execution of that action should be facilitated with negated sentences rather than with affirmative ones. In the first case, in fact, the inhibitory effect of negation should free the neuronal recourses responsible of the concerned activity from the computational load derived from the processing of the relevant concept, thus facilitating the execution of the concurrent task. In the second case, on the contrary, the simultaneous dependency of the two tasks on the same cognitive resources should overload the correspondent neuronal circuits, resulting in a more effortful execution of the motor activity. To verify this hypothesis, two connected experiments were performed. In the first experiments, participants were presented with affirmative and negative abstract verbs (e.g., *Io auspico/Io non auspico*, 'I wish/I don't wish), affirmative and negative proximal activity sentences (involving shoulder and arm muscles; e.g., *Io afferro/Io non afferro*, 'I grasp/I don't grasp), and affirmative and negative distal activity sentences (involving hand and finger muscles; e.g., *Io pizzico/Io non pizzico*, 'I pinch/I don't pinch'). While listening to the sentences, in addition, they were asked to perform proximal reach-to-grasp movement with their thumb and index fingers toward a sphere, in response to a visual go-signal presented either immediately or 500ms after the end of the sentence. In the second experiment, participants were presented with the same set of stimuli, but were asked to performed a grasp distal movement (grasping without reaching) with their thumb and index fingers towards

[49] Electromyography is used to record the electrical potential generated by muscle cells when they are electrically or neurologically activated. For this reason, it is an extremely useful technique for the identification of the activation level of voluntary controlled muscles.

one of two possible target objects (a coffee cup or a screw). The result of the first experiment showed that, as expected, the interpretation of negative proximal sentences had reduced interference on the execution of the reach-to-grasp proximal movement, resulting in faster reaction times and delayed grip aperture for negative versus affirmative proximal sentences, compared to both negative and affirmative abstract and distal sentences. Correspondently, the results of the second experiment (requiring the execution of a distal grasp movement) reflected interference reduction only for negative distal sentences, but not for the sentences of other conditions. Beyond confirming the authors' hypothesis, therefore, overall results show that the effect of negation is concept-specific, as demonstrated by the fact that its presence determines facilitation only for the execution of tasks closely related to the semantics of the negated concept.

2.2 Models and theories on the processing of negation

As is inevitable, the emergence of conflicting evidence on the interpretation of negation has lead researchers to the formulation of different and, in some cases, contrasting hypotheses on the processing of negation. Besides relying on different models of language processing and focusing on partially diverse aspects, current theories can be divided into two main groups accordingly to two considerations: (a) the *moment of integration* of negation into the sentence's interpretative process, and (b) the *processing cost* attributed to the interpretation of negative sentences. On the one side, in fact, *non-incremental models* assume that, differently from most of the other elements of the sentence, the interpretation of negation occurs only after the consideration of the negated meaning of the sentences and that, consequently, it requires extra time and extra processing resources in comparison with the interpretation of structurally similar, non-negative sentences. On the other side, *incremental models* suggest that the semantic contribution of negation is immediately incorporated into the interpretative process, exactly as it happens for non-negative words, and that, therefore, no second stage of sentence interpretation, and no extra time or extra effort is required for the processing of negative sentences.

Though many other – and possibly more subtle – distinctions could be drawn in parallel to this very general subdivision, we will rely on this classification as it reflects, as it will become clearer in the second part of this dissertation, a quite relevant issue with respect to the goals of the present study (and, in particular, to STUDY 1, see Chapter 3, Part 2).

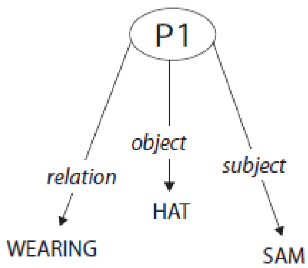
2.2.1 Non-incremental models

As briefly mentioned, non-incremental models are characterized by the assumption that the meaning of sentential negation is not integrated right away into the interpretative process. More precisely, they all share the idea that the interpretation of negative sentences pass through the consideration of its affirmative counterpart. Beyond this common feature, non-incremental models differ with regard to two main aspects (a) the theory of language comprehension assumed; (b) the way in which negation is being applied to the 'affirmative' representation of the situation described or, in other words, the way in which the negative meaning is 'captured'.

2.2.1.1 Propositional theories: Negation as a 'tag' on the proposition

Propositional theories (Kintsch & Dijk, 1978; Kintsch, 1988; McKoon & Ratcliff, 1992; Trabasso et al., 1971) represent the first model which has suggested that a negative sentence is encoded as an affirmative core. According to these account, the interpretation of linguistic material is based on the creation of a 'propositional' representation, that is, the representation of every informational unit large enough to carry a truth-value. Each proposition is defined as being composed by a relation and one or more arguments between which that relation holds. To exemplify, in propositional terms a sentence like *Sam wears a hat* would receive the interpretation: there is a person named Sam, there is a hat, and a particular relation holding between them (namely, that of 'wearing'), as illustrated below.[50]

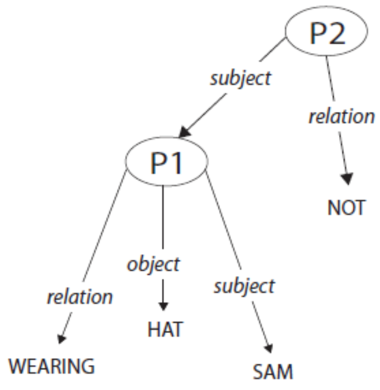
FIGURE 1. The propositional representation of an affirmative sentence.



Negation is considered as an overt linguistic operator taking a whole proposition as its argument. The presence of negation, therefore, is conceived to determine the construction of a higher level of propositional representation in which the proposition to be negated represents the argument, and the negative meaning represents the relation, as exemplified by the propositional representation of the sentence *Sam doesn't wear a hat* (FIGURE 2).

[50] Examples and relative representations are taken from Kaup (2006: 315,317).

FIGURE 2. The propositional representation of a negative sentence.



As a consequence, the interpretation of a negative sentence is considered to be necessarily more demanding than the interpretation of the corresponding sentence without negation, since the former is characterized by a more complex propositional representation than the latter.[51]

Within this theoretical framework and on the basis of experimental data reporting reduced accessibility of the negated concepts,[52] MacDonald & Just (1989) have formulated the so-called *search-for-alternatives* account. According to this latter proposal, the encapsulation of the concept under the scope of negation into a higher propositional level (expressing negation) would induce the comprehender to shift focus away from the negated concept towards an alternative replacement. As a consequence, after an initial processing insensitivity to the negative markers, the concept within the scope of negation would become very less accessible, as confirmed by the results of many studies on the issue (e.g. Giora, Balan, Fein, & Alkabets, 2005; Hasson & Glucksberg, 2006; Kaup, Yaxley, Madden, Zwaan, & Lüdtke, 2006; MacDonald & Just, 1989). More recently, the same hypothesis has been advanced by Ferguson, Sanford, and Leuthold (2008). Importantly, however, experimental evidence suggesting that the accessibility suppression of the negated term is not automatic, but highly depending on the discourse situation in which the negative sentence is uttered have also been reported (see, for example, Giora, Fein, Aschkenazi, & Alkabets-Zlozover, 2007).

[51] A similar explanation of the processing difficulty associated with negative sentences interpretation has been suggested by the proponents of the *syntactic account* who, however, do not attribute the major complexity of negative sentences to their interpretational structure, but rather to their structural properties. Most precisely, as explained by Horn (1989), early syntactic account's proponents assumed that negatives, such as other non-standard kinds of sentences (e.g., passives, interrogatives), might be characterized by relative transformational complexity, resulting in additional processing time. More recently, Christensen (2009) also empathized the structural difference between negative and affirmative sentences as the possible cause of the increased activation of left premotor cortex during negative sentence *vs.* affirmative sentence processing.

[52] See § 2.1.3 for a short description of MacDonald and Just (1989)'s study.

We will return to this point in § 2.2.2.2, dedicated to the discussion of suppressive and suppressive-like accounts of negation processing.

2.2.1.2 Early representational models: Negation as an operator applying to mental representations

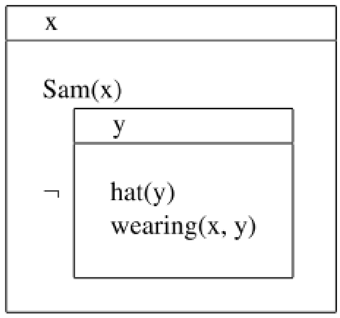
The idea that negative sentence comprehension is characterized by the application of a negative 'operator' to the representation of the situation negated has been re-proposed by early representational models of language comprehension, such as the so-called *situational-mental models* (Dijk & Kintsch,1983; Johnson-Laird, 1983; Morrow, Bower, & Greenspan, 1990, and Zwaan & Radvansky, 1998), and Kamp (1981)'s *discourse-representation theory* (DRT). Differently from propositional theories, representational approaches are characterized by the assumption that the comprehension process is grounded on the construction of *mental*, rather than propositional representations. As underlined by Kaup (2006), the difference is not simply terminological, but it is crucially connected to the nature of the linguistic representations assumed: while propositional representations were intended as a *description* of the state of affairs in a mental language, referential representations are conceived to be the *representation* of the state of affairs itself. More precisely, according to situational-mental models, the sentences to be interpreted are converted in a referential level composed by mental tokens (representing the relevant referents), and propositions (assigning properties and relations to these tokens). Very similar assumptions are made by DRT theory. To exemplify, under representational and DRT models the affirmative sentence *Sam wears a hat* receives a referential representation including two tokens, x and y, with x specified to be named *Sam* and y to be a hat. The fact that the hat is worn by Sam, in addition, is represented as a relation between the two tokes, as illustrated below.

FIGURE 3. The DRT representation of an affirmative sentence.

x y
Sam(x) hat(y) wearing(x, y)

Similarly to propositional theories, early representational models consider negation as a linguistic operator which is applied to a subordinate representation), as illustrated in FIGURE 4, corresponding to the representation of the sentence *Sam does not wear a hat*.

FIGURE 4. The DRT representation of a negative sentence.



As in propositional theories, therefore, the comprehension of a negative sentence is predicted to be more difficult than that of affirmative sentences as a consequence of the more complex representation involved. In contrast with propositional representations, nevertheless, negation does not apply both to the two tokens and to the relation between them (that is, the whole situation described, as it happened in propositional theories, but only to the relation of *wearing* and to the token corresponding to the referent *hat*. As a consequence, the two models make different predictions with respect to the availability of the two referents of the sentence. Though sharing the assumption that the accessibility of the referent *hat* is reduced, being in both cases under the negative proposition, the referents *Sam* is considered to be relatively inaccessible (exactly as *hat*) by propositional theories, but not by representational models, in which the same referent is not introduced within the scope of negation. Beside minor differences, therefore, propositional theories and situational-mental models seem equally suitable to account for experimental data reporting increased difficulty in negative sentence comprehension in comparison with affirmative sentences interpretation and evidence showing negated concepts' reduced accessibility.

2.2.1.3 The experiential-simulation model of language comprehension: The two-step simulation hypothesis

Last decades' comprehension researches have provided large evidence in favor of the *experiential view* of language comprehension, according to which the mental representations underlying language comprehension are grounded on non-linguistic cognitive processes, such as perception, action, imagery, etc. (see Zwaan, 2004 and Pecher and Zwaan, 2005 for an overview). The *experiential-simulation view* has gained strength also from important findings in neurological studies, which have confirmed the existence of a considerable overlap between the mental subsystems in which linguistically conveyed situational information is represented and those that are involved when these situation are directly perceived or enacted

(Pulvermüller, 2002; Rolf Zwaan & Taylor, 2006). Recent studies, in addition, have shown that motor processes are active during online comprehension (Ghio & Tettamanti, 2010; M Tettamanti & Buccino, 2005).[53] As repeatedly observed by Kaup and colleagues (see, for example, Kaup, Lüdtke, and Zwaan 2007), however, negative sentence pose a potential challenge to the experiential-simulation view. On the one side, in fact, negative sentences do not have by definition an equivalent in experience and, therefore, cannot receive a direct representation. On the other side, the assumption that language comprehension made use of non-linguistic representations made it not possible to consider negation as a linguistic operator explicitly tagging a certain representation as being false, as proposed by propositional theories and early representational models. For this reason, Kaup and colleagues have proposed the so-called *two-step simulation hypothesis*, according to which negative sentences pass through two temporally distinct stages: a first stage during which the comprehender constructs a mental representation corresponding to the negated situation described in the sentence (the 'negated state of affairs'), and a second stage in which she switches to a simulation matching the actual meaning of the sentence (the 'actual state of affairs', see Kaup, 2006 and Kaup et al. 2007).[54] While the assumptions concerning the first step of negative sentences interpretation have received, as we have seen, abundant empirical confirmation (see § 2.1.1.1), the mechanisms underlying the second stage are still not clear. In particular, many questions have arisen with respect to how the prior simulation is rejected, whether a representation corresponding to the actual meaning of the sentence is constructed and whether negated representations can be simulated in a format similar to affirmative propositions. According to Kaup and Zwaan (2003) and Kaup et al. (2007), the presence of negation is captured in the deviation between the two simulations: the representation of the negated situation, which would be simulated in an auxiliary representational system, and the representation of the described state of affairs, juxtaposed to the first. Differently from the simulations corresponding to affirmative sentences, in fact, the representation of the negated state of affairs would not be integrated within the representation of the described world and would be, therefore, rejected. Once the representation of the negated situation has been rejected, the comprehender may turn to integrate the negation into the comprehension process and to modify his/her representation accordingly. As we have seen, Kaup, Lüdtke, and Zwaan (2006)'s study on negative sentences with contradictory predicates provided interesting results in this respect. In particular, the study has shown that, when a negative sentence of the type *The door was not close* is followed by representation of the actual situation (e.g. an open door) after a sufficiently long time (e.g., 1500ms), a matching effect between the sentence and the picture is observable, resulting in shorter latencies than in those cases in which the picture matched the negated

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[53] The consideration of the same neuro-imaging findings have been more recently put at the basis of the so-called *Embodiment Cognition* theory, that will be discussed in § 2.2.2.2.1.

[54] A two-step account of negation processing had been previously proposed also by Carpenter and Just (1975) and Fischler, Bloom, and Childers (1983).

situation (e.g. a close door).[55] However, these findings provide only partial answer to the question of whether – and eventually how – the actual meaning of negative sentence can be mentally represented, being it valid only for the cases in which the situation which is negated corresponds to a highly predicable 'positive' situation (as it mostly happens with contradictory predicates, e.g. *not open* > close) or in which the discourse context provides enough information to allow the mental representation of the actual state of affairs (e.g., by presupposing an alternative situation). In order to account for all other cases in which neither the sentence nor the context provide any information with regard to the actual state of affairs (e.g., *There was no eagle in the sky*), therefore, Kaup and colleagues hypothesized that the comprehender may contrast the simulation of the negated situation created in the auxiliary representational system (e.g., the presence of an eagle) with an "empty" simulation of the actual situation (Kaup, Yaxley, et al., 2006).[56]

Whatever mechanisms underlie the second step of the process, the assumption itself that the processing of negation consists of two temporally distinct and subsequent passages is, anyway, sufficient to account for the fact that, as largely attested, negative sentences generally require a much more costly processing than their affirmative counterparts and seem to rely on non-automatic, working memory dependent processes (see § 2.1.1.3). The *two-step simulation* model, in addition, implicitly provides an explanation of the difference in reaction times between true and false negative sentences reported in sentence-picture verification task studies (see, for example, Kaup and Ludtke, 2008 and Vender and Delfitto, 2010). As explained by Kaup et al. (2007), the assumption that the first step of negative sentence comprehension is characterized by the construction of a simulation corresponding to the negated state of affairs, in fact, implicitly predicts that during the first stages of sentence processing the comprehender can take more advantage from the visualization of a picture illustrating the negated state of affairs (and therefore matching the mental simulation she is constructing at this stage of sentence processing) rather than from a picture corresponding to the actual meaning of the sentence under interpretation. As easily observable, this is exactly the case of false negative sentences, whose falsity is determined by their

[55] On the contrary, when the picture was presented with a delay of 750ms after the sentence, a match effect between sentences (e.g. *The door was open*/*The door was not closed*) and pictures representing the actual simulation (e.g. an open door) was observable only in the case of affirmative sentences, confirming that the first stage of negative sentence processing is not 'sensitive' to the negation (see § 2.1.1.1 for a description of the study).

[56] Interesting considerations with this respect have also been raised by Orenes, Beltrán, and Santamaría (2014)'s visual-word study, whose results have shown that, though comprehenders switch their attention to the alternative affirmative whenever possible (e.g., in binary contexts), they keep focusing to the negated situation in the cases in which it is not possible to imagine the correct alternative (e.g., multary contexts, see § 2.1.3 for a description of the study). In contrast with the predictions of the *two-step simulation* hypothesis, therefore, it may not be always necessary for the comprehender to construct a second mental simulation corresponding to the actual state of affairs in order to reject the representation of the negated state of affairs.

association with a picture not corresponding to their actual meaning but, rather, corresponding to the state of affairs which is negated by the sentence (e.g., the picture of a flying eagle following a sentence like *The eagle was not in the sky*, Kaup et al., 2007). In the case of true negative sentences, on the contrary, the visualization of a picture representing the actual state of affairs is in contrast with the mental simulation the comprehender is focusing her attention to during the first stages of sentence comprehension and does not produce any facilitation to the processing (on the contrary, it probably interferes with it). The different reaction times associated with the processing of true and false negative sentences, therefore, would be determined by the effect of facilitation or impediment produced by the match/mismatch between the picture and the mental simulation involved during the first stages of sentence verification.[57]

Though well-predicting increased difficulty in the comprehension of negative sentences in comparison with affirmative sentences, the *two-step simulation* account seems to be hardly compatible with other types of findings, such as the evidence showing that, when uttered in an adequately supportive discourse contexts, negative sentences seem to be interpreted with the same speed and easiness as affirmative sentences. According to Lüdtke and Kaup (2006), however, the fact that increased processing cost are reported only in those cases in which negative sentences have to be interpreted out of a pragmatically felicitous context has not to be considered in contrast with their model but, on the contrary, it can be considered totally in line with its predictions. According to two-step simulation hypothesis, in fact, the processing of a negative sentence has always, necessarily, to pass through the representation of the negated situation, independently from the context of utterance. When the sentence is used in a supportive support, nevertheless, the first step of the process is extremely facilitated by the fact that the context strongly suggests the negated situation, freeing the comprehender from the more processing time required for simulating ex novo the negated state of affairs. As reported by Lüdtke and Kaup (2006), in addition, in particularly felicitous context where it appears very natural that a prior expectation needs to be corrected, even the representation of the actual state of affairs seems to be ‘elicited’ by the context, further reducing the processing time. In the extreme cases in which a negative sentence is uttered in isolation or does not result immediately relevant to discourse context, on the contrary, the comprehension process is slowed down by the necessity of constructing the first mental representations from the scratch. Although resulting in very different behavioral responses, therefore, the processing of negation is not assumed to be qualitatively different under differently pragmatic circumstances, but only to be differentially influenced by the information provided by the context. Worth noting, this latter analysis is also in line with Deutsch et al.

[57] A similar effect of facilitation has been reported for the processing of affirmative sentences when followed by a picture representing the actual situation (true affirmative conditions), in comparison to the cases in which the sentence were associated to a sentence mismatching the meaning of the sentence (false affirmative condition; see Zwaan, Stanfield, and Yaxley, 2002).

(2006)'s observation that, in spite of the fact that in many circumstances negation is processed very easily when working memory resources are not otherwise taxed, its consideration becomes crucially more difficult when the concurrent execution of working-memory based tasks is required (see § 2.1.1.3). While the interpretation of negative sentences presented in felicitous pragmatic contexts may be considered to be a not very demanding operation in terms of working memory resources (as the context provides very much support to the simulation of the negated state of affairs, masking the inherent processing difficulty of negation), the absence of an adequate context of utterance is likely to tax working memory resources with the construction and mental comparison of two different mental representations, resulting in a higher processing difficulty.[58]

Potential criticisms to two-stage based account of negation processing may also come from the consideration of studies showing that negation has a (possibly) immediate suppressive effect on the lexical accessibility of the concepts under its scope (§ 2.1.3). As MacDonald & Just (1989)'s *search-for-alternatives* model clearly shows, however, the consideration of the suppressive nature of negation is not totally at odds with a two-step based account of negation processing, as suppression may represent the result of the 'rejection' of the negated state of affairs or, eventually, the mechanism itself at the basis of the integration of the negative meaning during the second stage of negative sentence comprehension. The lack in behavioral studies of precise information on the exact moment in which negated terms become inaccessible, however, makes it impossible to establish whether the suppressive effect of negation has to be considered incompatible with the temporal predictions made by Kaup and colleagues' model or not. More fine-grained analyses of the temporal dynamics underlying the interpretation of negation have been offered by recent fMRI studies, which reported a reduction of the cortical activation already before 500ms after negative sentence presentation (Alemanno et al. 2012; Bartoli et al. 2013; Tettamanti et al. 2008). Nevertheless, fMRI studies have so far limited the investigation to a very restricted set of sentences (simple and short declarative sentences only including action verbs and in most cases, hand-related ones) and to the execution of very simple tasks (in most cases, a passive listening task, with no need of evaluating the truth-value of the sentences presented). As a consequence, it turns out very difficult to compare recent neuro-imaging findings with behavioral studies adopting more complex verification paradigms. As observed by Bartoli et al. (2013), the execution of more complex tasks involving truth-value verification may make it necessary to engage the explicit and temporally disjoined simulation of both the negated and the actual state

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[58] Worth nothing, this latter observation may also explain why significant differences in the reaction times associated to the interpretation of negative and affirmative sentences are more 'visible' in those tasks in which working-memory load is more taxed (e.g., sentence-picture verification task), than in those which require no working memory involvement (e.g., passive reading tasks). Experimental studies are needed, however, to test the plausibility of these very intuitive considerations.

of affairs, resulting in more time dilated processing of negation during which motor deactivation could, possibly, follow an initial phase of motor activation.

2.2.2 Incremental models

Incremental models of negation processing are characterized, as we said, by the assumption that the negation is integrated right away during sentence comprehension and that, therefore, the interpretation of negative sentences is not different, in this respect, from that of affirmative ones.

Differently from the section dedicated to non-incremental models, we will not adopt as main criterion of classification of incremental models the reference to one or another theory of language comprehension but, rather, the consideration of which aspect is assumed to constitute the main feature of negation. On this basis, we will distinguish between *pragmatic accounts*, which emphasize the high pragmatic sensitivity to the processing of negation, and *suppressive-like accounts*, which focus on the inhibitory nature of negative markers.

2.2.2.1 Pragmatic accounts: The contextual nature of negation

As discussed above, negative sentences' context sensitivity has represented a central issue in the investigation on the processing of linguistic negation since very early psycholinguistic studies. The consideration of experimental evidence showing that, when negative sentences are uttered in pragmatically felicitous contexts, negative sentence comprehension does not seem to require much effort in comparison with that of structurally similar affirmative sentences (see, for example, Dale and Duran, 2011 and Nieuwland and Kuperberg, 2008) has lead to the formulation of different types of *pragmatic account*, characterized by the assumption that the increased difficulty associated with negative sentences has to be attributed, in all cases, to the absence of a felicitous context of utterance, as is particularly evident in many experimental paradigms.

While there are some supporters of the idea that negation is *intrinsically* contextual (e.g., Glenberg et al., 1999), most pragmatic accounts' proponents recognize that negation processing may have diverse cognitive dynamics in supportive and non-supportive contexts. As observed by Dale and Duran (2011), in fact, it does not seem plausible to assume that every-day communicative situations always provide the *appropriate* context for the utterance of a negative sentence. On the contrary, it seems likely that, at least in some cases, comprehenders have to face the interpretation of negation in non-supportive contexts. For this reason, Dale and Duran (2011) have proposed that the *dynamic structure* of negation change contextually, standing on the border between 'discrete' (or, in other words, non-incremental) and 'continuous' (incremental) processing. Very similar conclusions have been drawn by Nieuwland and Kuperberg (2008), according to which the fact that negation is incrementally incorporated when used in adequately supportive contexts does not necessarily exclude the possibility that negative sentence may receive a two-stage based interpretation under other circumstances. Similar hypotheses are also well in line with studies showing that, though in many cases negation is processed very quickly and unintentionally, such as when it is presented in non-anomalous pragmatic contexts (e.g., real-world condition, Ferguson et al. 2008), its interpretation clearly engages non-automatic, memory-based processes and it appears extremely slow down when discourse circumstances does not represent a plausible context of denial (e.g., non-world condition, Ferguson et al. 2008, see § 2.1.2 for a description of the study).

An alternative explanation has been offered by Tian, Breheny, and Ferguson (2010)'s *dynamic pragmatic account*. According to this view, the interpretation of isolated negative sentences does not rely on different cognitive processes with respect to that of pragmatically licensed sentences, though the former would be burdened by an additional process of pragmatic 'accommodation'. According to Tian and colleagues, this process would pass through the creation (and afterwards rejection) of a mental representation corresponding to the negated state of affairs, as predicted by the two-step simulation model, but through the projection of likely 'questions under discussion'- that is, questions which situate the segment in a common ground that could motivate the use of a negative sentence. To exemplify, the presentation of a sentence like *The bird is not in the air* in isolation would invite the comprehender to project the positive question *Is the bird in the air?*, reflecting the lacking presupposition that the negative sentence would be expected to address.[59]

Beside these minor differences, it is important to note that incremental *pragmatic accounts* assumes that negative sentences are not inherently harder than affirmative sentences, and that the absence of an adequate context is responsible for making an otherwise simple process more difficult. On the contrary, *non-incremental models* put emphasis on the fact that the interpretation of negative sentences relies on cognitive process partially different from those employed during the comprehension of affirmative sentences, and that felicitous pragmatic contexts have the effect of facilitating a process in itself difficult. As it can be easily noted, therefore, the two perspectives represent, at least to some extent, the two faces of the same coin, nevertheless reflecting very different assumptions on the nature of negative sentences.

2.2.2.2 Suppression and suppression-like based accounts

A second incremental approach to the processing of negation is represented by *suppressive accounts*, that is, models assuming that the main role of sentential negation is reducing the later accessibility of the concept within its scope, and that this reduction occurs in very first stages of sentence interpretation. More precisely,

[59] Tian, Breheny, and Ferguson (2010) report interesting evidence in favor of the *dynamic pragmatic account*. The reader interested to the details of the study is referred to § 2.1.2.

under this view, the comprehender would actively reduce the accessibility of the concept within the scope of negation to baseline levels. As we have discussed in § 2.1.3, a large number of experimental studies have provided support to the idea that sentential negation reduces the accessibility of the information to which it refers. There is, however, no general consensus with respect to the obligatoriness of the process and to the temporal stage in which it occurs. According to the proponents of the *narrow-view account*, suppression represents a default strategy which applies in all contexts (Carpenter and Just, 1975; Evans and Over, 2004). Nevertheless, counter evidence has been reported showing that the concepts in the scope of negation are not unconditionally dispensed with. These latter findings have lead to the formulation of the so called *retention hypothesis* (Giora, Aschkenazi, & Fein, 2004; Giora et al., 2007), according to which suppression is not automatic, but rather functional: when global considerations, such as relevance and coherence maintenance, invite for retention, the negated concepts are maintained and modified accordingly to the presence of negation (e.g., receiving a mitigated interpretation closer to its the original concept than to its opposite, Giora, 2006; Giora et al., 2005); when, on the contrary, the concept under negation is not useful for coherence purposes and/or global signals (such as, for example, topic-shift) invite to its deactivation, the accessibility of the negated terms is reduced (Hasson and Glucksberg, 2006).[60]

According to Mayo, Schul, and Burnstein (2004) and Paradis and Willners (2006), the possible suppression of negated concepts is also highly dependent from the predicates involved. In particular, Paradis and Willners (2006) extend the functional approach proposed by Giora and colleagues with the consideration of the boundedness and unboundedness of semantic configurations, according to which when negation occurs in combination with unbounded adjectives (such as, for example, *narrow*), it has the role of an attenuating degree modifier (expressing a meaning somehow different from *not narrow* = *wide*), while when it accompanies a bounded antonymic term (e.g. *dead*) it acts as a suppressive operator translating the term under its scope into the absolute opposite meaning (e.g., *not dead* = *alive*).

A second piece of evidence which seems to contradict incremental interpretations of negation based on its suppressive capacity is represented by psycholinguistic studies showing that the suppression of negated terms' accessibility would not be effective during very early stages of sentence interpretation, but even various hundreds of milliseconds - between 500ms and 1000ms – after sentence presentation (Kaup and Zwaan, 2003; Hasson and Glucksberg, 2006). These latter data, therefore, seem to speak in favor of the possibility that suppression may follow an initial stage of negation insensitivity, or may represent the second stage of a two-stage process of interpretation.

[60] Similar considerations on the accessibility of the information have been put forward by Kaup and Zwaan (2003), according to which concepts' accessibility is determined by its presence in the situation model (or, in other words, into the global context under consideration), independently from its being negated or not.

2.2.2.2.1 The Embodiment Cognition Theory and the ‘disembodiment’ effect of negation

More persuasive evidence of the inhibitory effect of linguistic negation has recently come from neuro-imaging studies developed within the *Embodiment* or *Grounded Cognition theory*, according to which language comprehension activates the same neural structures that enable the effective execution of the action described. Based on growing evidence confirming the involvement of specific sensorimotor neuronal systems in language processing,[61] embodiment cognition studies on negation have aimed at verifying whether linguistic negation may have an inhibitory effect on concept-specific neuronal activation typically involved in language processing. More precisely, as we have seen, neuro-imaging studies have focused on the interpretation of action verbs (and, in particular, on hand-related action verbs), which have been largely reported to induce activation of motor and premotor areas (Ghio & Tettamanti, 2010; Ghio, Vaghi, & Tettamanti, 2013). Interestingly, as mentioned before, the use of different experimental paradigms and techniques has brought converging evidence of the inhibitory effect determined by the interpretation of negation to the cortical activations typically elicited by the concepts within its scope (Tettamanti et al., 2008; Tomasino, Weiss, and Fink, 2010; Liuzza, Candidi, and Aglioti, 2011; Alemanno et al., 2012; Bartoli et al., 2013; Foroni and Semin, 2013; see § 2.1.3.1 for an overview). The combined use of neuro-imaging techniques with behavioral measures allowing high temporal sensitivity, such as the analysis of grip-force (Aravena et al. 2012) and of kinematic variations (Bartoli et al. 2013), in addition, has led to the observation that the effect of sentential negation on reaction times can be detected very early in the processing of simple, declarative negative sentences (already within the first 500ms after stimuli onset).

Nevertheless, embodiment cognition studies have provided – so far – only limited information on the processing of negation. ‘Disembodiment’ findings on negation, in fact, have concerned only a restricted range of verbs and negative constructions and, therefore, can only partially be compared with the rich tradition of the studies performed within the representational framework. In particular, evidence on the processing of non-actional concepts and sentences not referring to the first person are still almost completely lacking. These limitations reflect to some extent the limits of the embodiment cognition theory itself, in which some fundamental issues – such as a precise description of the crosstalk between language and motor systems, and of the conditions under which motor systems are recruited during language comprehension – have not been defined yet. As observed by Aravena et al. (2012), in addition, the evidence reported may receive alternative interpretations leading to a reconsideration of the functional role of sensori-motor systems in language processing. According to the *grounding by interaction* view

[61] See Jirak, Menz, and Buccino (2010) for a review.

proposed by Mahon and Caramazza (2008), as an example, the activation of the motor areas would represent an integration of abstract conceptual representations underlying language comprehension. Similarly, according to the so-called *secondary embodiment* hypothesis, language-induced sensori-motor activity may represent the result of the ‘spreading activation’ from other neuronal regions responsible of the amodal representations underlying language comprehension (Patterson, Nestor, & Rogers, 2007). To conclude, alternative models propose that sensori-motor systems are not obligatory for the retrieval of the word meaning, and that they may be involved only when motor features of meaning are required by the context (Aravena et al., 2012).

Despite these limitations, embodiment cognition studies represent a promising and important approach in the investigation of sentential negation (and of language comprehension in general) and have, therefore, to be taken into the proper consideration.

2.3 The use of sentence-picture verification paradigms and EEG in the study of negation: A closer look

2.3.1 The sentence-picture verification task and the processing of negation

The use of sentence-verification tasks in the investigation of language comprehension has a very long tradition. As it is well known, in this task subjects are presented with a sentence which can be followed either by a picture matching or mismatching the meaning of the sentence. The participants’ task is that of determining whether the sentence represents an accurate description of the following pictures or, in other words, whether the sentence has to be considered true or false on the basis of the ongoing picture. Traditionally, the time required to make the truth-value verification is assumed to indirectly reflect the processing cost determined by sentence interpretation. The first adoptions of this paradigm for the investigation of negative sentence interpretation coincides with very first employments of the paradigm itself in the mid-sixties and seventies (Gough, 1966; Slobin, 1966, Just and Carpenter, 1971; Trabasso, Rollins, and Shaughnessy, 1971, Clark and Chase, 1972). In most cases, the stimuli were composed by standard sentences describing the physical characteristics (e.g., *The dots are/aren’t red*, Just and Carpenter, 1971) or the spatial arrangement (e.g., *The star is/is not above the plus*, Clark and Chase, 1972) of very simple graphic signs. As already mentioned, the analysis of response times consistently revealed two main patterns of verification: (i) a sentence type effect, determining overall longer response times with negative sentences in comparison with affirmative sentences, and (ii) a truth-value effect different for sentence type, resulting in faster verification for true affirmative in comparison with false affirmative sentences and slower reaction times for true negative in comparison with false negative sentences. Clark and

Chase (1972) proposed one of the first models to account for this asymmetry relying on the assumption that linguistic and pictorial sources are mentally encoded in the same interpretative format, that is, as assumed by propositional theories of language comprehension, propositional units. As a consequence, according to Clark and Chase (1972), sentence-picture verification processes are assumed to involve the mental conversion of both the sentence meaning and the depicted situation into the same general, propositional format. The comparison between the two stimuli (necessary to determine the truth-value of the sentence) is therefore expected to be facilitated in those cases in which the underlying propositional representations of the two stimuli are matching from the ‘representational’ point of view. To exemplify, consider the affirmative sentence *The dots are red* to be followed by a picture illustrating either only red dots or only black dots. In the former case, the verification of the congruency between the two propositional representations (one corresponding to the sentence, the other to the picture) is facilitated by the fact of being both converted into the propositional concepts ‘dots’ and ‘red’. In the latter case, on the contrary, the representation of black dots initiated by the picture conversion into propositional units makes the comparison with the sentence-related representation significantly more difficult. In parallel, the corresponding negative sentence *The dots are not red* is assumed to be converted into a representation including the concepts ‘red’ and ‘dots’, together with the overt linguistic operator ‘negation’. As a consequence, its verification against the picture is expected to be easier in the case of a red dots containing picture (false condition) than when accompanied by an illustration of black dots (true condition). Very similarly, Carpenter and Just (1975) suggested that increased verification times could be determined by the number of mental ‘revisions’ required by the matching/mismatching between the two stimuli.

More recently, sentence-picture verification tasks have been repeatedly employed in the investigation of negation processing and, in particular, within the *two-step simulation hypothesis* (Kaup, Lüdtke, and Zwaan, 2007; Kaup, 2006; see § 2.2.1.3). As briefly reviewed above, in fact, the manipulation of the temporal delay between the two stimuli, on the one hand, and of their interpretational congruency, on the other, has allowed to provide important empirical support to the model proposed by Kaup and colleagues. In particular, the facilitation effect determined by the visualization of a picture corresponding to the negated state of affairs (e.g., the picture of a flying eagle 250ms after having listened to the sentence *The eagle is not in the sky*) during the first hundreds of milliseconds after sentence onset has been interpreted as a confirmation of the idea that the initial stages of negative sentence comprehension are characterized by the construction of a mental simulation not corresponding to the actual meaning of the sentence but, rather, to its affirmative counterpart (i.e., the representation of an eagle flying in the sky). Alongside, the observation that in later stages of sentence comprehension (e.g., 750ms after sentence onset) a similar facilitation effect is instead provided by the visualization of a picture illustrating the actual state of affairs has been taken as a proof of the fact that, at that point, the comprehender has switched to the simulation of the actual meaning of the sentence. Though sharing with Clark and Chase (1972) and Carpenter and Just (1975) the idea that the different patterns of verification times characterizing affirmative and negative sentences depend on the presence or absence of a correspondence between the two stimuli, the two-step simulation hypothesis presents important differences with respect to the previously proposed sentence-picture verification models. First, as we have said before, language comprehension is not considered to involve propositional-like representations but, rather, non-linguistic grounded mental simulations. Second, visual stimuli are not assumed to be in need of being converted in any representational format. Third, two temporally distinct mental representations of the sentence presented are thought to be involved. Accordingly, therefore, the easiness of sentence verification would not depend from the comparison between two different mental representations but, rather, from the match/mismatch between the mental representation engaged in that specific stage of sentence interpretation and the pictorial source itself. More simply, the relation between the mental situation simulated by the comprehender and the picture presented can be described in terms of *priming*, as clearly exemplified by Lüdtke et al. (2008)'s stimuli (TABLE 1, next page). While in the case of affirmative true sentences, in fact, the picture primes the mental representation under construction (i.e., a ghost in front of a tower), in the case of false affirmative sentences the former (i.e., a picture of a lion in front of a tower) is in clear contrast with the latter (i.e., the representation of a ghost in front of a tower). Similarly, while in the case of false negative sentences the mental representation constructed during the first stages of sentence comprehension, corresponding to the negated state of affairs, is 'primed' by the following picture (e.g., the picture of ghost in front of a tower after the sentence *In front of the tower there is no ghost*), in the case of true negative sentences there is no matching between the mental simulation created by the comprehender (corresponding to the negated situation, i.e., a ghost in front of a tower) and the picture presented (i.e., a lion in front of a tower).

According to Nieuwland and Kuperberg (2008), however, the different processing cost associated to affirmative and negative sentences during the execution of sentence-picture verification tasks could also be due, at least to some extent, to the very low pragmatic felicity characterizing this kind of experimental paradigms. In spite of most authors' unawareness, in fact, the properties of the pictures employed have important consequences on the naturalness of the different experimental conditions

TABLE 1. Examples of the Lüdtke et al. (2008)'s stimuli (English translation of the original German sentences).

Sentence	*Picture*
True affirmative (TA) *In front of the tower there is a ghost*.	
False affirmative (FA) *In front of the tower there is a ghost.*	
True negative (TN) *In front of the tower there is no ghost.*	
False negative (FA) *In front of the tower there is no ghost.*	

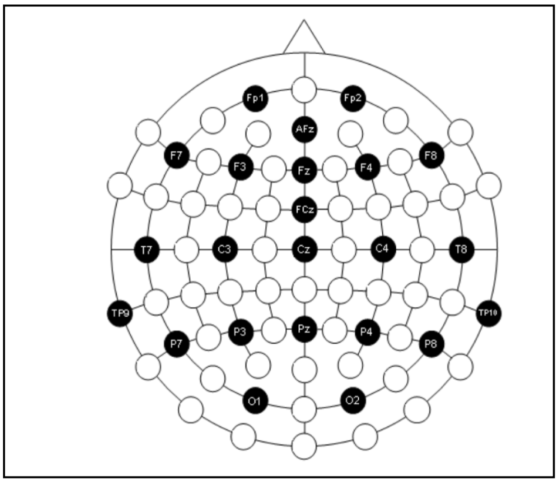
Consider, again, Lüdtke et al. (2008)'s materials above. As it can be observed, the four pictures significantly differ with respect to their relevance to the previously presented linguistic stimuli: in the case of true affirmative and false negatives, the representation of both the entity and the background mentioned in the sentence makes the picture highly relevant to the prior linguistic stimuli (though determining, in the case of the negative sentence, the falsity of the utterance); in the case of false affirmative and true negative sentences, on the contrary, the presence of an entity not mentioned in the previous linguistic stimuli (i.e., the picture of a lion in front of a tower after the sentence *In front of a tower there is no ghost*) gives the picture much less relevance within the discourse context. Though not posing problems for the interpretation of affirmatives sentence, this difference results crucial in the case of negative sentences, whose processing is characterized - as we have seen – by much higher pragmatic sensitivity. In particular, in experimental paradigms such as Lüdtke et al. (2008) the denial of a situation neither introduced in the previous linguistic context, nor recoverable in the following visual stimuli determines a sense of very weak pragmatic adequacy in the true negative condition (which, not casually, was reported to represent the most difficult condition in both Lüdtke and colleagues' study and in similar previous works). As we will see in more detail during the presentation of the experimental paradigm adopted for this dissertation, however, the difference in the experimental conditions' pragmatic felicity can be attenuated by taking specifically into account this critical issue during the elaboration of the experimental stimuli.

2.3.2 The use of EGG in the investigation of the processing of negation

2.3.2.1 The event-related potentials technique: A short introduction

Event-related potentials (ERPs, for short) are traditionally defined as very small voltages generated in the brain structures as reaction to specific events or stimuli (Blackwood and Muir, 1990). ERPs identification is based on the recording of neural activity trough electroencephalography (EGG), obtained by placing a series of electrodes on the surface scalp.[62] Electrode positions trough the scalp are identified through a standardized naming system composed by letters (indicating their proximity to underlying brain regions: F = frontal, C = central, T = temporal, P = parietal, O = occipital), and numbers indexing their laterality and distance from the midline (odd numbers = left hemisphere, even numbers = right hemisphere, z = midline, with greater number indicating greater distance from the midline). A map of the electrode montage following the International 10-20 System is reported in FIGURE 5 below.

FIGURE 5. International 10-20 system electrode montage.



Generally, the EEG records the differential potential between several active electrodes placed at sites of neuronal activity and one common inactive electrode placed at a site with no or only little brain activity, serving as reference. The ongoing voltage changes captured by the electrodes are amplified, sampled (usually at 250, 500 or 1000 Hz), and finally stored on a computer for further processing. Due to the relative smallness of ERPs voltage fluctuations in comparison with the larger amplitudes of the basal electroencephalographic

[62] The position of the electrodes are standardized by international guidelines. The most common electrode procedure is defined by the ‘10-20 International system’, according to which electrodes are located at distances of 10% or 20% along the longitudinal line across the head.

activity,[63] event-related potentials' extraction from the general EEG signal requires a series of filtering and averaging methods. The most frequent averaging technique involves the recording of a high number of EEG epochs, each of which time-locked to presentation of the same physically or conceptual identical stimuli, and is based on the assumption that the underlying mental process remains equal across several stimuli of the same type, while background activity is random. The so-obtained ERP waveforms reflect the electrical activity occurring at different points of the scalp and most likely derived from the concurrent activity of the postsynaptic potentials produced when a large number of similarly oriented cortical pyramidal neurons fire in synchrony. By contrast, the electrical activity produced in subcortical regions is measurable at the surface of the scalp and, thus, it does not fall into the EEG recording.

Despite of their very high temporal resolution (resulting to 1ms resolution or better under optimal circumstances), event-related potentials spatial origin has to be considered largely undefined, as the activity recorded at a certain point of the scalp does not necessarily correspond to the brain structures underlying that site; on the contrary, it could be originated by infinitely internal configurations. Nonetheless, ERPs can be divided into two main classes on the basis of their temporal occurrence: *exogenous* or *sensory* components, corresponding to early waves occurring within the first 80-100ms after stimulus, and *endogenous* or *cognitive* components, including all ERPs generated in later time windows. As indicated by the terms themselves, exogenous components are considered to be largely dependent from the physical parameters of the stimulus, whereas endogenous ERPs reflect the manner in which the subject evaluates stimuli, processes information and perform the task presented. Beyond this general classification, ERP components can be further described according to their *latency* (expressed in ms and indicating the point in time at the which the deflection occurs relative to the stimulus onset), *amplitude* (expressed in µV and plotted on the y-axis and reflecting the 'size' of the neural activity generated by a specific stimulus or event),[64] *polarity* (negative *vs.* positive deflection, depending on the pole orientation of electric voltage measured), and *scalp distribution*. In particular, polarity and peak latency have been adopted as main parameters for ERPs nomenclature, as exemplified by the N400 label, indicating a negative going deflection peaking around 400ms after stimulus onset. In some other cases, however, the site of registration is referred to (e.g., *anterior sustained negativity*) with the purpose of differentiating the EEG component from other same-polarity effect occurring within the same temporal window.

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[63] To exemplify, the amplitude of the effects typically induced by linguistic manipulations is in the order of a few µV, while background EEG activity (such as ocular, muscular and cardiac artifacts) is generally up to 100 µV. For a complete description of the methodological procedures see Picton et al. (2000) and Luck (2014).

[64] In general, components' amplitude is considered to reflect the processing demand and/or the efficiency of the cognitive processes under investigation (the greater the amplitude, major the involvement of cognitive processes). From the methodological point of view, ERP components' amplitude is measured in relation to a baseline, constituted by the EEG signal preceding the stimulus-onset (usually lasting 100 ms), where the mean amplitude is set to zero.

2.3.2.2 Event-related potentials in language processing

2.3.2.2.1 Semantic and discourse processing associated ERPs

The wide application – since the early eighties – of ERP methodology in the investigation of language processing has allowed the identification of a wide range of language processing associated potentials. The first event-related potentials elicited through linguistic stimuli manipulation was reported by Kutas and Hillyard (1980), which observed a centro-parietal negativity deflection occurring between 200 and 600ms (and peaking around 400ms) after the presentation of semantically implausible sentences. The effect has become popular with the label of N400 and has been subsequently associated with a number of semantic operations. In particular, it has been shown that, although every content word evoked N400 modulation to some degree,[65] its amplitude and latency vary in response to the word's plausibility, expectation (defined in terms of cloze-probability, that is, the percentage of individuals who would continue a sentence fragment with that word), and frequency in general language use. Significant N400 modulations have also been observed in priming paradigms of different types, such as semantic priming (with larger N400 associated to words and pictures not matching the semantic expectation derived from previously presented items) and phonological priming studies (in which alliteration and rhyme have been found to reduce the N400 amplitude).[66] Recent studies have shown that N400 is also sensitive to non-semantics related interpretative mismatches, such as impossible thematic role assignments (Bornkessel, Schlesewsky, and Friederici, 2002) and grammatical rules violations (e.g., incorrect choice of subject case in Hindi, Choudhary et al., 2009). To conclude, N400 has been reported to reflect world knowledge conflicts (i.e., larger N400 for false sentences than for true sentences) and pragmatic violations (Van Berkum, 2009).[67] The sentential frame is, however, not necessary for the elicitation of N400, which has been equally observed in association to single words' presentation, e.g. in experimental conditions in which a certain lexical item of a list mismatched the semantic category of the prior words. Interestingly, in addition, comparable N400 effects have been reported across different input modalities, including both linguistic (e.g. sign languages), quasi-language (e.g. pseudo-words) and non-linguistic stimuli, as long as meaningful (e.g., drawings, pictures and faces).[68]

Despite of the growing literature attesting N400 modulations, the exact nature of the effect (e.g., its functional role, its relative automaticity and/or dependency

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[65] In contrast, function words elicit no N400.

[66] See Swaab et al. (2011) and Kutas and Federmeier (2011) for an extensive review of the studies reporting N400.

[67] See Coulson (2011) for a review.

[68] To exemplify, a line drawing inconsistent with the semantic context created by a preceding sequence of words or line drawings elicit a N400-like effect (Ganis, Kutas, and Sereno, 1996). As reported in Kutas and Federmeier (2011)'s review, in addition, N400-like modulations have been shown to be elicited also by the execution of mathematical and memory tasks. See Kutas and Federmeier (2011) for a more detailed discussion of these findings.

upon attentional resources) is still object of open debate. According to Kutas and Federmeier, however, on the basis of current evidence N400 can be assumed to reflect both initial conceptual representations and their "need to be refined with time, either through continued interactions within semantic memory or via the application of later occurring processes that serve to select meaning features, revise initial interpretations, or otherwise update meaning representations (for example, adding information that might not have become available by the time the N400 was triggered)" (Kutas and Federmeier, 2011: 642).

Two other negative modulations, occurring with latency similar to N400, but characterized by a more anterior scalp distribution have been reported in association with other types of semantic and interpretive manipulations. The first effect has been observed to be activated by imaginable/concrete words (e.g., *banana*), in comparison with low-imaginable/abstract words (e.g., *justice*, see for example Holcomb and Kounios, 1999). Despite the high semantic sensitivity and temporal latency (around 300-400ms after stimulus onset) of the effect may suggest an overlap with the prototypical N400 wave, its anterior distribution has been interpreted as an indication of being generated by partially different neuronal sources in comparison with the 'canonical' N400.

The second effect, known as 'anterior sustained negativity', has been observed in response to interpretive difficulties and/or conceptual violations and has therefore been associated to discourse model elaboration (that is, the creation of a cognitive representation of the linguistic information to be processed). To exemplify, Münte, Schiltz, and Kutas (1998) and Dwivedi et al. (2006) reported larger sustained negativities during the interpretation of semantic violations involving temporal relations, mood and modality. Van Berkum and colleagues, on the other hand, observed that sentences containing a NP possibly associated to two equally suitable referents (e.g., *David had told the two girls to clean up their room before lunch time. But one of the girls had stayed in bed all morning, and the other had been on the phone all the time. David told <u>the girl</u> that ...*) elicits a more significant anterior negativity in comparison with NP unambiguously referring to a single entity in the preceding discourse (e.g., *David had told the boy and the girl to clean up their room before lunch time. But the boy had stayed in bed all morning, and the girl had been on the phone all the time. David told <u>the girl</u> that ...*, van Berkum, Brown, and Hagoort, 1999; van Berkum and Zwitserlood, 2003). A very comparable effect was reported by Dwivedi et al. (2010) during the interpretation of ambiguous anaphoric scopes. Coulson and Kutas (2001) observed the emergence of larger anterior negativity during the comprehension of jokes whose interpretation resulted inconsistent with the frame evoked by the previous linguistic context in comparison with non joking sequence endings, and interpreted it as a reflection of the frame-shifting needed to re-establish coherence. Similarly, Baggio and Lambalgen (2008) compared event-related potentials associated with sentences including *when* sentences either inducing a discourse model recomputation (such as in the case of the sentence *The girl was writing letters when her friend spilled coffee on the paper*, in which the fact that some coffee has been spilled out has the consequence of interrupting the action of writing letters) or initial discourse model extension (e.g., *The girl was writing letters when her friend spilled coffee on the tablecloth*). In line with authors' predictions, *when* clauses expressing actions which had the effect to disable the accomplishment of the preceding verb (thus initiating discourse model recomputation) elicited larger negative shifts compared to clauses in which the verb had a neutral effect on the activity describe in the main clause.[69] Importantly, in all these latter studies the negative shift differentiated from standardized N400 not only for the more anterior distribution on the scalp, but also for its very prolonged duration, emerging around 300-400ms and lasting for some hundreds of milliseconds. This latter peculiarity has allowed also distinguishing the 'anterior sustained negativity' from the anterior but not prolonged negative shift associated to words concreteness described just before.

To conclude, recent findings have revealed that particular cases of semantic re-analysis and extra-processing at the discourse level lead to the elicitation of P600 component, a centro-parietal positive shift peaking around 600ms after stimulus and typically associated, as we will see to the detection of syntactic and morphosyntactic anomalies.

2.3.2.2.2 Syntactic and morphosyntactic ERPs

A second, very productive field of application of the electrophysiological techniques into language comprehension is represented by syntactic and morphosyntactic processing. To start with, words that are primarily syntactic in nature, such as functional words (e.g., *to*, *with*), have been shown to a elicit a N280 effect at the left anterior electrode sites, which have been by contrast not reported with words with richer semantics such as content words (eliciting, as we said, the centro-parietal N400 component).

As already mentioned, morphosyntactic anomalies of different types, such as subject-verb agreement violations and phrase structure irregularities (e.g., verb tense violations), have been reported to associate with P600, a centro-parietal positive shift peaking around 600ms after stimulus. P600 instances have also been observed during the processing of syntactic ambiguities, garden-path-sentences, sentences characterized by increased syntactic complexity or-less-preferred structures, structure-dependent interpretational anomalies (such as thematic role violations and semantic violations in relative clauses), and 'semantic illusion' cases, that is, syntactically well-formed but semantically anomalous sentences.[70] Finally, similarly to N400, P600 has been shown to be not restricted to the linguistic domain and to be also evoked by the processing of other types of sequence irregularities, such as incongruous musical sequences, spelling mistakes and action sequences violations.[71] On the basis of these evidence, P600 has been

[69] As we will see in the next section, anterior sustained negativities have also been observed during the syntactic processing of filler-gap dependencies and during subvocal rehearsal tasks.
[70] See Brouwer et al. (2012) for a review of the 'semantic illusion' sentences eliciting P600.
[71] See Swaab et al. (2011) for a more detailed description of P600 studies and for related references.

traditionally interpreted as reflecting syntactic integration difficulties (Friederici, 2002) and processes of reanalysis and updating of previously misinterpreted information (Kaan and Swaab, 2003, Brouwer, Fitz, and Hoeks, 2012). P600 sensitivity to stimulus frequency (Hahne and Friederici, 1999) and task requirements (Gunter and Friederici, 1999), in addition, has allowed to associate the P600 to the class of the controlled, high-level processes of sentence comprehension.

In many cases, P600 emergence due to syntactic violations has been found to be preceded by the elicitation of a class of earlier negative shifts generally referred to as *Left Anterior Negativity* (LAN). Though having received its denomination on the basis of its recurrent left-oriented distribution, LAN instances have been observed to be possibly characterized (at least in some cases) by a bilateral distribution. The latency of this family of negative effects is also characterized by a discrete array of variation, ranging from cases of early instances occurring between 100-300ms after stimulus (early LAN, or 'ELAN') to cases of later emergence (around 300-500ms after stimulus). Early Left Anterior Negativity modulations have been found in response to phrase structure irregularities (e.g., **The pizza was in the eaten*, as opposed to *The pizza was eaten*, Friederici, Pfeifer, and Hahne 1993; Hahne and Friederici, 1999, and following studies), argument structure inadequacies and word category violations (such as sentences in which the word presented does not belong to the expected grammatical category, e.g., *The young apprentice went to see the new *<u>designing</u> in the museum*, Friederici, Hahne, and Mecklinger 1996). Interestingly, in German the latency of the negative shift has been shown to be influenced by the location of the violation within the critical word, resulting in earlier latencies when the violation concerned the word prefixes and later latencies in the cases in which the violation was encoded in the suffixes (Friederici et al. 1996, 1993; Hahne and Friederici, 1999). Later LAN (300-500ms after stimulus) have also been observed to respond to numerous types of morphosyntactic violations (either involving number, case, gender, and tense agreement, see for example Deutsch and Bentin, 2001) and to grammatical sentences containing long-distance dependencies, such as filler-gap constructions (Felser, Clahsen, & Münte, 2003). To conclude, Steinhauer, Drury, and Portner (2010) investigated the interpretation of sentences either containing licensed and unlicensed negative polarity items (e.g. *John hasn't ever been to Paris* vs. *John has *ever been to Paris*) and reported larger late LAN in the unlicensing relative to the licensing condition.[72] Due to its early onset, the ELAN has been interpreted to reflect highly automatic processing of initial structure building (Hahne and Friederici, 1999). Differently, the functional role of later LANs has not been determined yet. In particular, the frequently reported prolonged duration, together with its anterior (not always lateralized) distribution has raised the question of whether later prolonged LANs may constitute an instance of the semantic-conceptual sustained

[72] See Steinhauer and Drury (2012) for an exhaustive review of the studies reporting ELAN and later LAN modulations.

anterior negativity discussed in the previous section, rather than a pure morphosyntactic component (see Baggio and Lambalgen, 2008, and Steinhauer and Drury, 2012, for a discussion of this issue).

A third ERP wave reflecting morphosyntactic processing is represented by the so-called *Mismatch Negativity* (MMN), a fronto-central negativity (with reversed polarity at mastoids) occurring approximately 100ms after stimulus and generally considered to reflect the brain's detection of a deviant stimulus among standard input. Despite having been traditionally reported in association to auditory and visual stimuli mismatches, studies comparing the processing of syntactically correct minimal sentences (e.g. *we come*) with that of structurally similar sentences violating subject-verb agreement (e.g. **we comes*) have shown that MMN also reflects very early and automatic syntactic processing, resulting in larger amplitudes in the cases of grammatical violations (Hasting, Kotz, and Friederici, 2007; Pulvermüller et al., 2008),

2.3.2.2.3 ERPs related to the physical features of the stimulus

Besides the set of ERPs components reflecting the strictly linguistic information encoded in the input, electrophysiological investigation of language processing has allowed the identification of endogenous waves indexing the physical properties of the stimulus.

To start with, all types of auditory and visual stimuli have been reported to elicit the so-called N1-P2 complex, a negative deflection occurring at approximately 100ms after stimulus and followed by a positive deflection at around 200ms (Näätänen and Picton, 1987). Due to its very early latency, high automaticity and crucial sensitivity to the stimulus's physical features (e.g., loudness, fundamental frequency, etc.), N1-P2 waves have been associated to the neuronal activity in the primary sensory cortex.

A second ERP component characterizing the presentation of auditory stimuli is represented by the just mentioned *Mismatch Negativity* (MMN) effect, a fronto-central negativity occurring around 150-250ms after stimulus onset. In most studies, auditory MMN modulations have been reported to respond to the random presentation of a stimulus deviating from the repeated and standard trend of the previous sound sequences in one or more perceptual features (e.g., pitch, duration, intensity, rise time, etc).[73] As underlined by Näätänen, Kujala, and Winkler (2011), however, the MMN has been found to be sensitive also to more subtle and abstract properties, such as phonetic changes and musical regularities violations (but only in 'musical' subjects).[74] The amplitude and latency of MMN have been shown to be modulated by how different the deviant stimulus is from the standard, resulting in

[73] Numerous attempts to identify an equivalent to the MMN in the visual modality have also been reported. See Pazo-Alvarez, Cadaveira, and Amenedo (2003) and Näätänen, Kujala, and Winkler (2011) for a review.

[74] See Näätänen, Kujala, and Winkler (2011) for an extensive review and discussion of MMN findings.

larger and earlier MMN responses when the physical difference between standard and deviant is larger. In spite of this, the MMN shift usually becomes clearly visible only through a subtraction procedure, in which the ERP response to the standard stimulus is subtracted from the response elicited by the infrequent, deviant stimulus. The observation that the MMN can be elicited even in passive conditions without active attention allocation has suggested that it represents a measure of preconscious central auditory processing and, in particular, of automatic and implicit change detection mechanisms. In addition, the evidence that MMN is hardly elicited when standards and deviants stimuli are presented with long intervals from each other (e.g., more than 10 seconds, Sams et al. 1993) has suggested auditory sensory memory to be also crucially involved in the discriminability processes reflected by MMN.[75]

To conclude, prosodic mismatches have been showed to be indexed by the so-called *Right Anterior Negativity* (RAN) and *Closure Positive Shifts* (CPS) components. The former effect corresponds to a negativity shift recorded in the right hemisphere electrodes between 300 and 500ms after stimulus onset and first reported in response to the violation of the expected prosody for the particular syntactic structures presented (Eckstein and Friederici, 2005). Differently, the CPS have been identified to correlate with the perception of major intonational boundaries in both linguistic and pseudo-linguistic material, such as jabberwocky sentences (in which all content words are replaced by meaningless words); pseudo-word sentences (in which all function and content words are replaced by meaningless words) and delexicalized sentences (Pannekamp and Toepel, 2005).

2.3.2.3 ERPs studies on negation

As occasionally observed during the discussion of the currently available evidence on negation processing, the EEG-ERP methodology represents a particularly suitable technique for the online investigation of the temporal dynamics underlying the interpretation of negative sentences. Nevertheless, the relative few studies which have adopted the ERP methodology for the investigation of negative sentences so far have been characterized by very different experimental paradigms and, in some cases, highly contrasting findings. To facilitate the comparison of the study presented in the second part of this dissertation with previous electrophysiological findings on negation, therefore, we will devote this last paragraph to a more systematical retracing of the EEG studies on negation processing briefly reported in the previous sections.

The first important finding concerns the N400 component, whose modulation has been regarded as the main index of negation integration during sentence processing. Fischler, Bloom, and Childers (1983) tested a group of healthy subjects

[75] Numerous studies have shown that the auditory sensory memory, in turn, has an influence on attentive information processing and on automatic attention shifts. The reader interested in a deepen discussion of these issues is referred to Näätänen et al. (2011).

in a sentence evaluation task during which participants were asked to read world-knowledge related expressions and to evaluate the truth-value of each sentence within 1000ms after reading. The results showed that the final word of semantically 'congruous' sentences (e.g. *A robin is not a tree*; *Hawaii is not cold*) elicited larger N400 amplitudes than the final words of semantically 'incongruous' sentences (e.g. *A robin is not a bird*; *Hawaii is not tropical*). This insensitivity to the presence of negation has been taken as a strong demonstration that, as predicted by non-incremental models of negation processing, during the very first stages of sentence interpretation, negation is not yet integrated in the comprehension process. It has been noted, however, that the close proximity of some of the words composing the experimental stimuli (e.g. *robin-bird*, *Hawaii-tropical*) could have determined lexical priming effects possibly confounding the ERP latencies. Fischler et al. (1983)'s results have been confirmed and extended by a more recent study by Lüdtke et al. (2008), who made use of a sentence-picture verification task to investigate ERP effects for true and false sentences wither containing sentential negation or not. Participants were presented German sentences of the type *Vor/Auf dem X ist ein/kein Y* ('In front of X there is a/no Y') followed by a matching or mismatching picture, and they were asked to judge whether the previous sentence represented a correct description of the situation illustrated.[76] In order to control the amount of time needed for comprehending the actual meaning of the sentence, two time-conditions, differing for the delay with which the target picture was displayed after the sentence, were created: in the *short delay condition*, the picture was presented 250ms after the reading of the sentence; in the *long delay condition* the delay between the two stimulus was augmented to 1500ms. Importantly, experimental sentences were constructed in such a way that no possibly confounding lexical priming effects could arise between the subject of the sentence and the word indicating the background location. Equally important, the sentences could not be considered true or false in themselves at the moment they were read, as their truth-value could be determined just in relation to the following picture. Worth noting, this choice allowed to temporally separate the cognitive processes initiated by the interpretation of the strictly 'linguistic' information from those underlying the verification of sentence truth-value. A sort of *priming* effect facilitating the evaluation process was expected in the cases in which the object illustrated in the picture had already been mentioned in the sentence (true affirmative sentences and false negative sentences cases). In addition to ERP recording, response times were also taken into account. In the short delay condition, N400 activations replicated the patterns reported in Fischler et al. (1983), with larger N400 amplitudes in the cases in which the final word resulted incongruent with the picture, although contextually true with regards to negation (e.g. *In front of the tower there is no <u>ghost</u>* against a picture of a lion lying in front of a tower). Conversely, in the long delay condition, where the participants had more time to process the sentence before evaluating of the picture, N400

[76] An example of Lüdtke et al. (2008)'s stimuli is reported in TABLE 1 (page 72).

amplitudes were modulated in line with the truth-value of the sentence: N400 amplitudes were larger in the cases in which the final word was not depicted in the picture and it made the sentence contextually true with regards to negation (e.g. *In front of the tower there is no ghost* against a picture of a lion lying in front of a tower) in comparison with the cases in which the final word was 'congruent' with the picture, but truth-conditionally false with regards to actual meaning of the sentence (e.g. *In front of the tower there is no lion* against a picture of a lion lying in front of a tower). To conclude, N400 reductions correlated with shorter response times in both the short-delay and the long-delay condition.

As mentioned, nevertheless, Lüdtke et al. (2008)'s results have been the object of important criticism by Nieuwland and Kuperberg (2008), who underlined the fact that the N400 modulations associated with negative sentences interpretation might be crucially affected by the absence of appropriately supportive discourse. In the attempt to control the influence of pragmatic inadequacy on negative sentence N400 elicitation, Nieuwland and Kuperberg (2008) investigated the interpretation of pragmatically licensed and pragmatically unlicensed affirmative and negative sentences. As already mentioned above, pragmatically felicitous sentences were introduced by a single statement (e.g., *With proper equipments...*) relevant to the target affirmative or negative sentence, which could be either true or false. Pragmatically infelicitous sentences were introduced by the same statements used for the pragmatically felicitous sentences, although in these cases the introductive statement was almost irrelevant to the meaning of the following sentence (e.g., *With proper equipments, bullet-proof vest are/aren't very dangerous/safe*). An example of Nieuwland and Kuperberg (2008)'s stimuli is reported in TABLE 2 (next page). Event-related potentials were recorded from the critical word onset, that is, the word which determined the truth-value of the sentences (underlined in the examples).

The results showed that, when the sentences had been appropriately introduced, N400 responded to the actual truth-value of the sentence both in the case of affirmative and negative sentences, with false words enhancing larger N400 than true words. By contrast, pragmatically unlicensed sentences elicited increased N400 not only after false words in affirmative sentences, but also after true and false words in negative sentences (e.g., *With proper equipments, bullet-proof vest aren't very safe*), that is, irrespectively form the truth-value of the sentences.

TABLE 2. Example of Kuperberg et al. (2008)'s stimuli.

Pragmatically licensed sentences	
True affirmative	With proper equipment, scuba-diving is very <u>safe</u> and often good fun.
False affirmative	With proper equipment, scuba-diving is very <u>dangerous</u> and often good fun.
True negative	With proper equipment, scuba-diving isn't very <u>dangerous</u> and often good fun.
False negative	With proper equipment, scuba-diving isn't very <u>safe</u> and often good fun.

Pragmatically unlicensed sentences	
True affermative	Bulletproof vests are very <u>safe</u> and used worldwide for security.
False affirmative	Bulletproof vests are very <u>dangerous</u> and used worldwide for security.
True negative	Bulletproof vests aren't very <u>dangerous</u> and used worldwide for security.
False negative	Bulletproof vests aren't very <u>safe</u> and used worldwide for security.

Nieuwland and Kuperberg (2008)'s study was not free from methodological weakness as well. First of all, the adoption of a sentence verification task including real-world related statements whose truth-value could be immediately defined on the basis of general world-knowledge made it impossible to temporally distinguish the cognitive processes associated with the processing of the linguistic stimuli (i.e. affirmative *vs.* negative sentences) from that underlying sentence-verification. Secondly, the specific attempt at avoiding pragmatic infelicity, realized through the insertion of a an introductive statement (e.g., *With proper equipment*,…) restricting the context of validity of the following utterance (e.g., ….., s*cuba-diving is/isn't very dangerous*) had the effect of creating a strong bias for true sentences, rendering all types of false sentences extremely more unexpected in comparison with their true counterparts, as clearly emerging from a rating pretest conducted by the authors. During the pretest, a group of subjects not included in the ERP study was asked to rate each sentence with a score ranging from 1 (= unnatural) to 5 (= natural). The results showed that true affirmative and true negative sentences were perceived as rather natural (obtaining an average score of 4.02 and 3.90, respectively), whereas false affirmative and false negative sentences sounded very highly unnatural (obtaining a score of 1.38 and 1.36, respectively). Though the pretest ratings are likely to have been largely biased by the authors' instruction of giving low score of naturalness to false sentences, it cannot be excluded that the naturalness asymmetry between conditions may have had an unforeseen effect on ERP components.

Similarly to Nieuwland and Kuperberg (2008), Staab et al. (2008) recorded event-related potentials during the verification of affirmative and negative sentences (e.g., *... so he bought/he didn't bought the pretzels/the cookies*) which had been previously introduced by a short story (e.g., *During his long flight Joe needed a snack. The flight attendant could only offer him pretzels and cookies*) and by a bias sentence which had the specific purpose of orienting participants' expectations (e.g., *Joe wanted something salty…/Joe wanted something sweet….*). To simplify, a whole story ending by a true negative sentence would be constituted as follows (the target sentence is underlined): "*During his long flight Joe needed a snack. The flight attendant could only offer him pretzels and cookie. Joe wanted something salt, <u>so he didn't bought cookies</u>".* N400 analysis showed that false sentence endings elicited larger negativities than true ones. However, the effect reached significance only for affirmative sentences.

In sharp contrast with Staab et al. (2008) and Nieuwland and Kuperberg (2008), in addition, Ferguson et al. (2008) reported evidence indicating that event-related potentials are not *immediately* affected by prior contextual information's manipulation. As in Staab et al. (2008)'s and Nieuwland and Kuperberg (2008)'s studies, experimental sentences were accompanied by discourse contexts which made the utterance of the target sentence pragmatically appropriate, thus ensuring that N400 amplitudes could not be influenced by discourse-context anomalies. Very differently from other studies, nevertheless, negation was used to cancel real word expectations within a conditional statement (e.g.: *If cats were <u>not</u> carnivores, they would be cheaper for owners to look after*. *Families could feed their cat a bowl of carrots/fish and listen to it purr happily*). ERP results showed that the introduction of a negated-world context (e.g. *If cats were not carnivores*) did not immediately cause an inversion of the N400 effect to semantic violations at the critical word (*carrots/fish* in the example above), suggesting that the interpretation process was not immediately updated with the contrafactual information introduced by the *if* sentence.

More recently, Hald et al. (2013) investigated the effect of modality switching (that is, the verification of a property in one modality, e.g. auditory: *blender-loud*, after verifying a property in a different modality, e.g. gustatory: cranberries-tart) on the processing of affirmative and negative sentence. In line with Fischler et al. (1983) and Lüdtke et al. (2008), true negative sentences were characterized by larger N400 than false negative sentences in the modality-mismatching condition. In contrast, however, no differences in the N400 modulations were associated to the interpretation of true and false negative sentences in the cases in which no modality-switching was required.[77]

Besides the N400, other later positive ERPs have been observed during negative sentence processing. A 'late positivity effect', arguably reflecting the 're-integration' (after initial insensitivity) of negation into the interpretation process has been reported by Lüdtke et al. (2008) and Herbert and Kübler (2011). In the former study, adopting the sentence-picture verification paradigm, the effect started around 550ms after picture onset in the short-delay condition (SOA 250ms) and only 250ms after picture onset in the long-delay condition (SOA 1500ms). This difference has been interpreted as a consequence of the fact that the considerable delay with which the picture was presented in the long-delay condition gave to the comprehenders more time to finalize the integration of the negation into the meaning representation before evaluating the picture. Herbert and Kübler (2011) employed sentences like *Dogs cannot bark/fly*, where the truth-value of the sentences varied depending on the semantic relatedness of the subject with the predicate. Subjects were auditory presented to the sentences; no overt behavioral response from the participants was expected. The analysis of the ERPs revealed the emergency of a cortical positivity at the parietal electrodes in the time window from 600-1000ms after the target words onset, with larger amplitudes in the cases of false target words (e.g. *bark*) in comparison with true target words (e.g. *fly*). In line with non-incremental accounts of negative sentence processing, in both studies this 'late positivity effect' has been interpreted as an instance of the P600-like waves elicited by the re-integration of semantic anomalies and the updating of the mental representation of what is being communicated. In addition, Lüdtke et al. (2008) report the emergency of differences in the ERPs associated to the reading of the experimental sentences. In particular, a more pronounced N1-P2 complex was observed 80-120ms after the reading of the negative participle *kein* in comparison with *ein*. The N1-P2 complex, in addition, was followed by a larger posterior positive shift in negative relative to affirmative sentences. To conclude, enhanced negative shifts were observed after subjects nouns following *kein* in comparison with subject noun following *ein*, an effect interpreted as possibly belonging to the family of slow waves associated with memory process. More precisely, according to the authors, this latter effect may reflect the specific retrieval processes which take place after encountering negation and indicate that the listeners have to keep in mind that the sentence contained a negation, although not interpreting it immediately.

[77] Given the low relevance of the modality feature to the present dissertation, we will dwell on further discussing this very intricate issue. The reader interest in more detailed information is therefore referred to the original work.

3 DEVELOPMENTAL DYSLEXIA AS A CASE OF STUDY

3.1 Dyslexia: What it is

'Developmental Dyslexia' is commonly used to refer to a specific type of learning disorder, primarily manifested in the inability of effectively learning to read, write, spell, and decode single-words.[78] As for the other learning disabilities, the term does not include those children whose reading and writing problems can be considered the result of other primary deficits (such as sensory and/or physical handicaps, mental retardation, and emotional disturbance) or environmental factors (such as educational, cultural, or economic disadvantages). As underlined by the definition adopted by the International Dyslexia Association, on the contrary, dyslexia is generally defined in terms of *discrepancy* between a subject's reading skills and his/her intelligence and educational experiences:

> "Developmental Dyslexia is a specific disability that is neurological in origin and its characterized by difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities, often unexpected in relation to other cognitive abilities and the provision of effective classroom instruction" (www.eida.org/definition-of-dyslexia).

Despite the widely open debate on the precise origin and nature of the dyslexic deficit, a general consensus has been reached with regard to the neurobiological bases of developmental dyslexia.[79] Cross-cultural epidemiological studies, in addition, has provided important evidence of the high hereditability of the disorder (Scerri & Schulte-Körne, 2010), while considerable efforts within genetics studies have been devoted to the investigation of the so called 'genes of dyslexia' (e.g., Galaburda, LoTurco, Ramus, Fitch, & Rosen, 2006; Kaminen & Hannula-Jouppi, 2003).

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[78] 'Learning disabilities' refers to a number of disorders affecting the acquisition of one (or more) of the basic processes involved in the understanding of spoken or written language (reading, writing, mathematical abilities) or in movement and coordination skills (i.e., *dyspraxia*). The definition of Developmental Dyslexia as a learning disorder distinguishes it from 'acquired dyslexia', that is, the cases in which the reading disability derives from brain damage of various types.

[79] In particular, anomalous activation of the left hemisphere language network (e.g. Paulesu et al., 2001), abnormal white matter development (Rimrodt, Peterson, Denckla, Kaufmann, & Cutting, 2010), anomalous cerebellum (Stoodley & Stein, 2011) and planum temporal morphology (Bloom, Garcia-Barrera, Miller, Miller, & Hynd, 2013; Brambati et al., 2004), together with magnocellular deficits (e.g., Gori, Cecchini, Bigoni, Molteni, & Facoetti, 2014) have been reported. See Peterson & Pennington (2012) for a quite recent review of the neurobiological data about DD.

As largely attested, in most cases the dyslexic deficit does not occur in isolation, but it overlaps with one (or even more) other developmental impairments, such as *dysgraphia* (resulting in poor and slow handwriting, messy and unorganized papers, difficulty in copying); *dysorthographia*, a partially different type of transcription disorder crucially affecting the ability of properly acquiring the orthographic coding; *dyscalculia* (determining a general difficulty with math, mainly manifested in inaccurate counting, numbers reversal, calculation errors, difficulty in retaining math facts, vocabulary and concepts), and *dyspraxia* (characterized by poor motor skills, difficulty in planning and coordinating body movements, messy organization, poor sense of time, and general slowness in the execution of motor tasks). The comorbidity between dyslexia and writing difficulties seems to represent the most common case, as shown by the extremely high percentages of co-occurence with dysorthographia (98,7%) and dysgraphia (82,7) observed in a sample of 301 Italian dyslexic children (Gagliano et al., 2007). Recurrent overlapping with attention deficit (*Attention Deficit Hyperactivity Disorder*, *ADHD* for short, reflected in variable attention, high distractibility, impulsivity and hyperactivity) and with a more specific set of language deficits known as SLI (*Specific Language Disorder*, resulting in a general delay in the mastering of language skills, such as late talk and anomalous persistence of morphosyntactic errors in oral production) have also been attested (Germanò, Gagliano, & Curatolo, 2010; Newbury et al., 2011).

Dyslexia has been observed in all cultures and languages with a written language, including non-alphabetic writing systems, such as Korean and Hebrew. The diffusion of the deficit, however, is crucially influenced by the language's degree of transparency in the mapping between orthography and phonology, with less transparent languages (e.g., English) reporting a wider manifestation of the deficit in comparison with languages characterized by more consistent orthography, such as Italian and Japanese. Though the difficulties in the acquisition of writing and reading skills undoubtedly represent the main hints of the disorder, a large number of studies have shown that they are just the tip of the iceberg. In particular, deficits in the auditory processing (Gaab, Gabrieli, Deutsch, Tallal, & Temple, 2007; Georgiou, Protopapas, Papadopoulos, Skaloumbakas, & Parrila, 2010), visual and auditory attention (e.g., Facoetti et al., 2003), motor control (e.g., Stoodley & Stein, 2011), working memory capacity, and central executive functionality (e.g., Varvara, Varuzza, Sorrentino, Vicari, & Menghini, 2014) have been reported.[80] A very rich tradition of studies on dyslexic linguistic abilities, in addition, has shown that the linguistic-related deficits of developmental dyslexia are not restricted to writing and reading skills, but include a wide range of phonological problems, specific morphosyntactic impairments[81] and interpretive difficulties, which will be

[80] See Nicolson & Fawcett (2008) for a more extensive, though not extremely updated review of these evidence.

[81] The observation of morphosyntactic deficits in dyslexic subjects, together with the common feature of phonological deficits and the high comorbidity of the two disorders, has lead to the suggestion that developmental dyslexia and SLI may represent different degrees

briefly overviewed in § 3.2. For this reason, different models and theories in the last decades have suggested that writing and reading skills do not represent the core deficit of the disorder, but only the most visible dysfunction of a multifactorial disability (Menghini et al., 2010; Menghini, Finzi, Carlesimo, & Vicari, 2011). In particular, two main classes of proposals can be distinguished: the 'linguistic' models and the 'cognitive' models. According to the former, the writing and reading difficulties of dyslexic subjects are the consequence of a speech-specific phonological deficit. In particular, the *phonological deficit model* has proposed that developmental dyslexia is caused by a primary deficit in the representation and processing of speech sounds (Ramus, Rosen, Dakin, & Day, 2003; Snowling, 2000). The *auditory temporal processing hypothesis*, on the contrary, has suggested that the phonological deficit is secondary to a more basic auditory deficit impairing dyslexic children ability to perceive auditory stimuli that have short duration and occur in rapid succession (Georgiou et al., 2010; Tallal, 1980). According to the 'cognitive' models, on the other hand, the linguistic difficulties characterizing developmental dyslexia represent the consequence of a more general cognitive impairment. Just to mention the most relevant proposals, the *automaticity-cerebellum hypothesis* (Fawcett & Nicolson, 2008; Nicolson, Fawcett, & Dean, 2001) assumes that dyslexics' writing and reading difficulties derive from an automatization deficit due to deficient cerebellar functioning. Given the crucial involvement of the cerebellum in motor skills, the model can also account for the coordination and balance difficulties frequently observed in dyslexic children, though it does not offer any explanation for non-strictly phonological linguistic impairments in developmental dyslexia. A different view has been proposed by Vicari and co-workers (Vicari et al., 2005; Vicari, Marotta, Menghini, Molinari, & Petrosini, 2003), according to which developmental dyslexia derives from an impairment of the procedural *implicit learning* (that is, the unconscious learning based on the unintentional perception of regularities in the input), preventing dyslexic subjects to take benefit from the repeated association of stimuli or sequences of stimuli which typically accompanied new skills acquisition (see also Goldberg, 2014). A very different hypothesis, grounded on neurobiological evidence showing that dyslexic brains are characterized by significant abnormalities in the visual and auditory magnocells, is represented by the *magnocellular theory* (Stein & Walsh, 1997; Stein, 2001). According to this latter hypothesis, both reading and writing deficits of dyslexic subjects are the consequence of the auditory and visual disorders derived from a more general magnocellular dysfunction. Within this theoretical framework, the same disruption is also thought to underlie visuo-spatial attention and motor control/automatisation deficits typically found in dyslexic subjects. More recently, a similar proposal have been advanced by the *visuo-spatial attentional hypothesis* (Facoetti, Paganoni, & Turatto, 2000; Facoetti et al., 2003), according to which dyslexics' reading

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of severity of a unique language specific disorder. See Bishop & Snowling (2004) and Ramus, Marshall, Rosen, & Van Der Lely (2013) for a discussion of this very intricate issue.

disability is attributable to a specific deficit in the magnocellular-dorsal pathway, containing the main fronto-parietal attentional network (Gori, Cecchini, Bigoni, Molteni, & Facoetti, 2014). The consequent visuo-spatial attention inefficiency would hamper the accurate selection of the letters to be read from the other irrelevant signs or letters cluttering the written page, resulting in very slow and incorrect reading. Although deficits in the magno-dorsal pathway in dyslexic subjects have been reported, together with the successfully administration of rehabilitation treatments based on visuo-spatial, the *visuo-spatial attentional* model – as all the hypotheses mentioned so far – results crucially unsuitable to account for non-reading related linguistic weaknesses observed in developmental dyslexia. An explanation compatible with the whole range of phonological, morphosyntactic and interpretive deficits exhibited by dyslexic subjects have been proposed by *working memory-based models*, according to which all the variegated manifestations of the disorder are due to dyslexics' limited working memory capacity and efficiency. Given our major interest in working memory, developmental dyslexia and negation processing connection, we will cover this topic in more details in § 3.3. Prior to that, a short overview of the linguistic difficulties determined by developmental dyslexia is provided, including preliminary evidence on the interpretation of negative sentences in developmental dyslexia (§ 3.2) and main EEG findings reported in the investigation of linguistic abilities in developmental dyslexia (§ 3.2.4).

3.2 Linguistic deficits in developmental dyslexia

3.2.1 Phonological and phonology-related deficits

Given its direct impact on writing and reading abilities, phonology has initially represented the most widely investigated component in the study of dyslexic subjects' linguistic skills. A long tradition of studies has consistently reported that dyslexic subjects display a lower-than-normal phonological awareness (that is, the ability of consciously analyzing and manipulating speech sounds), as shown by the very poor performance in tasks requiring the deliberate activation and manipulation of speech units, such as analyzing words into consonants and vowels, finding rhyming words, detecting prosodic patterns, and inverting or deleting one or more phonemes from a given word (Bradley & Bryant, 1983; Stanovich & Siegel, 1994). Studies investigating children at risk of dyslexia (that is, preschool children with at least one parent diagnosed as dyslexic), in addition, highlighted early impairments in their phonological development, mainly manifested in delayed speech production, weak stress competence, and higher degree of voicing alternation, in comparison with age-matched non at risk children (De Bree, 2007; Gallagher, Frith, & Snowling, 2000; Scarborough, 1990). Studies involving adults dyslexics of different languages, moreover, have shown that, despite of significantly improved reading, writing and spelling skills, phonological impairment consistently persists into adulthood, as reflected by the poor performance in phonological awareness tests (Bruck, 1992; Ghidoni & Angelini, 2007; Ramus et al., 2003; Wilson & Lesaux, 2001) and in writing and reading tests crucially taxing phonological abilities (such as *non-word reading* and *word dictation under articulatory suppression*, e.g., Ghidoni & Angelini, 2007; Re, Tressoldi, Cornoldi, & Lucangeli, 2011). Beyond behavioral evidence, a large number of studies employing on-line (Desroches, Joanisse, & Robertson, 2006) and neuroimaging techniques have provided further evidence of dyslexics' phonological deficits, the most relevant of which is represented by the hypoactivation of the posterior temporal areas, classically considered to be highly involved in phonological processing (e.g., Rumsey et al., 1992).

As we will discuss in § 3.3.2, in addition, important deficits have also been observed in tasks depending on the phonological short-term memory, the cognitive component responsible for the storage of phonological forms. In particular, the *non-word repetition* test, involving the repetition of meaningless but phonologically plausible pseudo-words, has been reported to represent a critical task for both dyslexic children (e.g., Kamhi & Catts, 1986; Rispens, 2004), children at genetic risk of dyslexia (Carroll & Snowling, 2004; De Bree, 2007; Bree, Wijnen, & Gerrits, 2010; Gallagher et al., 2000), and adult dyslexics (Ramus et al., 2003).

To conclude, the observation that vocabulary impairments – mainly manifested in poorer and slower vocabulary acquisition – do not seem to represent a primary deficiency in children at risk of dyslexia, given its relatively late emergence (around 3 years of age; Scarborough, 1990), has led to the conclusion that they may represent a secondary output of phonological deficits. In parallel, dyslexic children and adults poor performance in *rapid automatic naming* tasks (that is, tasks requiring the immediate naming of objects, colors and letters; e.g., Felton, Naylor, & Wood, 1990; Ghidoni & Angelini, 2007; Willburger, Fussenegger, Moll, Wood, & Landerl, 2008) has been interpreted as a consequence of their difficulty in accessing phonological representations (Ramus & Szenkovits, 2008).[82] Further confirmation to the association between phonological impairment and disrupted vocabulary access has been offered by studies showing that the lexical and vocabulary abilities of dyslexic adults result crucially impaired only when tested under a condition of phonological processing overload (e.g., *lexical decision under articulatory suppression*, Re et al., 2011; *phonological recoding in lexical access*, Wilson & Lesaux, 2001).

[82] Worth noting, however, according to other researchers phonological awareness and rapid automatic naming have to be considered as different and independent abilities (Wolf, Bowers, & Biddle, 2000).

3.2.2 Syntactic and morphosyntactic skills

As mentioned, the last decades' studies have highlighted that the linguistic deficits associated to developmental dyslexia are far from being restricted to phonological and phonology-dependent abilities, such as writing, spelling and reading skills. The investigation of morphosyntactic and syntactic abilities, in particular, has shown that the grammatical competence is also impaired in dyslexic subjects, even if limitedly to specific and, to say it roughly, particularly 'complex' linguistic operations. First evidence in this direction has been reported by Byrne (1981), who explored dyslexic children's acquisition of English *though-sentences*, that is, sentences, such as (b) below, in which the subject of the main clause is the logical object argument in the embedded clause. These sentences are structurally identical to sentences in which the subject of the main clause is involved in an entirely different syntactic dependency, such as (a) below. Here is thus the classical minimal pair: (a) *The bird is happy to bite* vs. (b) *The bird is tasty to bite*: while in the former case the bird is the logical subject of the biting, in the latter it is – on the contrary – the logical object of the action. According to acquisition studies on typically developing children, the proper interpretation of sentences like (b) is acquired later than that of (a), not before than children enter school. Interestingly, Byrne (1981)'s study reported that the acquisition of the marked interpretation in which the bird represents the logical object of the biting is acquired even later by dyslexic children, who tend to erroneously interpret the bird as the subject of the biting even during school years.

A second very prolific domain of investigation of syntactic abilities in dyslexia is represented by the interpretation of relative clauses. Studies involving dyslexic and non-dyslexic children reported that both the comprehension and production of subject and object relative sentences result extremely more difficult for dyslexic subjects' than for control peers, especially in the case of object relative clauses (Bar-Shalom, Crain, & Schankweiler, 1993; Stein, Cairns, & Zurif, 1984, Guasti & Branchini, 2012).

A third case of syntactically complex sentences which have been reported to be problematic for dyslexic children is represented by passive sentences, whose interpretation and production are mastered significantly later in dyslexic children in comparison with non-dyslexic children (Reggiani, 2009).

A recent study by Guasti and colleagues, moreover, highlighted that dyslexic children experience more troubles than typically developing children in the production of object *wh*-questions (Guasti, Branchini, & Arosio, 2012).

The investigation of the acquisition of the binding principles governing the interpretation of pronominal expressions has led to contrastive evidence. In particular, Waltzman & Cairns (2000) reported that poor readers make significantly more errors with the interpretation of referential pronouns (e.g., *Pig*$_i$ *is drying her*$_j$,) than their control peers. Fiorin (2010)'s study on the interpretation of structurally ambiguous pronouns (involving sentences like *Every friend of Francesco painted his*$_{i/j}$ *bike*), on the contrary, showed similar mastering of bound and referential interpretations in dyslexic and non-dyslexic children. Differently from control children, however, dyslexic children tended to maintain a strong preference for one of the two interpretations during the whole task. A recent study by Guasti (2013) has extended the investigation of pronominal expressions acquisition to clitics production in Italian 9-years-old dyslexics. The results have revealed a reduced use of clitic pronouns in dyslexics in comparison with control subjects.

‘Strict’ morphosyntactic competence has also been shown to be deficient in dyslexics, resulting in poor sensitivity to subject-verb agreement violations (Jiménez, 2004), impaired inflectional morphology production (Altmann, Lombardino, & Puranik, 2008; Joanisse, Manis, Keating, & Seidenberg, 2000) and weak morphological awareness (Leikin & Hagit, 2006).

To conclude, a rich tradition of longitudinal studies involving children at risk of dyslexia, in addition, shows that significant differences in morphosyntactic and syntactic skills between at risk and non at risk children emerge at very early ages. Scarborough (1990) reported that, from the age of 30 until 48 months, at risk children produced shorter and less complex sentences compared to control children. More recent confirmation of early deficits in morphosyntactic skills have been provided by Rispens (2004)’s study with 5 and 6-year-old children at risk for DD. Van Alphen et al. (2004) and Wilsenach (2006)’s longitudinal studies showed that, differently from age-matched controls, children at risk of dyslexia aged 19 and 25 months could not discriminate between grammatical and ungrammatical sentences involving violations of the auxiliary selection or its absence within participle constructions (e.g., *De boer__ gewerkt*, ‘The farmer __ worked’). Van Alphen and colleagues (2004) additionally tested the production of plural nouns and inflected verbs in 3-year-old at risk for dyslexia and control children, showing that the former elicited very fewer correct forms in comparison to the latter. In Scarborough (1990) and Gallagher et al. (2000), moreover, syntactic abilities have been found to represent a very strong predictor of reading disabilities, even more than phonological skills.

3.2.3 Semantic, interpretive and pragmatic competences

Since recently, semantic and pragmatic abilities in subjects with dyslexia had been only sporadically explored. The observation that, during reading tasks, dyslexic children efficiently rely on the semantic context as a source of help for word identification, in fact, had been traditionally taken as a proof of the integrity of the semantic representations in developmental dyslexia (Nation & Snowling, 1998). More recent studies investigating spoken language comprehension in dyslexic children, however, have highlighted specific semantic and pragmatic deficits in dyslexia. Fiorin (2010) investigated the interpretation of Italian grammatical aspect by comparing the comprehension of spoken sentences either including imperfective (e.g., *Marco mangiava il gelato*, ‘Marco ate-IMP the ice-cream’) or present perfect tense (e.g., *Marco ha mangiato il gelato*, ‘Marco ate-PP the ice-cream’) through a picture-selection task, in which participants were asked to choose which of the two pictures presented (one illustrating a complete situation, the other depicting an ongoing situation) appropriately illustrated the sentence just listened. Differently from age-matched controls, dyslexic children frequently evaluated pictures depicting a completed action (e.g., a picture displaying Marco with smeared mouth and no ice-cream in his hands) as correctly illustrating imperfective sentences. Fiorin (2010) explained dyslexics' poor performance by assuming that the interpretation of imperfective grammatical aspect involves the performing of more complex reasoning in comparison with past perfect tense, exceeding dyslexic children processing resources. More precisely, the interpretation of imperfective past tense requires the computation of a conversational implicature according to which, if the speaker had wanted to refer to a complete situation, she would have used the past present tense but, since she did not, the action described has to be considered not completely performed yet.

Vender (2011) extended the investigation of semantic and pragmatic abilities in dyslexia to the interpretation of extra-phrasal pronominal relations and scalar implicatures. The first study included sentences in which the resolution of the anaphoric dependency cannot be determined on the basis of structural constraints but, on the contrary, requires the consideration of *saliency* principles. Two types of sentences were tested. The first type was represented by utterances involving the resolution of a zero pronoun, such as *Paperina ha ballato con Minnie e poi Ø ha preparato la cena* ('Daisy Duck danced with Minnie and then Ø prepared the dinner'). As explained by Vender (2011), the use of a zero pronoun is expected to encode the meaning according to which the topic of the sentences has not changed from that expressed in the previous utterance. As a consequence, the predication of the sentence containing the zero pronoun has to be referred to the same topic (that is, Daisy Duck in the example above). The second type of sentences corresponded to structurally similar sentences requiring the resolution of an overt pronoun, e.g., *Paperina ha ballato con Minnie e poi* <u>*lei*</u> *ha preparato la cena* ('Daisy Duck danced with Minnie and then <u>she</u> prepared the dinner'). In this latter case, the resolution of the anaphoric dependency is thought to be more complex, as it involves the computation of a conversational implicature, according to which, if the referent of the pronoun had been the topic of the previous sentence, the speaker would have used a zero pronoun. On this basis, the explicit expression of the pronoun is expected to encode the meaning according to which the previous topic does not represent the appropriate reference for the pronoun. As expected, 9-year-old dyslexic children made significantly more errors than their control peers in the interpretation of the pronominal expressions, actually paralleling the performance of 5-year-old children. The investigation of conversional implicatures also included the interpretation of sentences including quantifiers, frequency adverbs, and propositional connectives. In all cases, the informatively appropriate interpretation of the sentences was based on the assumption that if the speaker uses a weaker term in the scale (e.g., *sometimes* in place of *often* or *always* within the scale of frequency adverbs, *some* instead of *most* or *all* within the scale of quantifiers, *or* in place of *and* within the scale of propositional connectives), this entails that none of the more informative, stronger characterizations of the scale holds for the situation under interpretation. As for the resolution of pronominal assignments, the results showed that 9-year-old control children displayed an adult-like performance, while dyslexic performance equalized that of 5-year-old non-dyslexic children, reflecting a significant delay in the acquisition of the ability to compute scalar implicatures.

To conclude, the pragmatic competence of adult dyslexics has been the object of a pilot study by Griffiths (2007), who investigated the dyslexics' understanding of metaphors and irony together with their ability to extract inferential information from stories. The study consisted in the fulfillment of a self-reported questionnaire for the estimation of the pragmatic competence and by the administration of the *Right Hemisphere Language Battery* to a sample of control and dyslexic subjects aged 17 to 41 years. In line with the information that emerged from the questionnaire, the linguistic tests revealed more mistakes in dyslexic participants than in controls, supporting the existence of pragmatic deficits in developmental dyslexia. According to the authors, the pragmatic difficulties observed may be due to deficits in working memory, processing and automatization.

3.2.3.1 The interpretation of negation in developmental dyslexia

Vender & Delfitto (2010) and Rizzato, Scappini, & Cardinaletti (2013, unpublished) reported preliminary evidence of dyslexics' difficulty in the interpretation of negative sentences. In Vender & Delfitto (2010)'s study, a sentence picture-verification task was used to test dyslexic children comprehension of several types of negative sentences: internal sentential negation (e.g., *La gallina non sta facendo la spesa*, 'The hen is not doing shopping'), external negation, metalinguistic negation (e.g., *Non è vero che Biancaneve sta litigando con un nano,* 'It is not true that Snowhite is quarelling with a darf'), negative passive sentences (e.g., *Gatto Silvestro non è colpito da Titti*, 'Sylvester is not hit by Tweety'), negative quantifiers (e.g., *Nessuna formica sta bevendo il caffè*, 'No hant is drinking a coffee'), and negative concord constructions (e.g., *Grande Puffo non sta salutando nessuno*, 'Papa Smurf is not greating anyone'). The participants were asked to listen carefully to a series of exclusively negative sentences and to evaluate the truth-value of each sentence on the basis of the picture immediately following it. The picture, then, could illustrate a situation congruent with the meaning of the previous sentence or not, resulting in true and false conditions. Similarly to Lüdtke, Friedrich, Filippis, & Kaup (2008)'s paradigm discussed in § 2.3, however, the study was characterized by the use of pragmatically inappropriate contexts of utterance. In particular, in the case of true negative sentences the complete lack of relevance of the picture to the activity mentioned in the sentence produced an effect of strong pragmatic infelicity, violating the *plausible denial* constrains elaborated by Wason (1965). Rizzato, Scappini, & Cardinaletti (2013, unpublished), on the other hand, employed a pragmatically balanced sentence-verification task[83] to test the interpretation of negative sentences in dyslexic adults. Unfortunately, the test included a very low number of participants (5 undergraduate dyslexic subjects and 5 age-matched controls). In both studies, dyslexic subjects reported higher error rates, suggesting that the comprehension of negative sentences results significantly more effortful for dyslexic subjects in comparison with non-dyslexic controls. Due to the methodological bias mentioned above, however, the results of these two studies have to be taken with some caution, inviting to further research.

3.2.4 The use of EGG in the investigation of the linguistic deficits in developmental dyslexia

In parallel to behavioral studies, in the last few decades a series of electrophysiological studies have also been performed with the aim of better understanding which cognitive processes can be considered responsible of the dyslexics' difficulties in both written and oral tasks. The fine-grained temporal resolution of EEG, together with the well-established functional role of some of the linguistic ERPs reported in the literature, in fact, has represented the opportunity to distinguish between the cases in which the atypical linguistic performance of dyslexic subjects has to be attributed to a slowdown of the same cognitive processes characterizing typical language processing from the cases in which dyslexic subjects seem to resort to qualitatively different cognitive processes. Nevertheless, as we will briefly overview below, in many cases the investigation has lead to contrastive or – at least – inconclusive results. A large number of EEG studies made use of *phonological priming* tasks (consisting in the presentation of a target stimuli replicating or not, e.g. through rhyming/alliteration, the phonological characteristics of one or more previously presented items) to investigate the phonological processing in developmental dyslexia. The results largely confirmed dyslexics' phonological impairment (Ackerman, Dykman, & Oglesby, 1994; Bonte, Poelmans, & Blomert, 2007; Jednoróg, Marchewka, Tacikowski, & Grabowska, 2010; McPherson, Ackerman, Holcomb, & Dykman, 1998; Brian McPherson & Ackerman, 1999; Rüsseler, Becker, Johannes, & Münte, 2007), though partially diverging with respect to the component which differentiated dyslexic and non dyslexic subjects. In Bonte & Blomert (2004)'s study, the phonological processing associated to the execution of an *auditory lexical decision* and an *alliteration priming* tasks elicited comparable N400, but differently early auditory components (N1 and N2) in children with and without dyslexia. In Jednoróg et al. (2010), on the contrary, the presentation of a phonologically congruent or incongruent word after a series of six alliterating words determined a difference in N400 amplitudes between the two groups of subjects. In particular,

[83] The study employed a reduced version of the experimental protocol design for the STUDY 1 and the STUDY 2. The reader interested in more detailed information on procedure and materials, therefore, is referred to § 2.1.2, PART 2.

clearly reduced N400 in incongruent conditions and enhanced N400 in congruent conditions were reported for dyslexic children in comparison with controls.

The event-related potentials technique has also been employed in the investigation of dyslexics' syntactic and morphosyntactic competence. A series of studies on Hebrew-speaking subjects reported evidence of slower and more effortful recognition of words' grammatical functions in adults dyslexics in comparison with non-dyslexic peers (Breznitz & Leikin, 2000, 2001; Leikin & Hagit, 2006; Leikin, 2002). In Breznitz & Leikin (2000), in particular, the elicitation of the N100 and P300[84] components associated to words' grammatical functions categorization was reported to be significantly affected by the fast-paced reading rate in the dyslexic adults, resulting in shorter latency and increased amplitude of the components in accelerated reading conditions in comparison with slower reading conditions. Conversely, no difference in the amplitudes of the two components was observed in the control group. Sabisch, Hahne, Glass, von Suchodoletz, & Friederici (2006)'s study focused on the detection of phrase structure violations in a group of dyslexic children and a group of non dyslexic controls. The results showed comparable P600 but different early morphosyntactic processing in the two groups, reflected in the emergence of a typical ELAN in the controls, but not in the dyslexic subjects, who conversely reported a left anterior negativity occurring around 300-600ms later. In addition, the involvement of the right hemisphere in the formation of the prosodic structure (reflected by a wave of right anterior negativity, RAN, in control children) was not detected in the dyslexic group, suggesting that children suffering from dyslexia do not rely on prosodic information during syntactic processing, as normal children seem to do. Rüsseler, Becker, Johannes, & Münte (2007) investigated the ERPs associated to gender agreement violations in isolated word pairs consisting of a definite article and an agreeing or disagreeing noun in adult dyslexic and control subjects. In both groups, the detection of morphosyntactic violations was reflected in the N400 component. In the dyslexic group, however, the effect presented a delayed onset and a longer persistence in comparison with the control group. To conclude, Cantiani et al. (2011) investigated the ERPs activated by morphosyntactic violations in a group of dyslexic children, a group of dyslexic children also suffering from SLI, a group of age-matched children, a group of dyslexic adults, and a group of control adults. The stimuli contained different types of number agreement violations and were presented orally. Both control groups showed P600 activation, with slightly differences concerning latency, depending on the different developmental stage. In addition, control children revealed a significant LAN (Left Anterior Negativity) reflecting the detection of the morphosyntactic error. On the contrary, in all dyslexic groups a more broadly distributed negativity wave emerged, which was interpreted to not represent a LAN instance, but rather a N400 component. Dyslexic children failed to activate the P600, but this latter response was present in

[84] The P300 component is generally involved in the process of decision making, reflecting stimulus evaluation and categorization.

the group of dyslexic adults. Unexpectedly, children suffering from both dyslexia and SLI presented EEG patterns more similar to those of age-matched controls' one than dyslexics did. According to the authors, the N400-like effect reported in both dyslexic adults and children has to be considered as reflecting a lexical-semantical strategy adopted to compensate dyslexics' specific difficulty in handling inflectional morphology.

A quite large number of EEG studies concerning lexical and semantic processing in developmental dyslexia has also been performed. A first class of data is represented by studies comparing N400 elicitation in dyslexic and non dyslexic subjects during the execution of *semantic priming* tests. Despite very similar experimental paradigms, the different semantic priming studies reported very divergent results, including both evidence of delayed, reduced, anomalously prolonged or absent N400 effects in both dyslexic children and adults (Jednoróg et al., 2010; Johannes, Mangun, Kussmaul, & Munte, 1995; Stelmack, Saxe, Noldy-Cullum, Campbell, & Armitage, 1988) and children at risk of dyslexia (Torkildsen, Syversen, Simonsen, Moen, & Lindgren, 2007) and evidence of comparable N400 modulation in the two populations (Silva-Pereyra et al., 2003), though in same case atypically prolonged (Rüsseler et al., 2007) in dyslexics. A second class of data is constituted by studies investigating semantic violations in the written modality. In all the studies, semantically incongruous words associated with a N400 effect mostly localized in the left superior temporal cortex in both dyslexic and normal reading participants. In some of the studies, however, the effect was characterized by a delayed latency and/or a reduced amplitude in dyslexic relative to non-dyslexic subjects (Brandeis, Vitacco, & Steinhausen, 1994; Helenius, Salmelin, Service, & Connolly, 1999; Schulz et al., 2008), while in some others the inverse pattern was observed, with increased N400 amplitudes in dyslexic subjects in comparison with age-matched controls subjects (Robichon, Besson, & Habib, 2002). According to Brandeis et al. (1994), these differences do not have to be interpreted as an indication of impaired semantics in dyslexia but, rather, as a reflection of qualitatively different modalities to process word meaning. As observed by Helenius et al., (1999), in addition, the written presentation of the sentences does not allow concluding that the semantic processing *per se* is impaired, but only that semantic processing during reading is weaker. Less controversial findings were in fact reported in the EEG studies adopting the auditory modality, which generally failed to find main difference in N400 modulation between dyslexic and non dyslexic subjects (Helenius et al., 2002; Mody, Wehner, & Ahlfors, 2008; Sabisch et al., 2006), suggesting no specific semantic impairment in dyslexic subjects. Worth noting, however, the EEG investigation on the semantic abilities of dyslexic subjects have been so far limited to the consideration of the semantic congruency, while no studies have been performed on the interpretation of semantically more complex sentences, such as sentence requiring the computation of conversional implicatures or other particularly demanding interpretative processes.

3.3 Dyslexia and working memory

3.3.1 A short introduction to working memory

As previously mentioned, among the theoretical models which do not consider developmental dyslexia as a strictly language-specific impairment but, rather, as the consequence of a more general cognitive deficit, the hypothesis that the reading disability may depend on working memory limitations has also been proposed. Traditionally, working memory (WM) has been defined as the capacity to store and manipulate information (of any nature, be it verbal, phonological, or visuo-spatial) over brief periods of time. Many studies have proved its crucial role in both language acquisition (Adams & Gathercole, 2000; Tagarelli, Catarina, & Rebuschat, 2011) and processing. The temporary maintenance and retrieval of syntactic information required by long-syntactic dependencies interpretation and syntactic ambiguities resolution have been proved to correlate with working memory resources in both behavioral and electrophysiological studies (Kim & Christianson, 2013; Roberts et al., 2007; Hestvik, Bradley, & Bradley, 2012; Kim & Christianson, 2013; Sprouse, Wagers, & Phlips, 2012). The relationship between working memory capacity and lexical retrieval has been extensively studied as well, highlighting that people with low working-memory capacity have difficulties inhibiting inappropriate meanings in lexical disambiguation tasks (e.g., Gadsby, Arnott, & Copland, 2008). Furthermore, the influence of working memory on lexical learning has been reported (Majerus, Poncelet, Van der Linden, & Weekes, 2008; Leclercq & Majerus, 2010). Many studies have observed that WM plays an important role in learning a second language as well (Juffs & Harrington, 2011; Tagarelli et al., 2011). Particularly, its involvement in the acquisition of foreign language vocabulary, grammar and general proficiency (Andersson, 2010; Baddeley, Gathercole, & Papagno, 1998; Kormos & Sáfár, 2008; Masoura & Gathercole, 1999; Papagno, Valentine, & Baddeley, 1991; Ramus & Szenkovits, 2008) has been attested. To conclude, working memory has been demonstrated to be highly involved in writing and spelling skills (Colombo, Fudio, & Mosna, 2009), and to represent an excellent predictor of reading skills (Jarrett, 2009).[85] Despite being generally assumed to be constituted by some sort of short-term storing systems accompanied by monitoring/attention cognitive mechanisms,[86] the exact nature of working memory has not received unanimous definition in cognitive psychology. Nevertheless, given the minor relevance of specific

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[85] See Gathercole & Baddeley (2014) for an up-to-date, though theoretically driven, review of the main studies on the connection between working memory and language abilities.

[86] See Baddeley (2012) for a review of this kind of models. Alternative accounts have referred to the temporary storage systems as ‘short-term memory’, and have attributed the monitoring and coordination mechanisms supervising the manipulation of the retained information to the more general, non-memory specific executive function and attentive system. See Cowan (2008) for a discussion of the difference between *working memory* and *short-term memory*.

assumptions on working memory components and structure to the purposes of the present work, we will not deal with the considerations of the different models of working memory proposed within the scientific community and we will simply refer to the unspecified definition outlined above.

3.3.2 Working memory capacity in children and adults with dyslexia

Working memory deficits have been largely attested as a common feature of dyslexic individuals. Given its crucial role in writing and reading assessment, a very rich tradition of studies has been devoted to the investigation of phonological/verbal short-term memory. Several studies involving phonological span tests and verbal repetition tasks reported impaired phonological and verbal working memory in both dyslexic children (see, for example, Brosnan et al., 2002; Ericsson & Kintsch, 1995; Jeffries & Everatt, 2004; Menghini, Finzi, Carlesimo, & Vicari, 2011; Poblano, Valadéz-Tepec, de Lourdes Arias, & García-Pedroza, 2000; Smith-Spark & Fisk, 2007; Swanson, 1999) and adults (e.g., Ghidoni & Angelini, 2007, Smith-Spark et al., 2003; Alloway and Alloway, 2013).[87] In addition, Jeffries & Everatt (2004) and Schuchardt, Maehler, & Hasselhorn (2008) reported that low phonological working memory measures represent a major difference between dyslexic children and children with other special educational needs, who conversely were observed to manifest intact phonological abilities but lower-than-normal visuo-spatial and visual-motor coordination abilities. Correspondingly, Kibby, Marks, Morgan, & Long (2004) showed that phonological short-term measure represents a strong predictor of the non-word reading ability of dyslexic subjects.

Similar connections between dyslexics' phonological memory and their morphosyntactic and syntactic competence have also been demonstrated. Rispens & Been (2007)'s study on dyslexic children found a significant correlation between the degree of subjects' sensitivity to subject-verb agreement and their phonological short-term memory as assessed through the non-word repetition task. Correspondingly, Wiseheart, Altmann, Park, & Lombardino (2009) showed that short-term memory significantly predicted the difficulties experienced by a sample of compensated adult dyslexics in the interpretation of complex syntactic structures (e.g., passive and relative clause sentences) to the point that entering WM and word reading measures as covariates eliminated the difference in performance between dyslexic and age-matched control subjects. The role of phonological working

[87] Interestingly, in two recent studies item and order retention processes were separately assessed with the purpose of achieving a better understanding of short-term deficits in adults with dyslexia. Trecy, Steve, & Martine (2013) observed not only impaired order short-memory, but also inefficient short-term item memory. Hachmann et al. (2014), in contrast, reported controls-like accuracy in the recalling of individual items, but very much poorer performance when the task required the recognition of the serial order in which those items were presented. Similar evidence of selective impaired serial order processing in dyslexia have been reported by Szmalec, Loncke, Page, & Duyck (2011).

memory load in sentence comprehension has been further investigated by Robertson & Joanisse (2009), who made use of a sentence-picture matching task to evaluate the interpretation of sentences differing with respect to syntactic complexity (canonical *vs*. non-canonical word order), length (varied by adding adjectival information), and experimental task-related WM load (manipulated through a variation of the delay between the presentation of the sentences and the pictures) in a group of dyslexic and non-dyslexic subjects. The results showed that, though sentence comprehension was reported to get worse for all the participants when working memory load increased, the effect was more pronounced in the dyslexic group compared to the age-matched group. In addition, significant statistical correlation between phonological short-term memory (assessed through non-word repetition) and sentence comprehension under highly demanding conditions was reported. To conclude, Martin (2013) provided preliminary evidence of phonological working memory influence on second language acquisition in dyslexic subjects.

More controversial results have been reported with respect to dyslexics' short-term visuo-spatial memory, responsible for the retention of sequences of abstract figures and spatial positions, which has been observed to be normally functioning in some studies (e.g., Alloway, Wootan, & Deane 2014; Fiorin, 2010; Vender, 2011, Kibby, Marks, Morgan, & Long, 2004), but disrupted in some others (e.g., Brosnan et al., 2002; Menghini, Finzi, Carlesimo, & Vicari, 2011; Poblano, Valadéz-Tepec, de Lourdes Arias, & García-Pedroza, 2000; Smith-Spark & Fisk, 2007; Pickering, 2006, Helland and Asbjørnsen, 2004; Martinussen and Tannock, 2006).[88] As observed by Menghini and colleagues (2011), the reason of such contrastive evidence has likely to be attributed to methodological discrepancies among the studies, concerning both the kind of memory tasks used and the criteria adopted for the inclusion of the dyslexic subjects. As a consequence, no conclusive considerations on ‘pure’ visuo-spatial short term memory in developmental dyslexia can be drawn.

To conclude, deficits in the central executive and/or attentive domain have also been widely reported in both studies involving orientation, focusing, shifting attention and visual search, discrimination speech tasks, engaging and disengaging attention, and inhibition tasks (see, for example, Brosnan et al., 2002; Facoetti, Paganoni, & Turatto, 2000; Facoetti et al., 2003; Menghini et al., 2010). Furthermore, other studies have documented deficits in planning, monitoring and revising during problem solving and response shifting (Chaix et al., 2007; Mati-Zissi & Zafiropoulou, 2001; see also Nicolson & Fawcett, 2008 for a review), suggesting deficient executive functions in developmental dyslexia.

The extensive evidence speaking in favor of phonological memory impairment in dyslexia, together with the data suggesting an important correlation between this latter component and language processing in dyslexia, has led to the hypothesis

[88] Deficits have also been found in studies using tasks which evaluated orientation, focusing, shifting attention and search of visually presented materials (Menghini et al., 2010; Varvara, Varuzza, Sorrentino, Vicari, & Menghini, 2014).

that an isolated short term verbal/phonological deficit may underlying developmental dyslexia (Kibby et al., 2004; Poblano et al., 2000; Ramus & Szenkovits, 2008). The identification of executive and attentive impairments, on the other hand, has suggested that both dyslexics' phonological and visual memory deficits may represent a secondary outcome of the inefficiency of central executive/attention system in dyslexia (e.g., Facoetti et al., 2003). As a confirmation, Brosnan et al. (2002) showed that the poor performance reported by dyslexic subjects in a series of visuo-spatial, phonological and verbal memory tasks can be (at least partially) explained as deriving from dyslexics' difficulties in inhibiting the processing of the surrounding context, an ability crucially dependent on central executive/attentive functions. Similarly, Smith-Spark & Fisk (2007) noted that the reduced phonological and visual-spatial spans observed in a sample of dyslexic adults was related to task's complexity and became evident only in those cases in which the experimental procedure required a high memory-updating load, speaking in favor of a central executive dysfunction. Central executive inefficiency has also been proved to account for dyslexics' lower-than-normal reading and linguistic abilities (Berninger & Abbott, 2006; Robertson & Joanisse, 2009). In line with these latter findings, Varvara et al. (2014) observed that children with dyslexia show deficits in several abilities crucially involving the concurrent use of short-term storing and executive functions (such as verbal categorical and phonological fluency, visual-spatial and auditory attention, verbal and visual short-term memory, and verbal working memory), and that the 'spoonerism' measure (assessing the abilities to switch letters and sounds between two given words to create two other meaningful words) significantly predicted word and non-word reading performance. Although to a lesser extent, auditory and visual-spatial attention also explained the increased percentage of variance related to reading deficit in dyslexic and non-dyslexic children. On the basis of McLoughlin, Leather, & Stringer (2002)'s hypothesis, according to which the inefficiency of WM and, in particular, of the phonological and central executive components represents the common cause of all the primary deficits observed in dyslexic subjects, Fiorin (2010) and Vender (2011) suggested slightly different working memory models to account for dyslexics' poor comprehension of sentences which are complex from an interpretative point of view, such as those involving the computation of conversional implicatures (e.g., imperfective tense, scalar implicatures, and extra-sentential pronominal expressions) and negative sentences. Given the currently complete lack of experimental evidence in this direction, however, this latter proposal has to be considered as a speculative, though potentially plausible, hypothesis.

Part 2
The present study

1. INTRODUCTION AND RATIONALE

The present study aims at addressing two main issues. On one side, it was designed to contribute to the broad debate about the processing of negation (see relevant considerations in § 2.2) by providing novel electrophysiological data on the interpretation of negative sentences by a group of Italian healthy subjects, still lacking in the literature on the topic (STUDY 1). More specifically, it was intended to replicate Lüdtke et al. (2008)'s study with an experimental paradigm arguably free from the pragmatic infelicity characterizing this latter study. On the other side, the present research was intended to deepen the relationship between working memory resources, negative sentences interpretation and developmental dyslexia, in the line of research initiated by Vender and Delfitto (2010). From this perspective, the current study is framed within the investigation on both dyslexics' deficits in spoken language comprehension (see § 3.2 for a review), working memory resources in children and adults with Developmental Dyslexia (see the relative discussion in § 3.3.2), and negation processing dependency on non-automatic, working memory linked processes (STUDY 2).

1.1 Relevance of the present study to the broad debate on the processing of negation

As highlighted in the discussion of the different models and theories proposed to account for the interpretation of negative sentences, the current debate on the processing of negation mainly concerns four main issues, highly connected with each other: (a) the degree of difficulty of negative sentences interpretation in comparison with affirmative sentences, an aspect crucially related to the timing of integration of the negative elements into the interpretive process (i.e. incremental vs. non-incremental processing); (b) the influence of the pragmatic context to the easiness of interpretation of negative sentences; (c) the way in which the negative meaning is captured (i.e., through the rejection of the negated state of affairs representation vs. through a mitigation of the meaning/suppression of the concept under the scope of negation); (d) the model of language comprehension assumed. As already emphasized, all these aspects are interwoven with each other. While non-incremental models of negation have mainly attributed the well-reported increased difficulty associated to negative sentences relative to affirmative sentences interpretation to their being characterized by some kind of two-step based interpretation, incremental models have attributed it to the crucial lack of appropriate licensing context observed in many experimental studies. On a strict parallelism, while non-incremental models have proposed that the understanding of the actual meaning of negative sentences necessarily pass through the consideration and subsequent rejection/correction of its affirmative counterpart, some incremental models have suggested that negation has an immediate ‘suppressive’ effect to the concepts to which it refers to. To conclude, while most non-incremental models of negation are inevitably based on representational models of language comprehension, incremental theories have not necessarily argued in favor of one or the other language interpretation theory.[89]

As we have seen, the fine-grained temporal resolution of EGG-ERP method makes it a very suitable technique for disentangling the temporal stages characterizing the processing of negative sentences. Among the few EEG studies on negation currently available, however, the two studies specifically designed with this purpose have reported very contrasting results. Both studies, in addition, were not free from methodological limitations.

Lüdtke et al. (2008)’s sentence-picture verification task provided preliminary electrophysiological confirmation to the *Two-Step Simulation Hypothesis* by showing that N400 elicited by sentence-verification against a picture presented with a delay of 250ms is not modulated by the actual truth-value of the sentence but by the match/mismatch of its affirmative counterpart with the situation depicted. In addition, the following time window (500-1000ms) was characterized by the emergence of a late positivity in negative conditions, but not in the affirmatives one, an effect the authors interpreted to reflect reanalysis processes underlying the second stage of interpretation of negative sentences. The adoption of two different temporal conditions, the second of which characterized by a significantly extended delay between sentence and picture presentation (SOA 1500ms), allowed researchers to observe that, when the subjects are given more time to elaborate the meaning of a negative sentence before being forced (through the visualization of the picture) to determine its truth-value, negation effects occurs earlier (around 250ms after picture onset) and overall task’s demands decrease, in particular in the negative conditions. As mentioned, however, the characteristics of the pictures employed (in which the entity depicted in front of the background described did not corresponded to the one mentioned in the sentence in all conditions) determined significant differences in the pragmatic felicity of the

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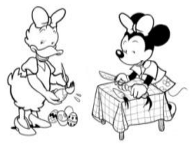
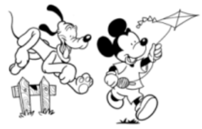
[89] An exception to this latter consideration is represented, as we have seen, by the ‘disembodiment’ account of negation, specifically referring to (and providing further evidence in favor of) the *Embodiment Theory Cognition* framework. According to this latter proposal, language comprehension depends on the activation of the same neural structures that enable the effective execution of the action described, and linguistic negation crucially determines the inhibition of this activation (with regard to the linguistic information under its scope). Though extremely promising, the investigation on negation processing within *the Embodiment Cognition Theory* has been so far focused only on a limited set of predicates (namely, first –person sentences mostly including hand action related verbs) and does not seem to be immediatly extendible to other type of utterances.

sentence-picture associations, with true affirmative and false negative sentences resulting extremely more ‘congruent’ to the corresponding picture in comparison with false affirmative and true negative conditions (see TABLE 1, page 72). A larger N400 in false affirmative and true negative conditions, therefore, could represent a consequence of the different gradient of relevance of the picture to the meaning of the sentence. For the same reason, the matching/mismatching between the entity mentioned in the sentence and that represented in the picture induced unequal *priming* effects across conditions, possibly influencing N400 modulations. Lastly, the very simple mechanism of verification allowed by the comparison of the sentences against pictures representing only one single entity (in some conditions not corresponding to that mentioned in the sentence) may have induced the participants to implement task-related shortcuts not requiring the full interpretation of the sentence, e.g. based on the only considerations of whether the sentence contained negation and whether the depicted situation corresponded to that mentioned in the previous sentence.

Nieuwland & Kuperberg (2008)’s sentence-verification study investigates ERP elicitation during the silent reading of pragmatically licensed (e.g., *With proper equipment, scuba-diving isn’t very <u>dangerous</u> and often good fun*) and pragmatically unlicensed negative sentences (e.g., *With proper equipment, scuba-diving isn’t very <u>dangerous</u> and often good fun*, see TABLE 2, page 83, for an example of all experimental conditions) containing mid-sentence critical words making the sentence true or false (e.g. *dangerous* in the examples above). To ensure attention to the stimuli, after having read each sentence participants had to perform a lexical decision task. No explicit verification of sentence truth-value was required. In striking contrast with the need of a first stage of simulation of the negated state of affairs, N400 amplitudes showed that participants were able to access the actual meaning of both affirmative and negative sentences just 400ms after the critical word presentation. As mentioned, however, the unbalanced context between true and false conditions created a stronger expectation for true sentences in comparison with false sentences. Lexical predictability and expectation, in addition, were not controlled.

Beside methodological limitations, however, the very different experimental paradigms adopted have rendered it very difficult to reliably compare the results of the two studies. For this reason, the present study was designed as a picture-sentence verification task replicating Lüdtke et al. (2008)’s study, though tentatively overcoming the main limitations of the original paradigm. In particular, more complex visual scenes have been adopted to avoid pragmatic infelicity effects and unbalanced *priming* between the picture and the sentences. Beyond attenuating pragmatic felicity differences across conditions, the use of more complex pictures (always representing two different characters, one of which corresponding to the subject of the previous sentence, and two different activities, one of which mentioned in the sentence) have made much more difficult for the participants to implement task-related strategy shortcuts, such as those possibly induced by Lüdtke et al. (2008)’s sentence-picture verification task. The use of sentences not related to real-world situations, in addition, has permitted to easily control the sentences' predictability and lexical anticipation. An example of the stimuli used is reported in TABLE 3.

TABLE 3. Example of the stimuli of the present study.

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

The main objective of STUDY 1 was the investigation of the dynamics underlying the processing of sentential negation within a pragmatically plausible experimental paradigm, in which the utterance of negative sentences could be interpreted in terms of exchange of the characters/activities described.[90] As for experimental hypothesis, a two-step based interpretational process was assumed to underlie the processing of negative sentence. As a consequence, ERP components similar to those reported by Lüdtke et al. (2008) were expected to be found in spite of the crucial difference in the pragmatic plausibility of the two studies.

[90] For more detailed information about the experimental method see the *Materials* and *Procedure* sections in the following paragraphs.

1.2 Dyslexia, negation and working memory

As we have seen, a growing number of studies on general linguistic abilities in children and adults with developmental dyslexia have highlighted that dyslexic deficits are not restricted to the well-known reading, writing and spelling impairments, and not even limited to the linguistic domain. Worth noting, as we have seen, many of the linguistic difficulties that have been recently uncovered cannot be regarded as a secondary outcome neither of the phonological deficit, nor of the related vocabulary development delay. In particular, besides strictly syntactic and morphosyntactic weaknesses, spoken language comprehension difficulties have been observed to emerge in all cases in which the interpretation of the linguistic input is not strictly referential, but involves inferential processes (e.g., extra-sentence anaphoric dependencies, imperfective verbal tense, scalar implicatures, jokes and metaphors) and other non-default interpretive processes (e.g., *though sentences*, ambiguous pronominal reference, negation). Vender & Delfitto (2010) and Rizzato, Scappini, & Cardinaletti (2014, unpublished) provided preliminary evidence that negative sentences are one of the problematic cases. The results of both these previous studies, however, have to be considered with some caution. Vender & Delfitto (2010)'s sentence-picture verification task, in fact, was characterized by the same level of pragmatic inadequacy characterizing Lüdtke et al. (2008)'s paradigm. Also in this case, therefore, the significant difference in accuracy between true negative and false negative sentences may have been strongly influenced by sentence-picture *priming* effects. The unbalanced distribution of the stimuli, together with the low number of items for experimental condition (three items for condition, for a total of 12 experimental items), in addition, further undermines the reliability of the results. Rizzato, Scappini, & Cardinaletti (2014, unpublished)'s study, on the other hand, was characterized by a very limited number of subjects (5 dyslexic adults and 5 control subjects) and, therefore, can only be considered a very preliminary pilot study. Due to their behavioral nature, moreover, the two studies have given no indication of *what* is disrupted in the on-line processing of negative sentence in subjects with developmental dyslexia. According to Vender (2011)'s, the poorer performance of dyslexic children has to be attributed to the their limitations in working memory capacity. Vender (2011)'s interpretation is grounded on the *Two-step Simulation* hypothesis elaborated by Kaup and colleagues, according to which – as we have seen – the interpretation of negative sentences is implicitly encoded in the sequencing of two distinct mental simulations, corresponding to the negated state-of-affairs and to the actual state of affairs described in the sentence. According to Vender (2011), the construction and evaluation of these two different simulations would constitute a costly operation in terms of working memory, especially in those cases in which the negated state of affairs is not present in the discourse context. In Vender & Delfitto (2010)'s sentence-picture verification task, this latter case is represented by the true negative condition, in which the picture following the target sentence always depicted a situation different from that negated (e.g., a hen reading a newspaper after a sentence like *The hen is not doing shopping*) and, therefore, did not provide any benefit to the construction of mental simulation of the negated state of affairs (i.e., a hen doing shopping). On the contrary, negative sentences interpretation was facilitated by the visualization of a picture always corresponding to the negated state of affairs described in the corresponding sentence (e.g., a picture of a boy riding a bike after the sentence *The boy is not riding the bicycle*). As explained by Vender (2011), although not being problematic for non-dyslexic children, the asymmetry in the working memory resources involved in the interpretation of the two types of negative sentence would account for the significantly poorer accuracy in true negative sentences verification in comparison with false negative sentences reported by Vender & Delfitto (2010). It is worth noting, however, that Vender (2011)'s explanation has to be considered speculative with this respect, since Vender & Delfitto (2010) reported no data supporting a direct relationship between working memory resources and negative sentences interpretation performance.

Preliminary evidence of linguistic negation processing dependency on working memory resources has been reported, as we have seen, by Deutsch et al. (2009). Nevertheless, this latter study did not concern the interpretation of negative sentences, but it only investigated the influence of working memory resources on the evaluative priming of negated and non-negated words.[91] As a consequence, therefore, this latter study offers only partial support to Vender (2011)'s suggestion.

Based on these premises, the second part of the present study aimed at deepening the understanding of the relationship between developmental dyslexia, negative sentence interpretation and working memory capacity. More precisely, the use of a pragmatically plausible sentence-picture verification task for the investigation of negative sentence processing by a group of Italian dyslexic subjects was intended to verify whether dyslexics' difficulties persist even in absence of major pragmatic differences across experimental conditions. The use of the EGG technique, on the other hand, had the purpose of gathering fine-grained temporal information on ongoing cognitive processes underlying negative sentence processing in dyslexic and non-dyslexic subjects. To conclude, participants' working memory assessment and analysis in relation with both behavioral measures (reaction times; accuracy) and event-related potentials' amplitudes associated to the processing of negative sentences was expected to provide information on the connection – if any – between negative sentences processing and working memory resources hypothesized by Vender (2011).

[91] See § 1.3.1.3 for a description of the study.

2. PRELIMINARY STUDIES

Prior to the execution of the main experiments (STUDY 1 and STUDY 2, presented in Chapter 3 and 4 of this second section, respectively), two preliminary studies have been carried out to control the adequacy of the experimental protocol for the populations for which it was designed. The first study was administered to a group of 10 Italian young adults (mean age 27;9). The second study involved a group of 33 Italian primary school-children (mean age 9;5). Since the two experiments were based on two slightly different versions of the original protocol, they will be presented separately in the following sections.

2.1 The preliminary study with Italian typically developed adults: Behavioral and EEG measures

2.1.1 Introduction

The first preliminary study involved a group of 10 Italian adults, and included both behavioral and electrophysiological measures. The purposes of this preliminary study were various. First of all, we aimed at verifying the feasibility of the task and the adequacy of the time settings adopted. On the basis of Lüdtke et al. (2008)'s short delay condition settings, the stimulus onset asynchrony (SOA) between the sentence and the picture presentation was set to 250ms. The picture visualization was extended to 350ms, that is, 100ms more than in Lüdtke et al. (2008)' paradigm. The different characteristics of the stimuli used in the present experimental protocol, however, could make it necessary to give a longer SOA interval and/or to further lengthen the image visualization. In Lüdtke et al. (2008), in fact, all experimental sentences predicated the position of a certain entity (e.g., a ghost, a lion, etc.) with respect to a background object (e.g., *In front of the tower there is a ghost*). The pictures, in addition, included the representation of a single entity, which could correspond to that mentioned in the sentences or not, depending on the truth-value of the sentence. As we already pointed out, therefore, it could be particularly easy for the participants to implement task-related shortcuts strategies for the verification of the truth-value of the sentences. On the contrary, the different type of sentences adopted in the present study (always describing whether a certain character was performing or not a specific activity through the use of a transitive verb followed by a object noun), together with the choice of inserting two different entities in each image, make the whole interpretive and verification process more difficult and, possibly, significantly longer.

The second objective of the preliminary study with adult subjects was that of evaluating the adequacy of the protocol for the realization of an EEG study. In particular, given that the displaying of two different characters within the same picture was expected to induce wider horizontal eye-movement than in Lüdtke et al. (2008)' study, a main concern of this preliminary study was controlling the quantity and the amplitude of the eye-movements elicited by the visualization of the sentence in the EEG recording.

Secondary purposes were verifying the sustainability of the task and, more generally, the adequacy of the experimental protocol for the identification of differences in event-related potentials emergence during the processing of affirmative and negative sentences.

2.1.2 Methods

2.1.2.1. Participants

A total of 10 Italian adults (mean age 27;9; SD 2;6) took part in the study. All participants were volunteers. Including criteria were being Italian native speaker. Exclusion criteria were diagnosis of learning disabilities, non corrected visual or auditory deficits or significant cognitive impairments.

2.1.2.2 Materials

For all participants, the same set of sentences and pictures (corresponding to one of the four lists of stimuli of the complete experimental paradigm) was used, for a total of 240 experimental items. Each item was composed by a sentence and a picture. All sentences were Italian sentences, composed by an animate agent as subject (i.e., a person/a cartoon character/an animal), a transitive verb in the gerund form (e.g., *sta mangiando*, 'is eating'), and an inanimate entity as object complement. Sentences could be either affirmative (60 stimuli, e.g., *Cenerentola sta pulendo il pavimento*, 'Cinderella is cleaning the floor') or negatives (60 stimuli, e.g., *Cenerentola non sta pulendo il pavimento*, 'Cinderella is not cleaning the floor'). All sentences were intended to describe equally plausible situations and could not be considered true or false by themselves, but their truth-value could only be determined trough the comparison with the picture. The pictures were black-and-white images representing two different characters performing two different actions. In all pictures, one of the two characters and one of the actions performed by the characters corresponded to those mentioned in the previous sentence. Depending on the truth-value of the sentence, the association between the character and the activity could correspond or not to that expressed in the sentence. The combination between sentence polarity and truth-sentence generated thus four experimental conditions: true affirmative sentences (TA, 60 stimuli), false affirmative sentences (FA, 30 stimuli), true negative sentences (TN, 60 stimuli), and false negative sentences (FN, 60 stimuli). An example of the four experimental conditions is reported in TABLE 3 (page 106).

Receptive vocabulary was controlled comparing the lexical items used in the sentences with Marconi, Ott, Pesenti, Ratti, and Tavella (1994)'s lexicon of primary school Italian children. The comparison confirmed that, except for very few exceptions (*cow boy* ‘cow boy’, *aquilone* ‘kite’, *sbucciare*, ‘to peel’), all lexical items were expected to be known since primary school.[92] Given the medium frequency of the few words which were not included in Marconi et al. (1994), we expected that they would not be problematic for the participants. A reduced set of 30 Italian transitive verbs was used. Each verb had eight occurrences through the experiment, once every 30 sentences. All sentences had been recorded by a female voice and had a variable duration between 2000 and 3000ms.

All characters depicted in the pictures were easily recognizable cartoon characters, animals or highly stereotyped figures (e.g., a policeman, a thief, etc.), each one appearing an equal number of times through the experiment. To facilitate their identification, the characters were always presented in fixed couples (e.g., Grumpy with Snow White, Daisy Duck with Minnie, the indian with the cow boy, etc., see examples in the Appendix A).

The reader interested in more detailed information concerning stimuli construction, counterbalancing and plausibility is referred to the *Materials* section of the main study (§ 3.2.2).

2.1.2.3 Procedure

2.1.2.3.1 Sentence picture-verification task

Each participant was tested individually in a silent, quiet room at the *Dipartimento di Scienze Neurologiche e del Movimento* (University of Verona). Prior to the beginning of the test, participants were familiarized with the couples of characters depicted in the pictures and were asked to memorize the name of those that they did not remember well. They were informed that they would listen to a series of sentences, each followed by a picture, and that their task would be to express whether they considered the sentence to be true or false on the basis of its congruence/incongruence to the following picture. The choice between true and false had to be expressed by pressing a corresponding button on the keyboard.[93] Participants were warned that the picture would not stay on the screen for long (350ms) and, that, therefore, they would have needed to pay very much attention to the appearance of the picture. In order to inhibit horizontal eye-movements, in addition, they were asked to limit eye movements as much as possible, together with any other movement not strictly necessary for the execution of the task. They had no time limitation for making their decision, but they were informed that it was important to express their judgments as quickly and accurately as possible. Once

[92] This aspect was taken into consideration with a view to the adoption of the experimental protocol with primary school children (see the paragraph dedicated to the preliminary study with children below).

[93] The numerical button 1 was assigned to the answer “true”, the numerical button 2 to the answer “false”.

the subject had pressed the true/false button, the subsequent stimulus was presented. No feedback on the subjects' responses was provided during the performance of the task.

Experimental stimuli were presented through E-Prime software. The 240 sentence-picture pairs were subdivided in 8 blocks of 30 sentences each; at the end of each block the participant had the possibility to take a break for as long as she preferred. During each trial, the participant first listened to the sentence. After a pause of 250ms, then, she was presented with a picture, which remained displayed on the screen for 350ms. Experimental items were preceded by a warming-up session to familiarize the subjects with the task and to make sure that she had correctly understood the instructions. This session was composed by 8 sentence-picture pairs similar to the experimental items.

The testing session had duration of about one hour and half, including about one hour necessary for the placing of the electrodes cap.

2.1.2.3.2 EGG recording

The electroencephalogram (EEG) was recorded from Ag/AgCl electrodes mounted on an elastic cap according to the International 10–20 system over frontal (Fp1, Fp2, Fz, FC1 and FC2), central (C3, Cz, C4, CP1 and CP2), parietal (P3, Pz and P4), occipital (O1 and O2) and posterior (Iz, I1, I2) areas of the scalp, and on the left mastoid. All of the electrodes were referenced to the right mastoid. Horizontal eye movements were detected by means of the electro-oculogram (EOG) that was recorded as the differential voltage between two electrodes placed near the external canthi of the left and right eyes. Vertical eye movements and blinks were detected by an electrode placed just above and below the right eye. The impedance of all the electrodes was kept below 5 kΩ. EEG and EOG signals was sampled at 500 Hz, filtered with a band-pass of DC 100 Hz, digitized and amplified.

2.1.3 Results

2.1.3.1 Behavioral measures

All participants were able to perform the task and reached a percentage of correct answers above 75%; therefore, all subjects were included in the analysis. Descriptive statistics of accuracy and response times are reported in TABLE 4 below. As for accuracy, no differences were found between affirmative and negative sentences. Response times, on the contrary, were influenced by both sentence polarity and sentence polarity by truth-value interaction. Negative sentences reported overall longer reaction times in comparison with affirmative sentences, but the two types of sentence were differently influenced by the truth-value variable: while false affirmative sentences had longer verification times than true sentences, false negative sentences received faster responses than true negative sentences.

TABLE 4. Descriptive statistics – Preliminary study with adults.

Average results (10 subject)	**True AFF**	**False AFF**	**True NEG**	**False NEG**
Correct responses out of 60 (SD)	56,20 (3)	55,40 (4,2)	53,50 (5,3)	56,80 (1,7)
Reaction times (SD)	1315 (335,6)	1447 (391,8)	1644 (352,4)	1609 (403,3)

Both accuracy and reaction times measures were submitted to a 2 (polarity) x 2 (truth-value) ANOVA. The analysis revealed an effect of *polarity* [F (1, 9) = 59.906, $p \leq .001$] and *truth-value by polarity* interaction [F (1, 9) = 5.529, $p \leq .05$] for reaction times, but not for accuracy [*polarity* F (1, 9) = 4.225, $p = .452$; *truth-value by polarity* interaction F (1, 9) = 3.297, $p = .103$]. The t*ruth-value* variable, on the other hand, was not significant either for reaction times [F (1, 9) = 1.793, $p = .213$] and accuracy [F (1, 9) = 3.187, $p = .108$]. The data resulting from the statistical analysis are summarized in TABLE 5.

TABLE 5. ANOVA results – Preliminary study with adults.

Dep. variables	**Effect**	**F (1,9)**	***p*-value**
Accuracy	polarity	4.225	.452
	truth-value	3.187	.108
	polarity*truth	3.297	.103
Reaction times	polarity	59.90	≤ .001 *
	truth-value	1.793	.213
	polarity*truth	5.529	≤ .05 *

2.1.3.2 EEG analysis

EGG recordings of four participants were excluded from the analysis because of unexpected technical problems. For this reason, only a qualitative analysis was performed on the data of the remaining six participants.[94] In order to verify the amount of horizontal eye-movements recorded on the EEG during the visualization of the picture, *eogh* virtual channel analysis was computed as the difference between the potential of a site placed on the right external chantus (RHEOG)

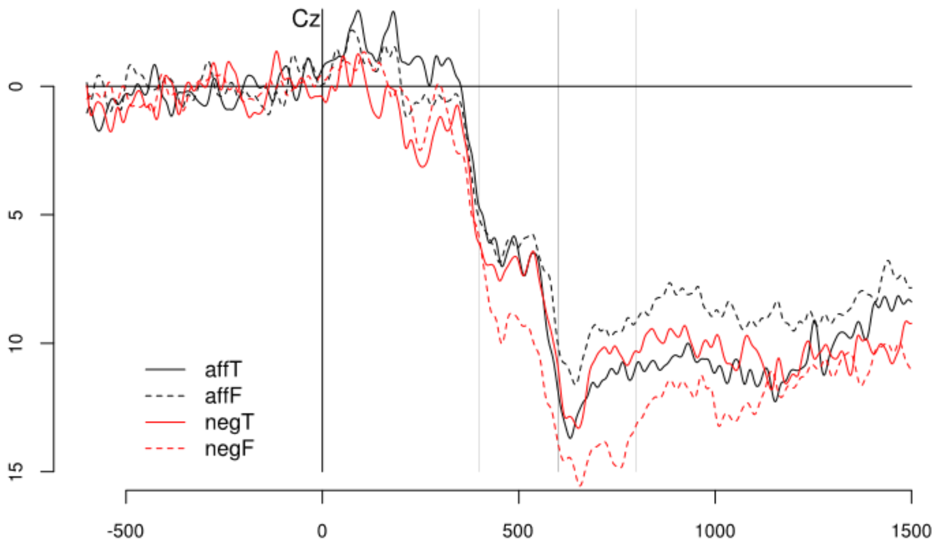
[94] The analysis of the EEG was made possible thanks to the collaboration of Francesco Vespignani (University of Trento).

minus a site placed on the left external chantus (LHEOG). Given that the eye has a positive dipole directed outward the head, a positive deflection in the *eogh* channel was read as a movement toward the right side, while negative deflections were read as a movement towards the left side of the screen. Data were just low pass filtered at 100Hz and no rejection of other artifacts was done; therefore, all the trials were considered. Visual inspection of single trails EEG recording within the early time between 200ms prior to image presentation and 400ms after its onset showed the presence of many horizontal saccades. All subjects except one tended to initially move the eyes toward left in all conditions. Eye artifacts were very large (around 14 μV).

In order to perform the analysis of the ERPs on the picture, epochs from 600ms prestimulus to 1500ms post-stimulus were excluded. EEG recordings were applied a low pass filter (80Hz) and the data were re-referenced to the average of the mastoids. Given that the high number of horizontal eye-movements made it impossible to remove all the trials contaminated, it was necessary to adopt eye-movements correction in order to perform ERPs analysis on the picture. For this reason, independent component analysis (ICA) was applied. It is worth noting, however, that ICA could not represent the most adequate solution for our case, as it generally requires much many EEG sites (around 64) and a good spatial sampling of the frontal region around the eye to correctly capture the artefactual component. Prior to ICA decomposition, data were resample at 200Hz. ICA components relative to vertical and horizontal eye movement were visually identified and removed (from 2 to 4 components were rejected). Data were then back projected and trials affected by residual eye movements or other artifacts were manually eliminated. Qualitatively, the ICA correction worked well only for some of the six subjects. Before single subjects averaging in the four experimental conditions, a baseline correction in the [-300ms, 0ms] interval was performed and a further low pass filter (30Hz) was applied. The resultant grand averages are plotted in FIGURE 1 – Appendix B.

The data show that a probable interaction between polarity and congruency emerged after around 600ms from picture onset. A closer look to Cz electrode (whose plot is magnified in FIGURE 6, next page), however, showed no clearly identifiable N400 patterns.

FIGURE 6. ERPs to the picture at Cz.



2.1.4 Discussion and conclusions

In line with previous findings, the behavioral results reflected increased difficulty in negative sentences relative to affirmative sentences interpretation, as indicated by significant differences in reaction times. The results of this preliminary study, therefore, confirmed that the experimental paradigm was adequate to capture behavioral differences in the interpretation of affirmative and negative sentences. Though extremely repetitive and relatively long, in addition, the task turned out to be highly sustainable for young adult subjects.

EEG data revealed that, despite the short time of visualization of the image (350ms), many early eye-movements were still present in the recordings. As a consequence, the necessity of adopting eye artifacts correction for ERP analysis was taken into consideration. No other technical problems emerged from the pilot application of the EEG technique. No significant results about the processing of negation could be inferred from the pilot study, neither in the direction of Lüdtke et al. (2008), nor in that of Nieuwland and Kuperberg (2008). The lack of interpretable N400 modulations, however, was likely to be due to the very low number of subjects and to the eye-correction technique adopted. All in all, therefore, we did not consider the limitations observed in the pilot study to represent discouraging factors for the execution of an EEG study on the processing of negation with a larger number of adult participants. This research is the object of STUDY 1.

2.2 A behavioral study on negative sentences interpretation in primary school children

2.2.1 Introduction

This second preliminary study, performed with a group of 33 Italian primary school children, had the double purpose of verifying whether the experimental task could be adequate to the cognitive capacities of children of an age similar to that of Vender and Delfitto (2010)'s participants and, eventually, to re-calibrate the experimental settings in order to make the task more sustainable for them. These concerns were motivated by the consideration of three main differences between our experimental design and Vender and Delfitto (2010)'s sentence-picture-verification task, concerning (a) the characteristics of the images, (b) the time available for their visualization, and (c) the duration of the task. As already discussed above, in Vender and Delfitto (2010)'s study the experimental pictures were characterized by the presence of a single subject, not always corresponding to the one mentioned in the previous sentence (see § 3.2.3.1 for a description of the study). Though simplifying the process of evaluation of the truth-value of the sentence, this choice determined an important unbalance in the pragmatic plausibility of the two conditions. To avoid this effect, as we said, we arranged our sentence-picture verification task such that the action mentioned in the sentence was always depicted in the correspondent picture. As a consequence, our images were characterized by the presence of two characters and two different actions, resulting in more complex visual scenes and, most likely, more difficult verification processes.

Other possible sources of extra difficulty derived from the fact that the protocol was intended to be employed in an EEG study. This latter aspect determined two main constrains for the experimental design. First of all, the necessity of having a high amount of EEG recordings for each experimental condition resulted in a very elevated number of stimuli (60 stimuli per condition in the original version of the protocol, 30 stimuli in the reduced version created for the preliminary study with primary school children). Differently from Vender and Delfitto (2010), in addition, true and false affirmative sentences were also included in stimuli with the purpose of investigating the processing cost specifically associated with the presence of negation. As a consequence, the task had a duration which could possibly exceed children's maintenance of attention. Secondly, as we said, the planned application of the same protocol in an EEG study made it necessary to control for participants' horizontal eye movements by limiting the time of visualization of the images to a fixed amount of milliseconds. Nevertheless, this limitation could in principle represent an extra difficulty in comparison with Vender and Delfitto's study, in which the pictures stayed on the screen until the child had provided her truth-value judgment.

2.2.2 Methods

2.2.2.1 Participants

A total of 33 Italian children (mean age 9;5) took part in the study. All children were attending the third year of primary school and had been recruited trough their school institutions (Scuola Primaria "C. Collodi", Isola della Scala, Verona, and Scuola Primaria "A. Cesari", San Giovanni Lupatoto, Verona). Children's parents were informed about the purposes and the procedure of the study and were asked written consensus concerning their children participation. Including criteria were being Italian native speaker (though not necessarily monolingual Italian speaker) and having an average school performance. Exclusion criteria were diagnosis of learning disabilities, non corrected visual or auditory deficits or significant cognitive impairments, poor knowledge of Italian.

2.2.2.2 Materials

For all participants, the same set of sentences and pictures were employed, for a total of 120 experimental items. The pictures and the sentences had the same characteristics of the stimuli used for the preliminary study with adults, but the number of the stimuli was reduced by half with respect to the original version of the paradigm, resulting in a total of 120 experimental items. As a consequence, the test was composed by 30 sentences for each condition (30 true affirmatives, 30 false affirmatives, 30 true negatives, 30 false negatives).

2.2.2.3 Procedure

Each participant was tested individually during school hours, in a quite silent room within the school. Prior to the beginning of the test, participants were familiarized with the couples of characters depicted in the pictures and were asked to memorize the name of those that they did not know well. They were reassured that they would simply play a game with the computer and they were instructed to listen carefully to the sentence and then to decide whether the picture matched the sentence or not by pressing the corresponding button on the keyboard.[95] They were warned that the picture would not stay on the screen for long and, therefore, they would need to pay very much attention to the appearance, although the task could appear quite long and demanding. They had no time limitation for making their decision, but they were informed that it was important that they express their judgments as quickly and accurately as possible. Once the subjects had expressed

[95] The numerical button 1 was assigned to the answer "true", the numerical button 2 to the answer "false". To facilitate the association of each button with the correspondent answer, the two buttons were covered by a green and a red sticker, respectively.

their judgments, the following sentence was presented. No feedback to subjects' responses was provided during the performance of the task.

For stimuli presentation, E-Prime software was used. The 120 sentence-picture pairs were presented in 4 blocks of 30 sentences each; at the end of each block the participant had the possibility to take a break for as long as she preferred and, if necessary, was motivated to continue the task although it could be felt as boring or difficult. Experimental items were preceded by a warming-up session to familiarize the subjects with the task and to make sure that all of them correctly understood the instructions. This session was composed by 8 sentence-picture pairs similar to those used as experimental items. During each trial, the participant first listened to the sentence, orally presented; then, she was presented with a picture on a computer screen in front of her. Both reaction times and accuracy were measured.

The amount of time occurring between the sentence and the picture (SOA interval) and the time of presentation of the picture were manipulated across subjects. The first 5 children were tested with a SOA interval of 250ms, after which the picture was displayed on the screen for 250ms. Since all five children had below chance performance with these settings, the time of presentation of the picture has been progressively lengthened with the following 7 children. The persisting poor performance suggested that the difficulties were probably due to the too short SOAs adopted, which did not give them time enough to process the first before being presented with the second stimulus, resulting in random answers to the picture. For this reason, a SAO of 1000ms was set for the remaining 21 children. Of these, 11 children saw the picture for 500ms (Group 1); the remaining 10 children saw the picture for 350ms (Group 2). This difference was intended to identify the shortest period of visualization of the picture necessary to 9 year-old children for correctly performing the task. The main features of Group 1 and Group 2 are summarized in TABLE 6.

TABLE 6. Main features of Group 1 and Group 2.

Group	Number	Mean age	SOA interval	Picture visualization
Group 1	11	9;6	1000ms	500ms
Group 2	10	9;4	1000ms	350ms

2.2.3 Results

As we said, the first 5 participants (tested with a SOA of 250ms and a picture presentation of 250ms) had a significantly below chance performance, indicating that the experimental designed proposed was likely not to be adequate to their cognitive capacities. These results were not unexpected, as the main objective of the preliminary study was precisely that of calibrating the time settings of the experimental design on children cognitive abilities. Subsequent attempts of manipulation of the duration of the SOA interval led to the observation that an inter-stimuli interval of 1000ms resulted tolerable for 9 years-old children. The remaining two groups of subjects, tested with this setting, reported more interesting results. Most of the participants of the two groups had an overall above chance performance, indicating that the task was compatible with their cognitive capacities. Nevertheless, many children appeared very fatigued and showed to lose concentration during the execution of the task and had to be convinced to continue. This observation indicates that, although both versions of the task (picture presentation set on 500ms/picture presentation set on 350ms) were feasible for 9-years-old children, the number of experimental trials represented a source of great difficulty for many of them.

For both groups, only participants with a percentage of correct answers above 75% were included in the analysis. This led to the exclusion of 3 children of Group 1 (500ms) and 2 children of the Group 2 (350ms). As a consequence, the results of 8 children for each group were considered. Descriptive statistics of accuracy and response times of Group 1 are reported in TABLE 7.

TABLE 7. Average correct responses and reaction times of Group 1.

Group 1 (500ms)	**True AFF**	**False AFF**	**True NEG**	**False NEG**
Correct responses out of 30 (SD)	27,4 (1,30)	26,3 (2,43)	22,1 (2,75)	25,3 (2,71)
Reaction times (SD)	2208 (619)	2525 (717)	3094 (882)	2930 (529)

The verification of negative sentences was characterized by poorer accuracy and longer reaction times with respect to affirmative sentences. The number of correct responses, in addition, was significantly lower for true negative sentences with respect to false negative sentences. Both accuracy and reaction times were submitted to a 2 (polarity) x 2 (truth-value) analysis of variance (ANOVA). The *polarity* variable resulted significant both with respect to accuracy [F (1, 7) = 17.157, $p \leq .005$] and reaction times [F (1, 7) = 43.739, $p \leq .001$]. *Truth-value*, on the other hand, was not significant neither for accuracy [F (1, 7) = 2.800, $p = .138$] nor for reaction times [F (1, 7) = 1.213, $p = .307$]. *Polarity by truth-value interaction* had a main effect on accuracy [F (1, 7) = 8.464, $p \leq .05$], while it only approximated significance for reaction times [F (1, 7) = 4.797, $p = .065$]. The relevant data are summarized in TABLE 8 below. The descriptive statistics of the performance of Group 2 are reported in TABLE 9.

TABLE 8. ANOVA results – Group 1.

Dep. Variables	Effect	F (1,7)	*p*-value
Accuracy	polarity	17.15	≤ .005 *
	truth-value	2.80	.138
	polarity*truth	8.46	≤ .05 *
Reaction times	polarity	43.73	≤ .001 *
	truth-value	1.21	.307
	polarity*truth	4.79	.065 •

TABLE 9. Average correct responses and reaction times of Group 2.

Group 2 (350ms)	True AFF	False AFF	True NEG	False NEG
Correct responses out of 30 (SD)	27,5 (2,14)	24,9 (1,36)	26,1 (2,17)	25,1 (3,72)
Reaction times (SD)	2642 (729)	3188 (463)	3340 (683)	3571 (942)

Similarly to Group 1, Group 2 exhibited longer reaction times for negative sentences relative to affirmative sentences. Despite this, no main differences in the average of correct responses were found between sentences of opposite polarity. On the contrary, the level of accuracy varied with respect to sentence truth-value, with false sentences reporting lower correct responses in comparison with true sentences, be it affirmative or negative. Again, a 2 (polarity) x 2 (truth-value) ANOVA was conducted on the two measures (accuracy, reaction times). Differently from Group 1, a main effect of *polarity* was found for reaction times [F (1, 7) = 6.669, $p \leq .05$], but not for accuracy [F (1, 7) = .256, $p = .628$]. The t*ruth-value* variable was significant for both reaction times [F (1, 7) = 6.389, $p \leq .05$] and accuracy [F (1, 7) = 8.988, *p* = ≤ .05]. *Polarity by truth-value interaction* was neither significant with respect to accuracy [F (1, 7) = 1.452, $p = .267$], nor to reaction times [F (1, 7) = .977, $p = .356$]. The results of ANOVA analysis are summarized in TABLE 10.

TABLE 10. ANOVA results – Group 2.

Dep. variables	Effect	F (1,7)	*p*-value
Accuracy	polarity	.25	.628
	truth-value	8.98	≤ .05 *
	polarity*truth	1.45	.267
Reaction times	polarity	6.66	≤ .05 *
	truth-value	6.38	≤ .05 *
	polarity*truth	.97	.356

The differences in the performance of the two groups were separately tested by means of 2 x 2 x 2 ANOVA analysis on accuracy and reaction times, with *group* (Group 1, Group 2) as between-subject variable and *polarity* (affirmative, negative) and *truth-value* (true, false) as within-subject variables. The analysis evidenced a lack of *group* effect on both reaction times [F (1, 7) = .184, p = .675] and accuracy [F (1, 7) = 1.743, p = .208]. The *truth-value by group interaction* reached significance with respect to accuracy [F (1, 7) =10.946, $p \leq$. 01].

2.2.4 Discussion and conclusions

In line with previous findings, the results of both groups showed that the processing of negative sentences need significantly more time in comparison with affirmative sentences, as reflected by overall higher response times in negative conditions in comparison with affirmative conditions. The lack of very strong differences in the overall performance of the two groups, in addition, indicates that both versions of the experiments can be considered adequate to 9-year-old children's cognitive capacities. This result suggests that, when given enough time to process the sentences before being presented to the picture (SOA = 1000ms), children perform above chance even reducing the time of visualization of the picture from 500ms to 350ms. The average accuracy of the two groups, however, was characterized by slightly different patterns. The major difficulty associated with negation, in fact, was reflected in higher error rates in negative conditions than in affirmative conditions in Group 1 (500ms), but not in Group 2 (350ms), which reported a very similar percentage of correct responses in affirmatives (87%) and negatives conditions (85%). Group 1's accuracy rates, in addition, were significantly influenced by the interaction between truth-value and sentence polarity, with true affirmatives reporting higher percentages of correct responses (91%) than false affirmatives (88%) and false negatives sentences receiving most accurate responses (84%) than true negative sentences (74%). Conversely, the accuracy of Group 2 was affected only by sentence truth-value (true conditions: 89%; false conditions: 83%). These differences suggest that the shorter SOA adopted with Group 2 may had the effect of making the verification process very difficult in general, thus rendering less visible the difficulty depending on the linguistic difference between the stimuli (i.e. affirmative *vs.* negative sentences).

Even if the limited period of visualization of the picture did not constitute an obstacle to the execution of the task by primary school children, other considerations discouraged the application of the paradigm for a EEG study with children. First of all, despite the fact that only half of the experimental items prepared for the EEG investigation (120 sentence-pictures pairs in place of 240) were included in this version of the experiment, the task was perceived as very long and demanding by the children. This perception was probably also due to the lengthening of the SOA interval up to 1000ms, which was however necessary for enabling their execution of the task. The very long response latencies, in addition, also contributed to the overall lengthening of the task. Taken all together, these observations made it hardly imaginable to test primary school children with the whole set of 240 experimental stimuli. Secondly, but not less importantly, most of the children who participated in the preliminary study could not stand still during the execution of the task, and waved their legs or clapped their fingers or move they heads around for most of the time. This latter factor resulted crucially problematic for a possible EEG study with children, as it would probably determine artifacts contamination of a quite high number of experimental trials. As a consequence, we considered the possibility of performing the EEG study with dyslexic adults, in place of primary school dyslexic children. This study is the object of STUDY 2.

3 STUDY 1: AN ERP STUDY ON THE PROCESSING OF NEGATION IN ITALIAN YOUNG ADULTS

3.1 Methods

3.1.1 Participants

A group of 27 Italian adults (mean age 27:6; SD 3;25) took part in the study. All participants were Italian native-speakers, had normal or corrected to normal vision, normal hearing, absence of neurological problems, and normal non-verbal QI.[96] They had all received a high school diploma and were undergraduate students or graduate subjects at the moment of testing. All participants were volunteers and did not receive payment for their participation.

3.1.2 Materials

The task included 240 experimental trials, each one composed by a sentence followed by a black and white picture. A total of 240 pictures were prepared. All the pictures represented a couple of easily recognizable characters, such as cartoon characters (e.g., Aladdin and Jasmine) or highly stereotyped characters (e.g., a policeman and a thief). To facilitate character recognition and to avoid strangeness in the coupling, a total of 30 fixed couples was chosen, each of which appeared in 8 pictures (e.g., Minnie and Daisy Duck, Little Red Riding Hood and the grandmother, Cinderella and the stepmother, Bart and Lisa Simpson, etc.). In all pictures, the two characters were performing two different actions, taken from a set of 60 very recognizable activities (e.g., closing the door, driving the car, washing dishes), corresponding to the predicates appearing in the experimental sentences. Each activity was depicted in eight out of the 240 pictures, each time performed by a different character. In half of the eight occurrences, in addition, the action was performed on a certain object, in the other half on another object. To exemplify, the action corresponding to the verb *chiudere* (‘to close’) was referred to a door in four experimental items, to a suitcase in the other four occurrences. The number of times in which the character mentioned in the sentence appeared in the right or in the left side of the pictures was not initially considered as a main factor of balancing; as a consequence, it resulted only roughly balanced. All the pictures illustrate common objects and actions plausible with the characters that were performing them. Pictures quality and properties had been equalized (bpi 95, 102x768 pixel) through the GIMP software. The full set of images used in the experiment is reported in the Appendix A.

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[96] Non-verbal QI was controlled through the administration of Caffarra et al. (2003)’s version of Raven’s Standard Progressive Matrices.

Each picture was paired with four sentences, for a total of 960 experimental sentences. The 960 sentences were used to create four lists of stimuli which counterbalanced items and conditions through the ‘latin square distribution’, on the basis of which each list included only one of the four sentences (true affirmative sentence, false affirmative sentences, true negative sentence, false negative sentence) associated to a certain picture. All sentences were Italian active sentences with a singular agent subject, a transitive verb on the present gerundive form, and an inanimate object as complement. For each list, half of the sentences were affirmative and half negative. Of the affirmatives, half of the sentences were true and half were false; equally, of the negatives, half of the sentences were true and half were false. As a consequence, the stimuli included four possible situations: (a) affirmative sentences expressing a correct description of the situation depicted; (b) affirmative sentences attributing the performance of the mentioned action to the wrong character; (c) negative sentences denying the attribution of the action performed by one characters to the alternative character represented; (d) negative sentences denying the execution of a certain action by the character actually performing it. The combination between the sentence polarity and sentence congruence/incongruence with the picture, therefore, yielded four experimental conditions: (a) true affirmative sentences; (b) false affirmative sentences; (c) true negative sentences; (d) false negative sentences. An example of the stimuli associated with each experimental condition can be found in TABLE 3. The full set of sentences created for one of the four lists is reported as an example in the Appendix A.

All sentences had a variable duration between 2000ms and 3000ms. They had been recorded by a female voice and digitally edited through the *Audacity* software. All sentences had a neutral prosody with no special focus on any of the words of the sentence, resulting in very ‘descriptive’ utterances. As said, receptive vocabulary was controlled comparing the lexical items used in the sentences with Marconi et al. (1994)’s lexicon of primary school Italian children. The comparison confirmed that, except for very few exceptions (*cow boy* ‘cow boy’, *aquilone* ‘kite’, *sbucciare*, ‘to peel’), the lexical items used in the sentences corresponded to very familiar words. Object complements nouns were mostly introduced by Italian indefinite articles or prepositions (e.g., *un*/*una, del*/*della*/*delle*, etc.), except from few cases of collocations, in which definite articles were used (e.g., *ascoltare la radio,* ‘listening to the radio’; *spegnere il fuoco*, ‘extinguishing the fire’; *preparare la tavola*, ‘setting the table’; *guidare la macchina*, ‘driving the car’ *guardare la televisione*, ‘watching the television’; *contare le carte*, ‘counting cards’; *pulire gli occhiali,*, ‘cleaning the glasses’, etc.).

3.1.3 Procedure

Each participant was tested individually in the *Brain Vision Lab* of the *Dipartimento di Scienze Neurologiche e del Movimento* of the University of

Verona. Positioning the electrodes cap took around 45 minutes. During the preparation, the participants were approximately informed about the type of data which would be recorded and were asked to limit all the movements not strictly related to the execution of the task during the testing session, with particular insistence on the importance of avoiding horizontal eye-movements as much as possible. They were informed that they would have been firstly auditory presented to a sentence and then to a picture, which would be displayed on the screen for a limited amount of time. They were told that their task was evaluating the truth-value of each sentence on the basis of the following picture, and that they had to express their judgment by pressing 1 (= true) or 2 (= false) button on the keyboard. They had no time limitation for making their decision, but they were informed that it was important for them to express their congruency judgments as quickly and accurately as possible. Once the subject had expressed her judgment, the following sentence was presented.

Around one week before the date of the test, each participant received an email containing the presentation of the 30 fixed couples of characters appearing in the experimental pictures, with the request of memorizing those she knew less well. For this reason, no specific time for the familiarization with the characters was planned before the beginning of the test. The participants who expressed the necessity of reviewing the couples of characters, however, were given some minutes to visualize them.

In order to counterbalance items and conditions, the 26 participants were tested with the four sets of sentences created by assigning one of the four sentences associated with each picture to a different list (‘latin square distribution’). 7 subjects were tested with List 1; 7 subjects with List 2; 7 subjects with List 3; 6 subjects with List 4. For each list, the 240 sentence-picture pairs were divided in 8 blocks, which were presented in random order. At the end of each block, the participant had the possibly to take a break for as long as she preferred. No picture and/or sentence were repeated twice across the blocks. To avoid confusion between the different pictures of each block, each couple of characters occurred only once per block. During each trial, the participant first listened to the sentence and then saw the picture. On the basis of Lüdtke et al. (2008)’s short-delay condition, the SOA interval was set on 250ms. Given the higher complexity of the pictures used in the present study in comparison with Lüdtke and collegues' ones (in which the picture displaying had been limited to 250ms), picture presentation was set up to 350ms, that is, the amount of time the pilot study demonstrated to be sufficient for adult participants to reach an above chance performance in the task. The participants did not receive any feedback on their responses. During the entire task, the EEG signal was continuously recorded. At the beginning of the task, a warming-up session common for all participants was administered to familiarize the subject with the task and to make sure she correctly understood the instructions. This session was composed by 8 sentence-picture pairs. Accuracy and the reaction times of these latter trials were not included in the analysis of the performance. All the sentences were auditorily presented through headphones, while the pictures were displayed on a computer screen placed on a table in front of the participants.

3.1.3.1 EEG recording

The electroencephalogram (EEG) was recorded from Ag/AgCl electrodes mounted on an elastic cap according to the International 10–20 system over frontal (Fp1, Fp2, Fz, FC1 and FC2), central (C3, Cz, C4, CP1 and CP2), parietal (P3, Pz and P4), occipital (O1 and O2) and posterior (Iz, I1, I2) areas of the scalp, and on the left mastoid. All of the electrodes were referenced to the left mastoid. Horizontal eye movements were detected by means of the electro-oculogram (EOG), which was recorded as the differential voltage between two electrodes placed near the external canthi of the left and right eyes. Vertical eye movements and blinks were detected by two electrode placed just above and below the right eye. The impedance of all the electrodes was kept below 5 kΩ. EEG and EOG signals was sampled at 500 Hz, filtered with a band-pass of DC 100 Hz, digitized and amplified.

3.2 Results

3.2.1 Behavioral measures

Only the participants who reached an accuracy of at least 75% of correct responses were included in the analysis. This led to the exclusion of one participant who did not realized that the action mentioned in the sentence was always depicted in the following one, although not being always performed by the expected character. Differently, all other participants referred that after some trials they had become aware of this pattern and had managed to take advantage from it for the evaluation of sentence truth-value in those cases in which they did not have the opportunity of looking at both situations depicted in the scene. Another subject was excluded from the analysis because of technical problems with the E-Prime software during the execution of the task. As a consequence, the analysis included was performed on 25 subjects (7 for List 1; 5 for List 2; 7 for List 3; 6 for List 4). For each subject, the average reaction times for each experimental condition were calculated. Reaction times deviating more than 2.5 standard deviations from mean were discarded from the analysis, together with the corresponding truth-value responses. This eliminated about 2% of the data. Descriptive statistics of the data included in the analysis are reported in TABLE 11.

TABLE 11. Average accuracy and response times – Study 1.

Average results (25 subject)	**True AFF**	**False AFF**	**True NEG**	**False NEG**
Correct responses out of 60 (SD)	56,4 (2,36)	54,8 (1,92)	52,4 (4,97)	55,1 (2,65)
Reaction times (SD)	1100 (265,2)	1263 (291,2)	1536 (352,6)	1531 (400,1)

A 2 (polarity) x 2 (truth-value) analysis of variance (ANOVA) was performed on both accuracy and reaction times. The *polarity* variable had a main effect on both accuracy [F (1, 24) = 12.589, $p \leq .005$] and reaction times [F (1, 24) = 142.450, $p \leq .001$]. The t*ruth-value* factor had a significant effect on reaction times [F (1, 24) = 9.518, $p \leq .005$], though not on accuracy [F (1, 24) = 1.678, $p = .208$]. To conclude, the *truth-value by polarity* interaction was significant for both accuracy [F (1, 24) = 11.616, $p \leq .005$] and reaction times [F (1, 24) = 13.686, $p \leq .001$]. For clarity convenience, the results of the statistical analysis are summarized in TABLE 12 below.

TABLE 12. ANOVA results – Study 1.

Dep. variables	**Effect**	**F (1,24)**	***p*-value**
Accuracy	polarity	12.58	≤ .005 *
	truth-value	1.67	.208
	polarity*truth	11.61	≤ .005 *
Reaction times	polarity	142.45	≤ .001 *
	truth-value	9.51	≤ .005 *
	polarity*truth	13.68	≤ .001 *

As it can be observed in the means of the two groups reported above, the significant *polarity* effect reflects the longer response times and higher error rates characterizing negative sentences interpretation in comparison with affirmative sentences. The *truth-value* effect on response times, on the other hand, seems to be mostly determined by the different response times associated to the verification of true and false sentences limitedly to the affirmative conditions. The *polarity by truth-value* effect shows that, in line with previous findings, accuracy rates were differently affected by sentence truth-value in affirmative and negative conditions, with false affirmative and true negative sentences reporting higher error rates than false affirmative and false negative sentences, respectively. A comparable effect characterized the average reaction times, though the difference between true and false conditions was extremely stronger for affirmative than for negative condition.

3.2.2 EEG analysis

ERPs extraction was performed through the *Fieldtrip* software (Oostenveld and Fries, 2011). Data of all other channels were re-referenced to the average activity of the two mastoids, filtered with an 80Hz low-pass filter and resample at 200Hz. On epochs extracted around the onset of the images [-600, 1500] ms, an ICA was calculated to remove ocular artifacts. After ICA calculation, topography and time course of the components were visually inspected to detect which components may be linked to blink, horizontal eye-movement and vertical eye-movement. No other components, even if likely to be linked to some type of artifact, were removed. For each subject, the number of removed components ranged from 1 to 3. After this stage, very noisy (broken or detached electrodes) channels were interpolated. In particular, it was necessary to interpolate one channel for 3 subjects and two non-adjacent channels for 2 subjects. Interpolation was performed through the 'spline interpolation method' implemented in *Fieldtrip.*

Automatic epoch rejection was performed prior to single subject average by excluding epochs for which at least one channel overcome the threshold of 140 µV in the difference between maximum and minimum voltage amplitude. Only subjects for which less of at least 60% of the total epochs were not rejected were included in the analysis. This led to the exclusion of 4 of the 25 subjects who participated to the study.

The remaining epochs were separately averaged for each subject and condition after removing baseline activity calculated as the average potential for each electrode in the
[-400,0]ms pre-stimulus interval. Data analysis was performed in shorter epochs [-400,1450] in order to eliminate interval border effects (residual artifacts that are only partially included in the epoch and filtering artifacts). Single subject averages have been used to calculate across-subjects grand-averages relative to each experimental condition. The obtained grand-averages have been plotted for the visual inspection of the results and used to calculate single channels' amplitudes in specific time intervals, selected on the basis of the visual inspection and of the relevant literature.

Grand average ERPs to the picture for the four experimental conditions are plotted in FIGURE 2 – Appendix B. The qualitative analysis of the grand averages led to the observation that true affirmative and false negative conditions, on the one hand, and false affirmative and true negative conditions, on the other, elicited similar negative deflections at posterior sites starting from the time interval between 400 and 600ms after sentence. More precisely, the negative shift was not modulated by the presence of negation, but rather by the match/mismatch between the character-action association mentioned in the sentences (even when negated) and the situation depicted in the picture, resulting in less negative deflections with true affirmative and false negative sentences in comparison with false affirmative and true negative sentences. The visual inspection of the grand averages of the four conditions also showed that the negative waves associated with affirmative and negative sentences, on the one hand, and true and false sentences, on the other, differentiated around 600ms after sentence onset. On the basis of these observations, a *match-mismatch* effect was calculated as (NT+AF) - (NF+AT), that is, the difference between (a) the sum of the wave averages of the true negative and false affirmatives sentences, and (b) the sum of the averages of the negative false and affirmative true sentences. *Polarity* effect and *truth-value* effects were also computed. The *polarity* effect was calculated as the differential waves between negative and affirmative conditions: (NT+NF) – (AT+AF). Similarly, the truth-value effect was calculated as the differential waves given by the sum of false conditions minus the sum of true conditions difference true and false conditions: (AT+NT) – (AF+AT). *Differential waves* were calculated for each single subject and averaged to produce grand average difference waves to further visually inspect how the two main experimental variables influenced event-related potentials from 600ms after sentence onset on. The waves derived from the consideration of the three effects are plotted in FIGURE 4 – Appendix B, where differential waves were smoothed for visualization purposes only. On the basis of the qualitative analysis of grand averages and effects, the following three time-windows were selected:

(1) TW1: 400-600ms, characterized by the polarity by truth-value interaction (*match-mismatch* effect);

(2) 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;

(3) TW3: 1000-1400ms, apparently characterized by a more sustained left-anterior negativity for true sentences in comparison with false sentences (*truth-value* effect).

T-test and ANOVA analysis on the different time intervals were performed with regard to four different groups of channels. The subdivision of the electrodes was determined by the crossing of two topographical factors, *longitude* (anterior, posterior) and *latitude* (left, right), yielding four pools of channels, each containing 3 electrodes: (a) Anterior Left (AL), including F3, C3, and CP1 electrodes; (b) Anterior Right (AR), including F4, C4, and CP2 electrodes; (c) Posterior Left (PL), including PO3, P3, and P1 electrodes; (d) Posterior Right (PR), including PO4, P4, and P2 electrodes. This choice was motivated by the purpose of verifying the statistical significance of the left-anterior negativity characterizing the two later time-windows (TW 2: 600-1000ms; TW3: 1000-1400ms).

Additionally, an in-depth analysis on a single cluster of parietal and central channels (including Cz, Pz, CP1, CP2, P3, and P4 electrodes) was performed with the aim of better understanding the time course of the centrally distributed *polarity by truth-value* negativity characterizing the first two time windows (TW 1: 400-

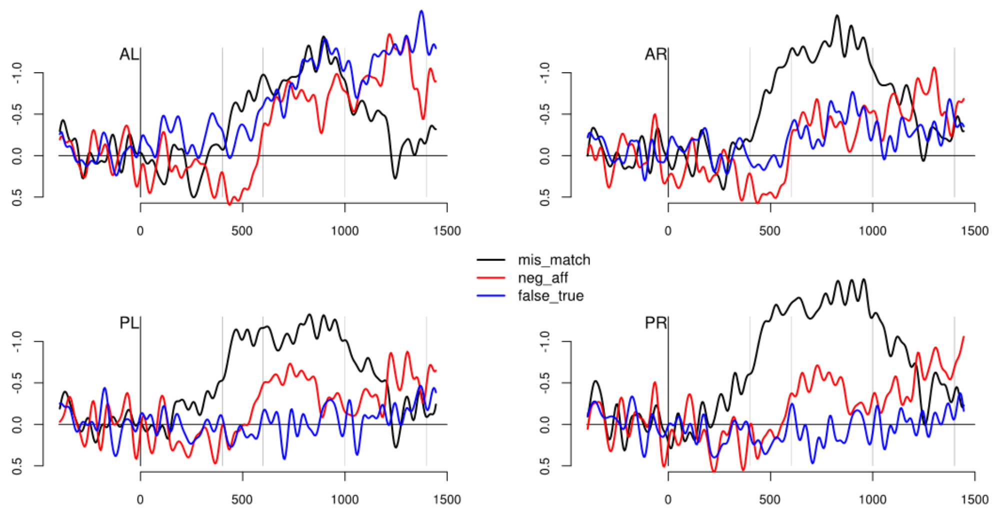
600ms; 600-1000 ms) and allowing for a comparison with the N400 effect reported by Lüdtke et al. (2008).

3.2.2.1 Four-groups of channels based analysis

The overall grand averages for the 3 differential effects of *mis-match*, *polarity* and *truth-value* in the four groups of channels (AL, ER, PL, PR) selected is reported in FIGURE (next page). Vertical lines are drawn accordingly to the time windows used in the statistical analyses below (400, 600, 1000, and 1400ms).

With respect to the four groups of channels selected, separate factorial analysis has been performed on the three time windows chosen: 400-600ms (TW1), 600-1000ms (TW2), 1000-1400ms (TW3). The analysis included four factors of two levels each: 2 topographical factors (*longitude*: anterior, posterior; *latitude*: right, left) and 2 factors concerning the experimental main variables (*polarity*: negative, affirmative; *truth-value*: true, false).

FIGURE 7. Grand-averages of the main effects at the four channels of electrodes.



TW 1: 400-600ms. The results of the ANOVA analysis concerning the first time window are reported in Table 13 below. Two main effects emerge:

(1) a statistically significant *polarity*truth-value* effect characterizing the negative going deflection starting around 400ms after picture onset and reflecting, as we said, the match-mismatch between the sentence and the picture;

(2) a *polarity*longitude* effect, likely to reflect the fact that negative sentences are more positive (0.37 µV, see Table 14) than affirmative sentences at the anterior sites.

TABLE 13. ANOVA analysis of ERP data in TW1.

Effect	**F (1,20)**	***p*-value**	**ges**
Polarity	5.24	.477	.00053
truth-value	2.74	.870	.0000081
Longitude	4.44	≤ .05 *	.041
Latitude	1.22	.281	.0024
polarity*truth	1.20	≤ .001 *	.010
polarity*long	5.93	≤ .05 *	.00036
truth*long	1.74	.201	.00023
polarity*lat	4.78	.497	.000025
truth*lat	1.76	.198	.00012
long*lat	3.02	.097 •	.0021
polarity*truth*long	3.59	.072 •	.00054
polarity*truth*lat	1.52	.231	.00012
polarity*long*lat	1.22	.729	.0000027
truth*long*lat	1.66	.211	.000046
polarity*truth*long*lat	2.99	.995	.00000000088

As for the *polarity*truth-value* effect distribution, no strong interaction with topographical factors was reported, in line with the visual inspection that shows a very broadly distributed nature of the effect. The *polarity*truth-value*long* approaching significance interaction, however, suggests a posterior focus of the effect.

TABLE 14. Longitude-related differences (negative minus affirmative).

Longitude	**AFF**	**NEG**	**Difference**
Anterior	3.739	4.104	.365
Posterior	5.704	5.738	.033

TW 2: 600-1000ms. Main results of the ANOVA on the second time window selected are reported in TABLE 15. As it can be observed, the time interval between 600 and 1000ms after picture onset was characterized by three main effects:

(1) a *polarity* effect, reflecting a broadly distributed increased negativity for negative sentences in comparison with affirmative sentences;

(2) the persistence of the *polarity*truth-value* effect that emerged in TW1 (400-600ms), accompanied by an approaching significance polarity*truth-value*latitude interaction;

(3) a *truth-value*longitude* significant effect, suggesting participants' sensitivity to sentence truth-value at this stage.

As observable in the plotting of the three effects under investigation (Figure 4 – Appendix B) and confirmed by the different means of the effect in the anterior and posterior sites (Table 15), the *truth-value by longitude* interaction is most probably due to the increased negativity associated to false sentences relative to true sentences at the anterior sites.

Table 15. ANOVA analysis of ERP data in TW2.

Effect	**F (1,20)**	***p*-value**	**ges**
polarity	3.00	.0986 •	.0029
truth-value	2.11	.161	.0013
longitude	6.49	≤ .05*	.056
latitude	5.18	≤ .05*	.0092
polarity*truth	11.35	≤ .005*	.019
polarity*long	.17	.684	.000024
truth*long	14.47	≤ .001 *	.0015
polarity*lat	1.04	.319	.000095
truth*lat	2.34	.141	.00038
long*lat	3.28	.084 •	.0023
polarity*truth*long	.36	.551	.000057
polarity*truth*lat	3.59	.072 •	.00035
polarity*long*lat	1.13	.300	.000044
truth*long*lat	3.05	.096 •	.00016
polarity*truth*long*lat	.10	.743	.0000067

Table 16. Mean amplitude and differences of true and false conditions (truth-value effect) in the anterior and posterior electrodes.

Longitude	**False**	**True**	**Difference**
Anterior	6.350	7.035	- .684
Posterior	4.529	4.499	.029

TW 3: 1000-1400ms. The results of the factorial analysis on TW 3 are reported in TABLE 17 below. As main effect, a *truth-value by longitude* interaction, comparable to the one reported in TW2 but further characterized by the three-factor interaction *truth-value***long***lat*, was observed.

TABLE 17. ANOVA analysis of the ERP data in TW 3.

Effect	**F (1,20)**	***p*-value**	**ges**
Polarity	2.96	.100	.0052
truth-value	1.81	.192	.0022
Longitude	22.83	≤ .001 *	.14
Latitude	14.03	≤ .001 *	.024
polarity*truth-value	1.14	.296	.0033
polarity*longitude	1.41	.248	.00033
truth*longitude	7.60	≤ .05 *	.0015
polarity*latitude	.38	.544	.000058
truth*latitude	2.67	.117	.00086
long*latitude	1.84	.189	.0020
polarity*truth*long	.45	.509	.000076
polarity*truth*lat	1.70	.206	.00019
polarity*long*lat	2.07	.164	.00018
truth*long*lat	5.65	≤ .05 *	.00056
polarity*truth*long*lat	0.05	.821	.0000073

As revealed by the mean differences between conditions of opposite polarity (TABLE 18), the effect has to be attributed to the major difference in the anterior left quadrant. No persistence of the truth-value by polarity effect characterizing the previous time windows was found in TW 3.

TABLE 18. Differences between affirmative and negative (*polarity* effect) sentences in the four quadrants of channels.

Longitude	**Latitude**	**AFF**	**NEG**	**Difference**
Anterior	Left	4.384	5.586	-1.201
Anterior	Right	6.587	6.875	-0.288
Posterior	Left	1.773	1.897	-0.123
Posterior	Right	2.795	2.823	-0.027

3.2.2.2 Centro-parietal cluster analysis

The four-based channels analysis allowed the identification of a negative, centrally distributed *polarity by truth-value* effect, presenting the typical topography of N400, but with a very much longer duration. In order to provide better understanding of the effect, an in-depth analysis on a centro-parietal cluster of electrodes was conducted. The CP cluster, where the effect appeared to be maximal, was composed by six electrodes: Cz, Pz, CP1, CP2, P3, and P4. ANOVA analyses on the average ERP amplitude in the CP cluster with *truth-value* and *polarity* as 2-level factors were run every 50 ms from 0 to 1450ms after picture. Only significances which were maintained lasting for at least three consequent time intervals were considered to be relevant. The interaction between *polarity* and *truth-value* resulted significant from 450 to 1050ms time window, confirming the very long latency of the effect already emerged in the four-groups based analysis above. The most relevant time intervals and the corresponding analysis main statistical data are reported in TABLE 19.

TABLE 19. The *polarity by truth* effect at the CP cluster.

Time interval	**F (1,20)**	***p*-value**	**ges**
300, 350ms	1.27	.271	.0014
350, 400ms	.70	.410	.0012
400, 450ms	3.59	.072	.0052
450, 500ms	14.11	≤ .001 *	.016
500, 550ms	14.57	≤ .001 *	.017
550, 600ms	10.91	≤ .005 *	.018
600, 650ms	10.64	≤ .005 *	.018
650, 700ms	8.47	≤ .01 *	.018
700, 750ms	9.08	≤ .01 *	.021
750, 800ms	9.16	≤ .01 *	.027
800, 850ms	9.95	≤ .005 *	.032
850, 900m	8.10	≤ .005 *	.027
900, 950ms	14.49	≤ .005 *	.031
950, 1000ms	12.92	≤ .001 *	.028
1000, 1050ms	7.67	≤ .05 *	.018
1050, 1100ms	4.31	≤ .05 *	.014
1100, 1150ms	3.26	.085 •	.012
1150, 1200ms	3.09	.093	.011
1200, 1250ms	0.48	.495	.027

On the contrary, only weak and late effects were associated to *truth-value* and *polarity* variables. No sequences including at least three sequentially significant 50ms intervals were found, though both variables reached significance in few of the intervals occurring more than 1000ms after the onset of the picture. The most relevant time windows and data are reported in TABLE 20 and TABLE 21 below.

TABLE 20. The *truth-value* effect at the CP cluster.

Time interval	F (1,20)	*p*-value	ges
1250,1300ms	3.59	.072	.0048
1300, 1350ms	3.23	.087	.0063
1350, 1400ms	8.35	≤ .01 *	.011
1400, 1450ms	6.32	≤ .05 *	.0089
1450, 1500ms	3.83	.064	.0074

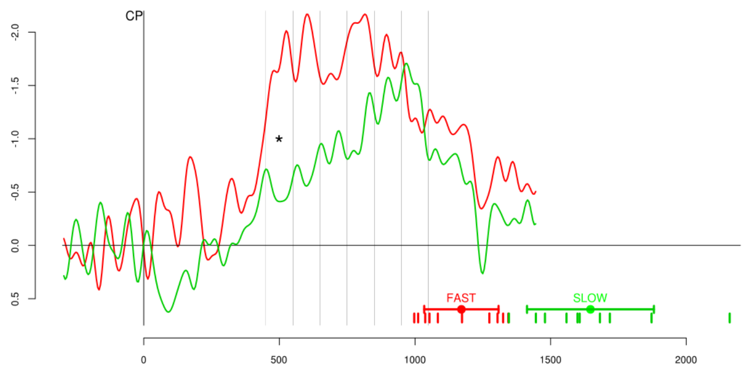
TABLE 21. The *polarity* effect at the CP cluster.

Time interval	F (1,20)	*p*-value	ges
1200, 1250ms	4.52	≤ .05 *	.012
1250,1300ms	3.36	.081	.010
1300, 1350ms	4.30	.051	.011
1350, 1400ms	1.89	.18	.0053
1400, 1450ms	4.95	≤ .05 *	.013
1450, 1500ms	5.37	≤ .05 *	.016

3.2.2.2.1 Correlations between the polarity by truth-value effect and reaction times

A possible explanation of the extremely long latency of the N400-like *polarity by truth* effect is represented by the hypothesis that it persists until the subject expresses her truth-value judgment about the sentence and/or executes the behavioral response. This would make the long duration of the effect to be not a truly long effect for every subject, but a kind of artifact due to the averaging of many subjects with different speed of processing. To test this hypothesis, the relationship between the duration of the *polarity by truth-value effect* and behavioral response times was investigated: if the rational above makes sense, we would expect that the N400 has an earlier latency (onset and offset) for fast responders and a later latency for slow responder. This would make the effect more compatible with the N400 reported in the literature, according to which this component is usually limited in the 200-600ms interval from the onset of the critical stimulus (see, for example, Kutas & Petten, 2006). We pursued this testing by implementing a median split of our subjects' group on the basis of RTs averaged across the four experimental conditions. The median RT for the whole group corresponded to 1344ms and allowed to separate 'slow' subjects (N=10) and 'fast' subjects (N=11 subjects). The grand averages of the *polarity by truth-value* effect at the CP cluster (Cz, Pz, CP1, CP2, P3, and P4) for the two groups are reported in FIGURE 7.

FIGURE 7. 'Fast' (red line) and 'slow' (green line) grand averages on the CP cluster.



Contrary to expectations, t-tests on the mean amplitudes of the two groups (run every 100ms time intervals)[97] revealed no significant difference in the N400-like overall duration of the two groups. In both fast and slow subjects, in fact, the effect had a similar average duration of 1100ms after picture onset. On the contrary, the two groups of subjects reported different N400 amplitudes in the first stage of sentence verification, with fast subjects showing a significantly larger effect with respect to slow subjects in the 450-550 time window [t (19) = - 2.270, $p = \leq .05$].

3.3 Discussion and conclusions

Both behavioral and electrophysiological data provide evidence in favor of non-incremental accounts of negation. The significantly differences in reaction times and error rates shows that, even in pragmatically balanced conditions, the interpretation of negative sentences results significantly more effortful than that of affirmative sentences. Differently from previous studies (e.g., Lüdtke et al., 2008), typically reporting the well-known AT > AF > NF > NT scale of difficulty, no difference in reaction times between true and false negative sentences was reported. As more extensively observed during the discussion of the use of the picture-sentence verification task in the study of negation processing (§ 2.3), this diverge was probably due to the different experimental paradigm adopted in the current study. In particular, the insertion of two different characters and activities within each picture prevented the facilitation effects deriving from simple *priming* between the two stimuli which characterized Lüdtke and colleagues' paradigm. For this reason, the general slowdown observed in the interpretation of negative

[97] No correction for multiple comparisons was adopted.

sentences can only be attributed, in the current study, to the linguistic specificity of the sentences, that is, to their being negative, and not to extrinsic factors deriving from the experimental design and/or stimuli characteristics, such as the pragmatic asymmetry across condition observed in Lüdtke et al. (2008). Despite of the absence of facilitating *priming*-conditions between the sentence and the picture, significant differences in both accuracy and reaction times were reported between true and false affirmative sentences. Two explanations are possible. On the one hand, the longer reaction times associated to false affirmative in comparison with true affirmative sentences may represent a consequence of the higher markedness of former. According to this view, the slower verification and higher error rates characterizing false affirmative sentences would be due to the unexpected use of an affirmative sentence for the expression of a false information. On the other hand, the effect may be determined from the perceptual complexity derived from the split of the character and the activity mentioned in the sentence into two visually distinct elements within the following picture, crucially characterizing the false, but not the true affirmative condition. The same explanations can be raised to account for the partially unexpected difference in accuracy observed between true and false negative sentences. Conversely to affirmative conditions, in this latter case the most marked condition would be represented by true sentences as a consequence of the fact that negative sentences are rarely used to predicate the truth outside of specific communicative contexts (e.g., the correction of a previously provided wrong information/presupposition). The very frequent association of sentential negation with the expression of wrong information (deriving, for example, from the prototypical use of negation for voluntary lying and denying), on the contrary, would render the interpretation of false negative sentences slightly more appropriate than that of their true counterparts within the experimental design proposed, in which the participants had been warned that the sentences could represent either a correct (true) or an incorrect (false) description of the following picture. The lack of a rating pre-test evaluating the naturalness of the experimental sentences adopted, however, makes it impossible to choose between the pragmatic and the perceptual complexity based explanations just suggested. Whatever reason motivates the different accuracy of true and false negative, moreover, one might wonder why a similar difference does not characterize the reaction times of the two negative conditions as well. A possible, yet very speculative answer to this latter question is provided by the hypothesis that the general slowdown associated with the interpretation of negative sentences has the effect of minimizing the difference in truth-value related processing costs.

Tough only partially replicating Lüdtke et al. (2008)'s findings, the results of the analysis of EGG are also in line with non-incremental, two-step models of negation processing. In particular, the very similar negative amplitudes evoked by true and false sentences of opposite polarity during the first stage of sentence verification (400-600ms) can be interpreted as a signature of the first interpretive step hypothesized by Kaup and colleagues, during which the comprehender elaborates the simulation of the non-negated state of affairs. Worth nothing, the use of more complex visual scenes in comparison with those employed by Lüdtke et al. (2008) prevented that the N400 component could be influenced by simple *priming*/*non-priming* effects between the content of the two stimuli presented. Importantly, in addition, the emergence within the same time interval of a *polarity* effect (characterized by a very different topographical distribution than N400) shows that, despite very similar N400 amplitudes, the two types of sentences are not perceived as identical. Differently from Lüdtke et al. (2008), the *polarity by truth-value* effect persisted also in the following time window (600-1000ms), during which it was accompanied by the emergence of a anterior left *truth-value* effect. The presence of this latter effect represents an indication of the fact that, as predicted by the *two-step simulation hypothesis* proposed by Kaup and colleagues, the comprehender has switched to the mental simulation of the actual meaning of the sentences as defined by the presence of negation. The sustained duration of the N400, on the other hand, suggests that the activation of the negated state of affairs is not suppressed right away after the first step of interpretation, but is maintained also during the application of the negative operator into the interpretative process (step 2). The analysis of the later time window (1000-1040ms) selected, in which a fully developed effect *truth-value* was reported, confirmed that N400 latency characterizes the whole interpretative process. On the basis of these consideration, it can be hypothesized that the interpretation of negative sentences does not rely on a strictly *sequential* two-stages process but, rather, on the progressive elaboration of the two mental simulations (one corresponding to the negated state of affairs, and one to the actual meaning of the sentence), which become simultaneously available and thus comparable starting from 600ms after picture onset.

Differently to Lüdtke et al. (2008), no parietal late-positivity deflection (interpreted by the authors as a 'direct' signature of second-step re-analysis determined by the integration of negation into the interpretative process) characterized the negative sentences interpretation in the present study. As mentioned, indirect evidence of the computation of negation was provided in the current study by the emergence of a *truth-value* related negativity at the left anterior electrodes starting from around 600ms after the picture. Though not fully understandable, this difference might be due to the already discussed differences between the two experimental designs adopted.

To sum up, despite differences in some of the components reported, the present study can be considered as a replication and extension of Lüdtke et al. (2008) findings. In particular, the reduction of the *priming* effects between the sentence and the picture prevented the implementation of non-linguistic task-specific shortcut strategies. Very importantly, in addition, the adoption of a pragmatically controlled design leads to the observation that, even in pragmatically felicitous contexts, negative sentences interpretation seems to require a cognitively costly two-step, non-incremental processing. As the reader may remember, this latter consideration is however in sharp contrast with the evidence reported by Nieuwland & Kuperberg (2008), in which N400 deflection reflected the immediate interpretation of the negative operator. Further investigation is needed to better clarify which key factors – beyond sentences pragmatic licensing – enabled a similar speed of interpretation of negation.

4 STUDY 2: AN ERP STUDY ON NEGATION, WORKING MEMORY AND DYSLEXIA

4.1 Methods

4.1.1 Participants

A group of 15 adults took part in the study (mean age 22;4; SD 2;19). All participants were Italian native-speakers, had normal or correct to normal vision, normal hearing, absence of neurological problems, and normal non-verbal QI.[98] They had all received a high school diploma at the moment of testing, and had received an official diagnosis of developmental dyslexia supplied by a certified psychologist or speech therapist of the Italian National Health System. Nevertheless, only those subjects who still showed significant writing and reading difficulties were included in the study.[99] This led to the exclusion of one subject whose performance suggested he had largely compensated reading and writing problems. They were recruited trough the Dyslexia Services Offices of University of Verona and University of Brescia, trough local associations dealing with dyslexia and through announcements on the web pages of nearby universities. Subjects who incurred in extraordinary travel expenses for their participation in the study were reimbursed.

The participants of Study 1 (25 Italian adults, mean age 27;3; SD 3;25) were included in the study as control group.[100] To avoid the accidental inclusion of subjects unaware of being dyslexics, writing and reading skills of the participants of the control group were also controlled. None of them, however, showed below average performance; as a consequence, they were all included in the control group.

4.1.2 General procedure

The study consisted of two sessions. The first session included a series of behavioral tests concerning subjects' writing and reading skills and working memory capacity. The second session was constituted by the sentence-picture verification task designed to test subjects' comprehension of negative sentences. During the execution of this second part, ERPs was recorded via TMS-compatible

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[98] Non-verbal QI was controlled through the administration of Caffarra et al. (2003)'s version of Raven's Standard Progressive Matrices.

[99] Writing and reading skills were assessed trough a selection of the tasks elaborated for the diagnosis of dyslexia in undergraduate Italian students by Re et al. (2011). The results of these tests are reported in the *Behavioral assessment*'s results section (§ 4.3.2).

[100] The two subjects which had been not included in the analysis of the data in STUDY 1 were not considered for the inclusion in this second study.

EEG equipment (BrainAmp 32 DC, BrainProducts GmbH, Munich, Germany). Both behavioral (error rates; response times) and electrophysiological data were considered.

Each participant was tested individually. The first session was held in a quiet room, free from distractions, located either at the *Dipartimento di Filologia, Letteratura e Linguistica* or at the *Dipartimento di Scienze Neurologiche e del Movimento* of the University of Verona, according to the convenience of the participant. The second session took place in the *Brain Vision* laboratory at the *Dipartimento di Scienze Neurologiche e del Movimento* of the University of Verona. The first session lasted around one hour for each participant; the second session lasted approximately one hour and half for each participant, including about 45 minutes necessary for the placing of the electrodes cap.

4.1.3 Materials

4.1.3.1 Behavioral assessment

4.1.3.1.1 Writing and reading abilities

Subjects' writing and reading abilities were assessed through a subset of the tests proposed for the diagnosis of dyslexia in young Italian adults into the *Battery for the Assessment of Reading and Writing in Adulthood* (Re et al. 2011). Two reading tasks and two writing tasks were chosen from the *Battery* with consideration to their very high discriminatory power: the *Word reading* test, the *Non-word reading* test, the *Word dictation*, and the *Word dictation under articulatory suppression.*

In the *Word reading* test, the subjects were asked to read aloud four series of isolated words as quickly and accurately as they could. Both reading speed (calculated as number of syllables read in one second) and mistakes were considered. In the second reading test, the *Non-word reading*, the subjects were asked to perform the same task (reading aloud as quickly and accurately as possible) with four series of non existing words. This difference in the materials determines an extra effort in this second task, as the reader cannot benefit from lexical knowledge. For this reason, *Non-word reading* represents a very good task for determining subjects' real ability of decoding, especially in the case of dyslexics, who very often resort to lexical knowledge as a source of help in the decoding. Worth noting, the task obtained a score of 96% (considering both speed and accuracy together, and a score of 92% and 96% respectively, considering the two variables separately) of probability of correctly discriminating an undergraduate student with dyslexia from an age-matched undergraduate student without dyslexia (Re et al. 2011).

The *Word dictation* consisted in a normal dictation, in which the subject had to handwrite a series of 24 isolated Italian words which were pronounced at a constant rhythm of one word every 3 seconds. During the second writing task, the

Word dictation under articulatory suppression, the subject had to perform the same task with a different series of 24 Italian words, but she was also asked to repeat the syllable 'la' continuously and aloud during the dictation. As explained by the authors of the test, the request of concurrently repeating the syllable 'la' has its ratio in preventing the resort to the so-called 'articulatory loop', a component crucially involved during writing and reading, especially during the early stages of their acquisition, when the two processes have not yet become automatic. While progressively reducing its role in typical writers and readers once they have mastered the two skills, the resort to the articulatory loop remains fairly constant in dyslexic subjects. As a consequence, dyslexics writing ability is expected to significantly deteriorate under those conditions in which they cannot take profit from the articulatory loop. The *Word dictation under articulatory suppression* represents exactly this situation: the phonological loop, in fact, is not only prevented from being a source of help, but it also represents a source of phonological interference. As a consequence, this latter task constitutes a very reliable test for discriminating dyslexic adults from non dyslexics adults on the basis of their writing ability, as shown by the very high probability-based effect size reported by Re and colleagues (around 98%).

4.1.3.1.2 Working memory capacity evaluation

Subjects' working memory was assessed through five tests evaluating the functionality of the three components traditionally assumed to form subjects' general working memory capacity: the phonological short-term memory, the visuo-spatial short-term memory, and the central executive.[101] Short-term phonological memory was tested through the *Digit span forward* and the *Digits span backward* tests (standardization by Monaco, Costa, Caltagirone, & Carlesimo, 2013). In the first test, the subject was presented with some sequences of digits, pronounced at a rate of approximately one digit per second, and she was asked to repeat each sequence just after having listened it, reporting the digits in the same order in

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[101] This tripartite model of working memory has been originally elaborated by Baddeley & Hitch (1974), according to which working memory is composed by a limited capacity attention controller, called *central executive*, responding to different cognitive functions (e.g., attention, active-inhibition, planning, updating, maintenance and integration of information) and two peripheral slave systems devoted to the temporary storing and rehearsing of information pertaining to a single modality: acoustic and verbal information in one case (*phonological loop*), and visual and spatial information in the other (*visuo-spatial sketchpad*). The original model has been largely revised and refined during the last years by Baddeley himself and co-workers (see Baddeley, 2012, for a review and discussion). Alternative models, providing very different perspectives on the working memory system, have also been suggested (see, for example, Cowan, 1997; Cowan, 2008, Ericsson & Kintsch, 1995; Ericsson & Delaney, 1999). A systematic consideration of the different models of working memory proposed goes beyond the scope of the present dissertation and the author's competence. The choice of adopting Baddeley and colleagues' model in the current study was motivated by the fact that it represents, so far, the most frequently used for the investigation of working memory and dyslexia.

which they had been pronounced. The series had increasing length; two sequences for each length were included. The test was stopped when the sequences of digits reached a length such that the subject could not correctly remember them, indicating that the quantity of the material to be stored exceeded his/her short-term memory capacity. The *Digit span backward*, as the name itself explains, represents the backward version of the digit recall: again, the subject was asked to listen a series of digits of increasing length, but this time she was asked to repeat them in the reverse order with respect to the order in which they had been pronounced. As observed by Baddeley (1996), the execution of this task has a double involvement in working memory: on the one side, it involves the phonological component of working memory, which has the role – as in the forward version of the same task – of temporary maintaining the digits in storage; on the other, the mental manipulation of the units stored, necessary for the repeating of the sequence in the reverse order, is carried out by the central executive. Also in this case, the test was administered in Monaco et al. (2013)'s version and the span was determined as the maximum length of the sequence repeated in the correct reverse order.

The short term visuo-spatial memory was determined through the *Corsi forward* and *Corsi backward* tests (Monaco et al. 2013's standardization). In both tests, the subject was presented with a board on which nine cubic blocks were fixed. Each block appeared identical to all the others on the side visible to the subject, but it was marked with a serial number (from 1 to 9) on the side visible to the experimenter. The experimenter touched a sequence of blocks at a rate of approximately one block per second and the subject was asked to reproduce the sequence just after having seen it. While in the forward version of the test, the subject had to reproduce the sequences by touching the blocks in the same order in which the experimenter had touched them, in the backward version she was asked to reproduce the sequences in the reverse order with respect to the order followed by the experimenter. Similarly to the backward version of the *Digit span* test, the execution of the backward version of the *Corsi* test is assumed to involve both the temporary storage of the information and its manipulation, carried out under the supervision of the central executive. While the results of two forward versions *Digit span* and the *Corsi block* tests purely depend upon the capacity of the two storages components at issue (short-term phonological memory and visuo-spatial short term memory), therefore, the results of the backward versions of the two tests are generally considered as a measure of the coordinate use of two concerning storage system with the central executive.

Beside the indirect measure of central executive offered by the two tests just mentioned, the same component was also evaluated through the administration of the *Paper-and-pencil dual task* elaborated by Della Sala et al. (2010). In this latter test, the efficiency of central executive was calculated as the difference in the performance obtained during the execution of two distinct tasks in the single task modality and in the dual task modality, in which the two tasks had to be carried out simultaneously. The first task was a digit span task, resembling the Digit span forward task described above. The second task consisted in using a pencil to draw a line through a series of circles arranged in a path of 319 circles on a paper over a 90-s period. The performance measure was the number of circles crossed within the allotted time.

4.1.3.2 Sentence-picture verification task materials

The same materials of STUDY 1 were used.

4.1.4 Sentence-picture verification task procedure

The same procedure of STUDY 1 was adopted. Of the dyslexics, three subjects were tested with List 1, four subjects were tested with List 2, three subjects were tested with List 3, and four subjects were tested with List 4.

4.2 Results

4.2.1 Behavioral assessment

The performance of only 13 out of the 15 subjects recruited in the dyslexic group was included in the analysis. As mentioned, in fact, one subject was excluded from the group as he performed above chance in the writing and reading tests, indicating very well-compensated or erroneously diagnosed dyslexia. A second subject was excluded because she failed to reach a minimum of 75% correct responses in the sentence-picture verification task, which was considered as cut-off measure for the inclusion in the analysis. On the same basis, the performance of all the 25 control subjects was taken into consideration.

4.2.1.1 Reading and writing abilities

As mentioned, the evaluation of subjects’ reading ability included speed and accuracy measures. In both reading tests, reading speed was defined as the number of syllables read in one second, while accuracy corresponded to the error rates, calculated by assigning 1 point to each word read incorrectly and 0.5 score to each auto-corrected error. The writing performance was measured as the sum of the words incorrectly written or omitted in each of the two dictation tasks. The results of the two groups were compared by means of an independent sample t-test. The analysis of the results of the word reading test, the non-word reading test and the dictation under articulatory suppression showed dyslexic participants experienced significantly greater difficulties in writing and reading in comparison with non-dyslexic subjects. The simple dictation task, on the contrary, did not reveal significant differences between the groups, showing that adult dyslexics manage to write with an almost comparable speed and accuracy than non-dyslexic adults under normal dictation circumstances. Relevant data and statistical significance of the T-test between the two groups' performance are reported in TABLE 22.

TABLE 22. Dyslexics *vs*. controls: Writing and reading tasks.

Task	Controls (= 25)	Dyslexics (= 13)	t (36)	*p-value*
Word reading speed: mean and (SD)	6.00 (1.14)	3.35 (1.15)	6.72	≤ .001*
Non-word reading speed: mean and (SD)	3.98 (.93)	1.82 (.62)	7.47	≤ .001*
Word reading errors: mean and (SD)	.36 (.670)	2.19 (1.52)	5.08	≤ .001*
Non-word reading errors: mean and (SD)	1.20 (1.18)	5.88 (3.05)	– 6.88	≤ .001*
Word dictation: mean and (SD)	.12 (.332)	.69 (1.032)	– 1.94	= .073 •
Articulatory condition: mean and (SD)	1.16 (1.49)	14.62 (6.07)	10.59	≤ .001*

4.2.1.2 Working memory tests

As expected, the analysis of the results of the *Digit span forward* and *Digit span backward* revealed significant differences between the two groups in the short-term phonological memory. In line with previous studies, no main differences were found in short-term visuo-spatial memory. The performance of the two groups in the dual task test was also comparable, indicating no significant central executive impairment in adult dyslexics. Relevant data and statistical significance of the comparison between the two groups' performance are reported in TABLE 23 (next page).

4.2.1.2.1 Effects of the age factor on behavioral measures

Since the two groups had a significantly different mean age, which could – in principle – have had an influence on writing, reading and working memory skills, a regression analysis with age as predictor factor and single task performances as dependent variables was performed. The analysis revealed that age did not play a significant effect on most of the cognitive capacities under investigation. The only exception was constituted by non words-reading speed, which was found to be to some extent affected by age in dyslexic subjects [F (1, 11) = 5.132, $p = \leq .05$, $R^2 = .318$]. Since reading speed does not represent a main parameter of the current study as it mainly represented an inclusion criterion for subjects' ascription into the two groups, age influence on this parameter was not considered to constitute a problematic aspect.

TABLE 23. Dyslexics *vs*. controls: Working memory tasks.

Task	**Controls** (= 25)	**Dyslexics** (= 13)	**t (36)**	***p*-value**
Digit span forward: mean and (SD)	6.68 (1.445)	5.54 (.877)	3.14	≤ .005 *
Digit span backward: mean and (SD)	5.48 (1.194)	4.31 (1.182)	2.88	≤ .05 *
Corsi forward: mean and (SD)	6.37 (1.40)	5.61 (.75)	1.79	.081 ·
Corsi backward: mean and (SD)	5.72 (1.20)	5.92 (.862)	–.53	.594
Dual task: mean and (SD)	90.89 (6.41)	91.25 (7.70)	–.15	.878

4.2.1.2.2 Working memory and writing and reading skills connection

In order to deepen in the relationship between working memory and developmental dyslexia, a simple linear regression analysis with working memory capacity as a predictor and writing and reading measures as dependent variables was performed. Contrary to expectations, no strong connections between the abilities under investigation were found. The phonological working memory[102] significantly predicted both word reading accuracy (t = 3.375, $p \leq .005$) and writing skills under articulatory suppression (t = 3.723, $p \leq .005$), but the model described only a very limited range of variance, as shown by very low R^2 measures (*word reading* R^2 = .165; *word dictation under articulatory suppression* R^2 = .202). The central executive efficiency, measured through the *paper-and-pencil dual task* described above, had a significant influence on the error rates observed in the non-word reading task (t = 2.190, ≤ .05) though, again, the correlation explained a low percentage of variance (R^2 = .118).

[102] Independent variables: *Digit span* forward, *Digit span* backward.

4.2.1.3 Sentence-picture verification task

4.2.1.3.1 Dyslexic group

As mentioned, all dyslexic participants except one had a percentage of correct answers above 75%. For this reason, 13 of the 14 dyslexic subjects who participated in the study were included in the analysis. Descriptive statistics of accuracy and response times are reported in TABLE 24.

TABLE 24. Average accuracy and reaction times – Dyslexic group.

Average results (13 subject)	**True AFF**	**False AFF**	**True NEG**	**False NEG**
Correct responses out of 60 (SD)	53,7 (3,04)	51,2 (3,52)	49,9 (3,20)	50,6 (3,91)
Reaction times (SD)	1505 (429)	1710 (444)	2069 (867)	1839 (694)

Both accuracy and reaction times were submitted to a 2 (polarity) x 2 (truth-value) analysis of variance (ANOVA). The results of the analysis are summarized in TABLE 25. As reported, the *polarity* effect characterized both accuracy [F (1, 12) = 5.215, $p \leq .05$] and reaction times [F (1, 12) = 6.796, $p \leq .05$]. As indicated by the means of affirmative and negative conditions, the effect reflects the higher processing difficulty associated to negative sentences interpretation in comparison with affirmative sentences, resulting in increased response times and higher error rates. No difference was reported with respect to sentence *truth-value*, neither for the accuracy F (1, 12) = 2.770, $p = .112$] nor for reaction times [F (1, 12) = .017, $p = .899$]. To conclude, 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 TA > FA > FN > TN.

TABLE 25. ANOVA results – Dyslexic group.

Dep. Variables	**Effect**	**F (1,12)**	***p*-value**
Accuracy	polarity	5.21	≤ .05 *
	truth-value	2.77	.112
	polarity*truth	11.10	≤ .01 *
Reaction times	polarity	6.79	≤ .05 *
	truth-value	.017	.899
	polarity*truth	7.67	≤ .05 *

4.2.1.3.2 Dyslexics *vs*. controls performance in the sentence-verification task

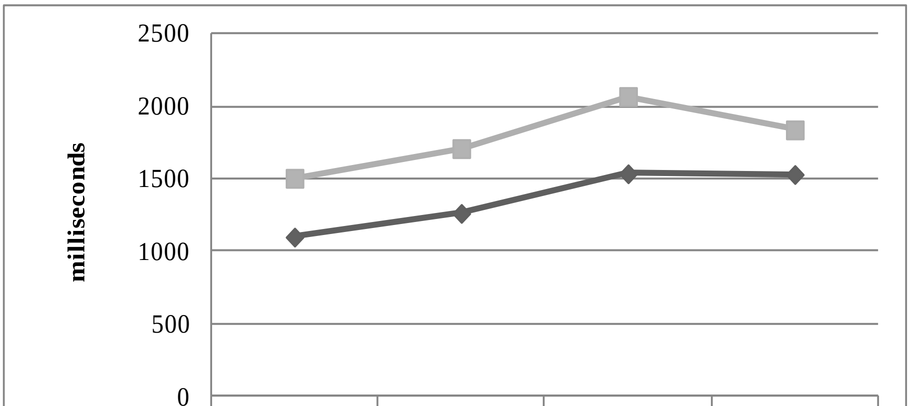
The average accuracy and reaction times of dyslexic and non-dyslexic subjects are displayed in GRAPH 1 and GRAPH 2, respectively. The statistical comparison between the two groups was performed through a 2 (group) x 2 (polarity) x 2 (truth-value) ANOVA. The main data of the analysis are reported in TABLE 26.

TABLE 26. ANOVA on the sentence-picture verification task.

Dep. Variable	**Effect**	**F (1,36)**	***p*-value**
Accuracy	polarity	45.80	≤ .001 *
	polarity*group	.003	.953
	truth-value	.729	.399
	truth-value*group	1.387	.247
	truth-value*polarity	22.03	≤ .001 *
	truth*polarity*group	4.290	≤ .05 *
Reaction times	polarity	16.40	≤ .001 *
	polarity*group	.125	.725
	truth-value	.208	.651
	truth-value*group	4.113	≤ .05 *
	Truth-value*polarity	15.415	≤ .001 *
	polarity*truth*group	.420	.521

As shown by the mean of the two groups (reported at the bottom of GRAPH 1, next page), the significant *polarity*truth-value*group* effect on reaction times is mainly determined by the larger difference between true and false sentences in the negative condition in comparison with affirmative sentences observed in the dyslexic group relative to the control group. The *polarity by group* effect on reaction times, on the other hand, reflects the more pronounced difference between the reaction times associated to affirmative and negative sentence in the control group in comparison with the dyslexic group.

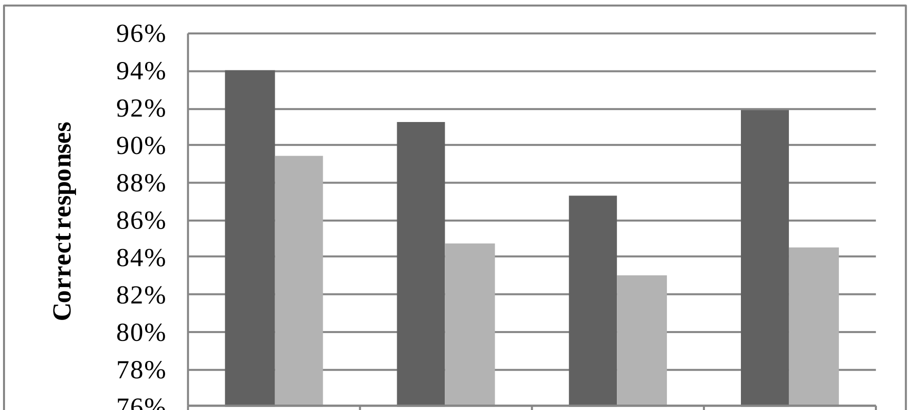
GRAPH 1. Dyslexic vs. control groups: Average reaction times.



	True Affirmatives	False Affirmatives	True Negatives	False Negatives
Controls	1100	1263	1536	1531
Dyslexics	1505	1710	2069	1839

The significant *truth-value by group* interaction on accuracy was probably determined by the larger difference between true and false negative sentences observable in the control group (corresponding to an average of 87% and 92% of correct responses, respectively) in comparison with the dyslexic group, whose error rates did not differ very much between in the negative conditions (corresponding to an average of 83% and 84% of correct responses, respectively).

GRAPH 2. Dyslexic *vs*. control group: Average accuracy.



	True Affirmatives	False Affirmatives	True Negatives	False Negatives
Controls	94%	91%	87%	92%
Dyslexics	89%	85%	83%	84%

4.2.1.3.2 Working memory and negative sentence processing relationship

In order to verify the working memory influence on negative sentence processing hypothesized by Vender (2011), a linear regression analysis with working memory measures as independent variables and the behavioral performance (accuracy, reaction times) in the picture-sentence verification task was executed. Both accuracy and reaction times of the 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 TABLE 27. As shown by the very low R^2 values, however, the model accounts only for a limited amount of the variance. The fact that phonological working memory played a similar influence on both affirmative and negative sentence verification, in addition, suggests that the effect has to be attributed to experimental task characteristics, rather than reflecting a causal connection between negation processing and working memory capacity. In particular, the significant correlation between the two measures could be due to the necessity of remembering the sentence presented until the visualization of the picture and during the consequent evaluation of sentence truth-value.

TABLE 27. Linear regression analysis with phonological working memory (*digit span* forward and backward) as predictor.

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

No significant interaction between the sentence-picture verification measures and the visuo-spatial working memory, on the one hand, and central executive, on the other, was observed.

4.2.2 EEG analysis

The same method used for EEG extraction, epoch rejection and grand averages calculation in STUDY 1 was adopted. As in Study 1, only subjects for which at least 60% of the epochs could be analyzed were included. This led to the exclusion of 3 of the 15 dyslexic participants. Dyslexics' grand average ERPs to the picture are displayed in FIGURE 3 – Appendix B. The visual inspection of the grand averages was driven by the comparison with the three main effects observed with non-dyslexic subjects in STUDY 1: the *match-mismatch* effect, the *polarity* effect, and the *truth-value* effect. The waves derived from the consideration of the three effects are plotted in FIGURE 5 – Appendix B, where differential waves were smoothed for visualization purposes only.[103]

The visual inspection of the grand averages and of the main effects of the two groups revealed a main difference concerning the earlier 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 (F7, T3, C3), 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 and with a reversal of the effect for affirmative sentences. Another difference between the plots of the grand averages of the two groups is represented by the delayed onset in the dyslexic group of the difference between true and false affirmative sentences, emerging around 400ms after stimulus in the control group and around 600ms in the dyslexic group. To determine the statistically relevant differences between the two groups, the same analyses performed in Study 1 were carried out including the data from both studies and using *group* (control N= 21, dyslexic N = 10) as between-subjects factor. In particular, two different statistical analyses have been carried out:

(1) A four-groups of channels based analysis (<u>AL,</u> including F3, C3, and CP1; <u>AR</u>, including F4, C4, and CP2; PL, including PO3, P3, and P1 electrodes; <u>PR</u>, including PO4, P4, and P2 electrodes). Again, the analysis was separately conducted on the three time intervals of interest: <u>TW1</u> 400-600ms, <u>TW2</u> 600-1000ms, <u>TW3</u> 1000-1400ms.

(2) An in-depth analysis on a single cluster of parietal and central electrodes (including Cz, Pz, CP1, CP2, P3, and P4 electrodes), with the attempt of better understanding the time course of the *negativity by polarity* effect in the two groups.

4.2.2.1 Four-groups of channels based analysis

The overall grand averages of the dyslexic group for the 3 differential effects of *match/mismatch*, *polarity* and *truth-value* in the four groups of channels (AL, ER, PL, PR) selected are reported in FIGURE 8. Vertical lines are drawn accordingly to

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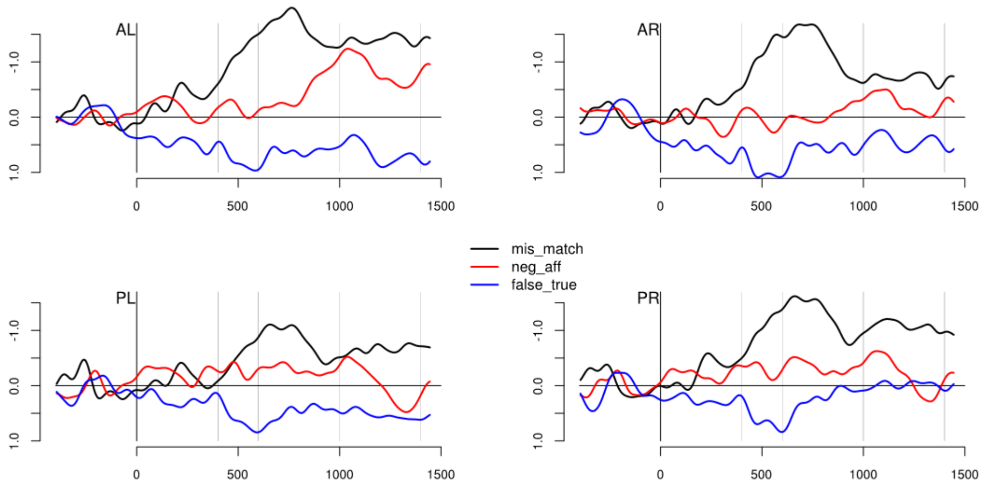
[103] As for non-dyslexic subjects, the three effects was calculated as follows: *match-mismatch* effect = (NT+AF) – (NF+AT); *polarity* effect = (NT+NF) – (AT+AF); *truth-value* effect = (AT+NT) – (AF+AT).

the time windows used in the statistical analyses below (400, 600, 1000, and 1400ms).

FIGURE 8. Main effects' grand-averages in the four channels of electrodes – Dyslexic group.



The analysis design was composed by five factors of two levels each: 2 topographical factors (*longitude*: anterior, posterior; *latitude*: right, left), 2 factors concerning the experimental main variables (*polarity*: negative, affirmative; *truth-value*: true, false), and one between-subjects variable (*group*: dyslexic, control). As mentioned, factorial analyses on three different time-windows have been separately performed.

TW 1: 400-600ms. The results of the ANOVA in the time interval between 400 and 600ms are reported in TABLE 28 (next page). The main effect concerns the significant *group***polarity***truth-value***long* interaction, reflecting the earlier emergence of different ERPs for negative relative to affirmative sentences in the dyslexic group in comparison with control subjects.

TABLE 28. ANOVA on TW1 (400-600ms).

Effect	**F (1,30)**	***p*-value**	**ges**
group	.55	.462	.012
polarity	.14	.713	.000089
truth	4.77	≤ .05 *	.0010
longitude	5.08	≤ .05 *	.030
latitude	.67	.419	.0010
group*polarity	.58	.453	.00037
group*truth	7.55	.010	.0016
group*longitude	.39	.534	.0024
group*latitude	.42	.522	.00064
polarity*truth	24.85	≤ .001 *	.011
polarity*longitude	3.86	.058 ˙	.00029
truth*longitude	.27	.607	.000026
polarity*latitude	.80	.379	.000031
truth*latitude	2.37	.133	.000088
long*latitude	6.12	≤ .01 *	.0022
group*polarity*truth	.03	.861	.000014
group*polarity*longitude	.13	.717	.000010
group*truth*longitude	2.15	.153	.00020
group*polarity*latitude	.01	.928	.000000
group*truth*latitude	.22	.641	.000008
group*long*latitude	.0022	.962	.000001
polarity*truth*longitude	.706	.407	.000064
polarity*truth*latitude	3.16	.085 ˙	.00015
polarity*long*latitude	.07	.784	.000001
truth*long*latitude	1.83	.185	.000038
group*polarity*truth*long	5.23	≤ .05 *	.00047
group*polarity*truth*latitude	.07	.789	.000004
group*polarity*long*latitude	.97	.331	.000014
group*truth*long*latitude	.045	.833	.000001
polarity*truth*long*latitude	1.65	.208	.000026
group*polarity*truth*long*lat	3.19	.083	.000051
polarity*truth*latitude	.55	.463	.012
polarity*long*latitude	.14	.713	.000089

As shown by the means of the two groups (reported in TABLE 29 and TABLE 30 below), the effect can be more specifically ascribed to the large difference in the negativity elicited by the negative conditions between the two groups at the anterior sites, where true negative sentences elicited a more negative deflection than false negative sentences of about 2 µV in the dyslexic group, but just about 0.5 µV in the control group.

TABLE 29. Mean amplitude and difference of true and false negative/affirmative conditions at the anterior and posterior electrodes – Control group.

Longitude	Polarity	False	True	Difference
Anterior	affirmative	6.03	7.89	-1.86
Posterior	affirmative	4.09	5.38	-1.28
Anterior	negative	6.67	6.18	.49
Posterior	negative	4.96	3.62	1.34

TABLE 30. Mean amplitude and difference of true and false negative/affirmative conditions at the anterior and posterior electrodes – Dyslexic group.

Longitude	Polarity	False	True	Difference
Anterior	affirmative	6.14	6.95	-.81
Posterior	affirmative	3.26	3.95	- .68
Anterior	negative	7.30	5.26	2.04
Posterior	negative	4.01	2.58	1.42

TW 2: 600-1000ms. The results of the ANOVA on the second time interval selected are reported in TABLE 31. The time interval between 600 and 1000ms after picture onset was mainly characterized the significant *group*truth-value* effect, further qualified by a *group*truth-value*longitude* interaction. Aside from effects involving the group factor, the *truth-value*longitude* and the *polarity*truth* effects already reported to characterized TW 2 in the control group was found to be significant.

As in Study 1, the *polarity*truth-value* effect reflects the larger N400 elicited by true and false sentences with opposite polarity. As already mentioned, however, while in the control group the effect represents the continuation of the same component in TW1, in the dyslexic group the effect was observed to emerge only from TW 2 on, around 600ms after picture onset. The *truth-value by longitude* interaction, suggesting participants' sensitivity to sentence truth-value at this stage, is most probably due to the different amplitude of the negativities elicited by sentences with opposite truth-value at the anterior sites. As indicated by the significant *group*truth-value*longitude* interaction, however, the effect shows important differences between the two groups. In particular, as observable in the grand averages and in the means of the effect at the anterior sites, reported in TABLE 32, while in the control group the effect can be attributed to the increased negativity associated to false sentences relative to true sentences of both polarities, the dyslexic group seems to be characterized by the inverse pattern, resulting in more negative going deflections for true sentences in comparison with false sentences. A closer look to the grand averages, however, suggests that in the dyslexic group the effect could exclusively depend on the more sustained negativity elicited by the negative true condition already observed in TW 1 (400-600ms). Given the lack of a four-way interaction including *polarity*, however, this last consideration results purely speculative.

TABLE 31. ANOVA analysis of ERP data in TW2.

Effect	**F (1.30)**	***p*-value**	**ges**
group	.239	.628	.0054
polarity	3.71	.063	.0023
truth	.070	.793	.000028
longitude	12.93	≤ .001 *	.074
latitude	5.05	≤ .05 *	.0067
group*polarity	.190	.665	.00012
group*truth	4.96	≤ .05 *	.0020
group*longitude	.30	.587	.0018
group*latitude	.41	.522	.00056
polarity*truth	21.22	≤ .005 *	.020
polarity*longitude	.058	.811	.0000063
truth*longitude	4.63	≤ .05 *	.00049
polarity*latitude	1.44	.238	.000099
truth*latitude	1.40	.245	.00011
longitude*latitude	3.65	.065 •	.0014
group*polarity*truth	.0001	.991	.0000001
group*polarity*longitude	.11	.732	.000012
group*truth*longitude	6.52	≤.05 *	.00069
group*polarity*latitude	.00014	.99	.0000000
group*truth*latitude	2.26	.142	.00017
group*long*latitude	.72	.402	.00028
polarity*truth*longitude	.044	.834	.0000053
polarity*truth*latitude	3.05	.09	.00018
polarity*long*latitude	3.02	.092	.000083
truth*long*latitude	3.40	.075 •	.00011
group*polarity*truth*long	1.63	.21	.00019
group*polarity*truth*lat	1.05	.313	.000063
group*polarity*long*lat	.36	.551	.0000100
group*truth*long*latitude	.31	.581	.0000105
polarity*truth*long*lat	2.65	.113	.000091
group*polarity*truth*long*lat	2.63	.114	.0000909

TABLE 32. *Group*truth*longitude* interaction (TW2 600-1000ms).

Group	Longitude	False	True	Difference
Control	Anterior	6.35	7.03	-.68
Dyslexic	Anterior	6.72	6.106	.61
Control	Posterior	4.52	4.49	.02
Dyslexic	Posterior	3.63	3.26	.36

TW 3: 1000-1400ms. Main results of the factorial analysis on TW 3 are reported in TABLE 33 below. The only effect involving the factor group is the interaction *group*truth-value*longitude*, for which the means (reported in TABLE 34 below) suggest an interpretation similar to the one given for TW2 (600-1000ms). As in Study 1, the *truth-value*longitude*latitude* emerges without any interaction with the group factor, confirming a major difference between conditions with opposite truth-value in the anterior left quadrant. In addition, a significant *polarity*longitude*latitude*, unreported in Study 1, was observed. This latter effect is probably due to the difference between affirmative and negative conditions in the anterior left quadrant, which appears to be even more pronounced in the dyslexic group than in the control group, where it does not reach statistical significance. To conclude, the *polarity*truth* effect discussed in TW2 effect approximates significance; even adding the dyslexic group in the design, however, this latter effect results only marginal in this time window. A more in-depth analysis of this effect in the three time windows selected is provided by the analysis at the CP cluster reported below.

TABLE 33. ANOVA analysis of the ERP data in TW3.

Effect	F (1,30)	*p*-value	ges
group	.57	.455	.012
polarity	3.68	.064 ·	.0039
truth	.31	.58	.00026
longitude	34.38	≤ .05 *	.15
latitude	17.03	≤ .001 *	.018
group*polarity	.27	.606	.00028
group*truth	2.45	.127	.0020
group*longitude	.017	.896	.000094
group*latitude	1.40	.245	.0015
polarity*truth	3.81	.06 ·	.0061
polarity*longitude	2.38	.133	.00046
truth*longitude	2.65	.113	.00044

polarity*latitude	.79	.379	.00009
truth*latitude	.84	.366	.00014
longitude*latitude	1.22	.278	.00078
group*polarity*truth	.41	.525	.00067
group*polarity*longitude	.07	.792	.000013
group*truth*longitude	4.26	≤ .05 *	.00071
group*polarity*latitude	.043	.836	.000049
group*truth*latitude	3.79	.06 •	.00065
group*long*latitude	1.00	.323	.00065
polarity*truth*longitude	.049	.827	.0000055
polarity*truth*latitude	.53	.47	.000042
polarity*long*latitude	4.33	≤.05 *	.00030
truth*long*latitude	5.74	≤ .05 *	.00038
group*polarity*truth*long	.74	.393	.000085
group*polarity*truth*lat	1.49	.231	.00011
group*polarity*long*lat	.28	.594	2.01
group*truth*long*lat	.74	.395	4.96
polarity*truth*long*lat	2.29	.14	.00018
group*polarity*truth*long*lat	2.75	.107	.00021
polarity*truth*latitude	.57	.46	.012
polarity*long*latitude	3.68	.06 •	.0039

TABLE 34. *Group*truth*longitude* interaction (TW 3 1000-14000ms).

Group	**Longitude**	**False**	**True**	**Difference**
Control	Anterior	5.48	6.23	- .75
Dyslexic	Anterior	5.23	4.71	.52
Control	Posterior	2.28	2.36	- .076
Dyslexic	Posterior	1.40	1.14	.25

4.2.2.2 Centro-parietal cluster analysis

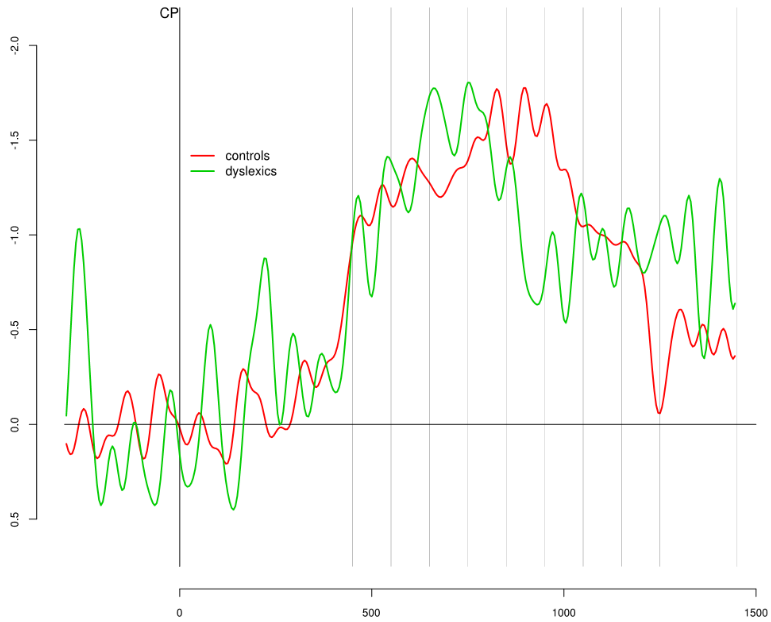
The ANOVAs on the four channels of electrodes revealed no significant differences between the two groups with respect to the *polarity***truth-value* interaction that characterized the first stages of interpretation in the control group (see *EEG analysis*, STUDY 1). To further verify the similarity of the N400-like effect in the two groups, a series of the t-tests was performed on a centro-parietal cluster of electrodes (including the six electrodes Cz, Pz, CP1, CP2, P3, and P4). A t-test every 100ms time intervals included from 500 to 1400ms after picture onset was run. The results of the analysis are reported in TABLE 35.

TABLE 35. *Polarity by truth-value* effect at the CP cluster.

Time interval	Controls (mean)	Dyslexics (mean)	t (1,30)	*p*-value
500, 600ms	-1.126	-1.053	-.168	.867
600,700ms	-1.301	-1.340	.066	.947
700,800ms	-1.279	-1.622	.516	.609
800,900ms	-1.573	-1.517	-.076	.939
900,1000ms	-1.576	-.940	-.886	.382
1000,1100ms	-1.360	-.861	-.748	.460
1100,1200ms	-1.002	-.924	-.097	.923
1300,1400ms	-.683	-.957	.322	.750

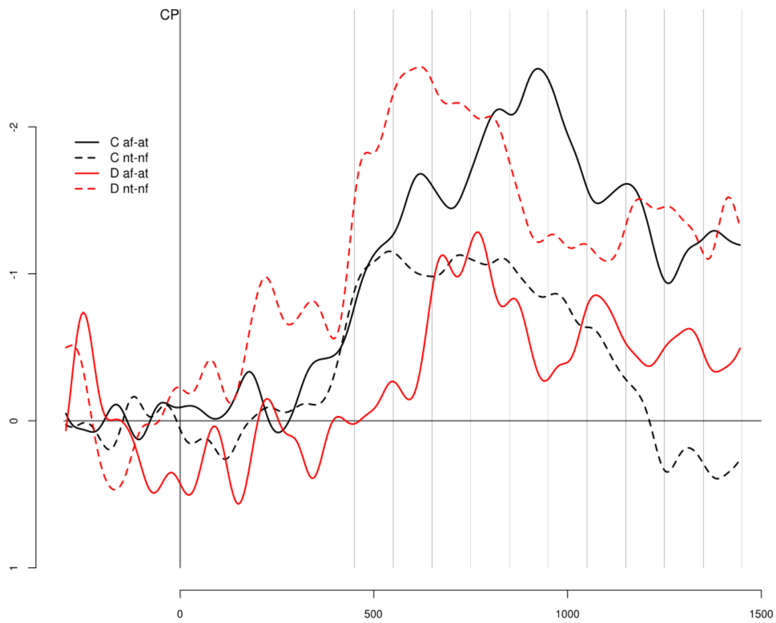
The t-tests did not show any significant difference in the elicitation of the N400 in dyslexic and control subjects on the average effect determined by *match-mismatch* relationship between the sentence and the picture, independently from the presence of negation. As shown by the grand averages of the effect at the CP cluster, reported in FIGURE 9, in addition, the effect had similar amplitude and latency in the two groups, starting from around 400ms and lasting until around 1450ms after picture onset. As already observed in the four quadrant analysis, however, the dyslexic group shows a large effect of *truth-value* already in an early time window.

FIGURE 9. *Polarity by truth-value* effect at the CP cluster.



In addition, the qualitative inspection of the grand-averages of the dyslexic group shows that the effects of *truth-value* is not perfectly reversed in the 400-600ms interval, as it conversely happens in the control group. While for the control group, in fact, negative true and affirmative false sentences appear indistinguishable on CP sites between 400 and 600ms, for the dyslexics an early and large *truth-value* effect is reported for negative sentences (with true sentences resulting more negative than false, both in cento-parietal and, even more, at frontal sites), but no difference between affirmative sentences with opposite truth-value emerges before 600ms after picture onset. This difference makes it likely that the apparent similarity of the average *polarity by truth*/*match-mismatch* effect in the CP sites of the two groups is not likely to be an informative comparison, since it may be due to very different patterns in the two groups. This difference makes it likely that the apparent similarity of the average *match-mismatch* effect in the CP sites of the two groups is not likely to be an informative comparison, since it may be due to very different patterns in the two groups. For this reason, we run a further analysis on the differential waves that contribute to the *polarity by truth-value* well known effect at centro-parietal sites by separating the component of the effect due to negative sentences (negative true minus negative false) from that due to affirmative sentences (negative false minus negative true). The plot in FIGURE 10 confirms that the composition of the overall effect is different in the two groups in that, especially in the first two time windows, the controls show a nice symmetric effect, while for dyslexics the effect is very large for negative sentences, but near to absent for the affirmative ones.

FIGURE 10. Disaggregated analysis of the *polarity by truth* effect components at the CP cluster.



To test this statistically, we performed separate ANOVAs with a within factor *polarity* (2 levels: negative and affirmative difference wave) and a between factor *group* (2 levels: control and dyslexic). The outcome of the ANOVA, reported in TABLE 36 below, shows significant *condition by group* interactions in the time intervals (450, 550ms), (550, 650ms), (750, 850ms), (850, 950ms), (1350, 1450ms).

TABLE 36. Polarity effect (differential negative and affirmative wave) at the CP cluster.

Time interval	Effect	F (1,30)	*p*-value	ges
450,550ms	dyslexic	≤ .05 *	.8673	.0006
450,550ms	control	4.162	.0502	.0467
450,550ms	dys*cont	8.401	.0069	.0899
550, 560ms	dyslexic	≤ .005 *	.9476	.0001
550, 560ms	control	1.179	.2862	.0115
550, 560ms	dys*cont	12.413	.0014	.1095
650, 750ms	dyslexic	.267	.6094	.0065
650, 750ms	control	≤ .05 *	.8522	.0003
650, 750ms	dys*cont	3.572	.0685	.0302
750, 850ms	dyslexic	≤ .01 *	.9400	.0001
750, 850ms	control	.432	.5158	.0036
750, 850ms	dys*cont	4.967	.0335	.0401
850, 950ms	dyslexic	.786	.3824	.0171
850, 950ms	control	1.665	.2068	.0183
850, 950ms	dys*cont	4.522	.0418	.0482
950, 1050ms	dyslexic	.560	.4600	.0115
950, 1050ms	control	1.192	.2836	.0147
950, 1050ms	dys*cont	3.640	.0660	.0435
1050, 1150ms	dyslexic	≤ .005 *	.9236	.0002
1050, 1150ms	control	1.053	.3131	.0116
1050, 1150ms	dys*cont	1.357	.2532	.0149
1150, 1250ms	dyslexic	.103	.7500	.0022
1150, 1250ms	control	.668	.4203	.0081
1150, 1250ms	dys*cont	3.462	.0726	.0407
1250, 1350ms	dyslexic	.412	.5260	.0096
1250, 1350ms	control	1.028	.3187	.0100
1250, 1350ms	dys*cont	2.956	.0959	.0281
1350, 1450ms	dyslexic	.161	.6909	.0040
1350, 1450ms	control	2.387	.1328	.0197
1350, 1450ms	dys*cont	6.602	.0154	.0526

To better qualify the effects in the two early time windows, in addition, separate-test t-tests on the critical conditions for the first two time windows have been performed.

Interval 450-550ms. In the first time window analyzed, paired t-test against zero for each condition and group shows that for the controls the effects for affirmatives [diff = 1.13 μV, t (20) = 3.34, $p \leq .01$] and negatives [diff = 1.12 μV, t (20) = 3.39, $p \leq .01$] are both significant. On the contrary, for the dyslexic group the effect is significant for negative [diff = 1.96 μV, t (10) = 4.49, $p \leq .01$], but not for affirmative sentences [diff = 0.14, t (10), $p < 1$]. Paired t-test of the condition effect restricted to dyslexic subjects confirms the difference between affirmative and negative sentences [t (10) = 3.20, $p \leq .01$], while no similar difference emerges for the controls. An additional between groups t-test showed that the difference between the amplitude of two groups' effects in the negative sentences did not result significant, despite being clearly numerically larger for dyslexics.

Interval 550-650ms. In the second time window, paired t-test against zero for each condition and group shows that for controls the effects for affirmative [diff = 1.56 μV, t (20) = 3.42, $p \leq .01$] and negative [diff = 1.03 μV, t (20) = 2.46, $p \leq .05$] were both significant. As in the previous interval, however, in the dyslexic group the effect is significant exclusively for negative sentences [diff = 2.43 μV, t (10) = 5.40, $p \leq .01$], and not for affirmative sentences [diff = 0.25, t (10), < 1]. Paired t-test of the *polarity* effect restricted to dyslexic subjects confirmed the difference between affirmative and negative sentences [t (10) = 3.06, $p \leq .05$], while no difference emerged for the controls. An additional between groups t-test on the difference between the amplitude of the two groups in the negative sentences showed that they were larger in the dyslexic than in the control group [t (30) =2.09, $p<0.05$].

4.3 Discussion and conclusions

Despite the small dimension of the dyslexic group, the paradigm used allowed the identification of statistically significant differences in both working memory measures and behavioral and electrophysiological patterns associated to the verification of negative sentences at the picture. In line with the previous literature on the topic, the results of the working memory tests revealed significantly weaker phonological working memory, but intact visuo-spatial memory in the dyslexic undergraduate students in comparison with the age-matched controls. Interestingly, however, the analysis of the connection between phonological working memory capacity and reading and writing skills showed that the memory span measures significantly predicts the accuracy in the *non-word reading* and in the *dictation under articulatory suppression* tasks. Worth noting, however, the correlation explains only a limited amount of the variance in the two tasks, suggesting that phonological working memory is not the only factor involved in adults' dyslexic writing and reading performance. The lack of a stronger correlation between the two abilities, nevertheless, may also be due to the type of statistical analysis performed, which included all subjects, without drawing any group distinction (e.g., controls *vs.* dyslexics/low span *vs.* high span subjects/other). Alternatively, the poor writing and reading may be interpreted to reflect a persistent lack of automation of the two skills, deriving from the concurrent inefficiency of the phonological working memory with other cognitive processes not investigated in the present study. In contrast with previous evidence, in addition, no central executive inefficiency was reported in the sample of dyslexic subjects. As we realized only after the performance of the participants to this study, however, this divergence is most probably attributable to the low sensitivity of the task I used for the assessment of central executive functions. The fact that already another study adopting a paper-and-pencil dual task failed to find differences between a group of Italian dyslexic adults and a group of age-matched control subjects (Ghidoni & Angelini, 2007), in fact, suggests that dual tasks of the type adopted in the present study do not deal with the aspects of central executive system which have been reported to be problematic for dyslexic subjects. A very brief review of the studies reporting a central executive impairment in dyslexic subjects, in fact, shows that the main deficits in this domain relate to attention sustainability, planning and coordination skills, rather than to the ability of concurrently performing two tasks crucially depending on different cognitive resources.

The results of the sentence-picture verification task are only partially in line with the findings reported by Vender & Delfitto (2010) and by Rizzato, Scappini, & Cardinaletti (2014). The overall performance of the dyslexic group was characterized by slower response times and higher error rates in all conditions in comparison with control subjects, indicating that the dyslexic participants experienced more difficulty in the execution of the task in general, and not only in the verification of the negative sentences. Similarly to the control subjects, dyslexic subjects exhibited more difficulty in the interpretation of the negative sentences in comparison with affirmative sentences, resulting in higher error rates and longer response times in the negative conditions in comparison with affirmative conditions. Beyond sentence polarity, the performance of the two groups was also crucially affected by the interaction between truth-value and polarity. Nevertheless, partially different patterns were reported in the two groups in this respect. As for affirmatives, in both groups false affirmative sentences were similarly associated to higher error rates and longer reaction times in comparison with true affirmative sentences. As for the negatives, as we have seen, the two groups showed slightly different patterns. With respect to accuracy, the control group reported the well-known inverse symmetry, with higher error rates for true than for false negative sentences; the dyslexic group, on the contrary, reported no difference in the accuracy for the two negative conditions. With respect to reaction times, differently, the dyslexic group was characterized by a pronounced difference between true and false negative sentences (with the former being interpreted slower than the latter), in comparison with non-dyslexic adults.

This pattern of data does thus not entirely support the hypothesis of a specific difficulty with negative sentences but speaks about an overall difficulty of dyslexics in the execution of the task. This latter hypothesis is supported also by the results of the regression analysis performed to evaluate the influence of working memory capacity on the interpretation of affirmative and negative sentences. As said, the statistical analysis reported a significant correlation between the phonological component of WM and the behavioral measures (accuracy, reaction times) of all four experimental conditions. Contrary to Vender (2011)'s hypothesis, however, the lack of a difference in the correlation between affirmative and negative conditions suggests that the working memory involvement may be mostly due to the working memory load of the experimental task (requiring the subjects to remember the sentence until the presentation of the picture), rather than to different processing cost associated to interpretation of the two types of sentences.

The analysis of the ERPs elicited by the presentation of the picture provided not very clear information about the processing of negative sentences in developmental dyslexia either. To start with, as we have seen, the four quadrants analysis revealed a complex interaction between group, longitude, polarity and truth-value in the first of the time windows we considered (400-600ms). In particular, while in the control group the first processing stages appeared to be exclusively determined by the match-mismatch between the sentence and the picture (see the *Discussion* of the Study 1, § 3.3), eliciting a N400-like component at posterior sites symmetric for affirmative and negative sentences consistent with the predictions of the two-stage hypothesis, the dyslexic group showed different effects for affirmative and negative conditions already at this stage. More precisely, while true negative sentences were found to elicit a long standing broad distributed negativity (emerging about 400ms after picture onset and presenting its maximal amplitude at frontal sites) in comparison with false negative sentences, no similar effects were found when the picture was following the affirmative sentences. This effect is hard to qualify in terms of well known ERP components, and it is also hard to relate to the frontal effect emerging as a function of *truth-value* found in later time windows for control subjects (see STUDY 1). This latter effect, in fact, was characterized by an opposite voltage polarity (a larger negativity for false sentences with respect to true ones), and characterized both affirmative and negative sentences. The centro-parietal analysis detailed at the level of the specific contributions to the overall N400-like effects by affirmative and negative conditions showed a further early difference between the sentence-picture matching after the presentation of affirmative and negative sentences. The first time window we considered (400-600ms), in fact, highlighted a very different pattern for the two groups of subjects: differently from controls, dyslexic subjects presented a delayed N400-like effect for affirmative sentences (which was found to emerge only after around 600ms), but showed an earlier and large effect for negative sentences, which was found to be even larger than that observed in the control group in 550-650ms interval. Even if the small number of subjects, the limited number of frontal recording sites in our experimental setup, and the unexpected topography of the effect make it very difficult to give a clear functional interpretation of this early effect, the difference in timing on the onset of the effects which associated to affirmative and negative sentences in the two groups of subjects allow to make some speculative considerations. The early difference between affirmative and negative sentences, on the one hand, and between true and false negative conditions, on the other, in fact, suggests that dyslexic subjects' interpretation of negative sentences may rely on different interpretative and/or cognitive processes with respect to those predicted by the *two-step simulation hypothesis*. In particular, while in non-dyslexic subjects the first stage of interpretation was mainly concerned with the comparison between the 'content' of the sentence and the picture, without considering whether that content has to be negated or not to obtain the proper meaning of the sentence, the dyslexic subjects do not seem to engage in a similar process, as confirmed by the complete absence of the N400 match-mismatch effect for affirmative sentences. Among the two negative sentences, in addition, the large and early negativity elicited by true negatives suggests that this latter sentences may be treated somehow differently with respect to the other types of sentences tested. The anterior distribution of the effect, together with its sustained latency, suggests that the effect may represent an instance of the 'anterior sustained negativity' typically associated, as we mentioned, to interpretive difficulties, conceptual violations and, more in general, to the discourse model elaboration (see § 2.3.2.2 for a review). This latter explanation would be consistent both with the observation of the particularly longer response times reported for true negative sentences in comparison with false negative sentences, and with the hypothesis, suggested in the *Discussion* of the Study 1 (§ 3.3), that true negative sentences may be characterized by a higher pragmatic sensitivity with respect to false negative sentences. In this view, the effect may reflect the re-computation of the discourse model determined by the use of a negative sentence to express correct information, unexpected under the pragmatic context provided by the experimental task. Worth noting, however, if this were the case, it would imply that the dyslexic participants could have processed the actual meaning of the negative sentences already at around 400-500ms after picture onset, a hypothesis which results in a clear contrast not only with the *two-step simulation* model of the negation, but also with the well-known processing limitation of dyslexic subjects. As for the later time windows, since the very large differences between the two groups observed in the very first stages of sentence verification suggests not to try to further elaborate the comparison between the two groups at later stages of processing, we will limit our observation to the consideration that the emergence of a *truth-value* effect in the second and third time windows analyzed indicates that the dyslexic participants have finally processed the truth-value of the sentence (as indeed confirmed by the above-chance accuracy level). Given the significant difference in both accuracy and reaction times, however, the different strategy adopted by the dyslexic group has to be considered less functional than the one used by the control group in both the affirmative and the negative conditions.

To sum up, the results of the present study do not provide confirmation to Vender (2011)'s hypothesis, according to which the interpretation of negative sentences would crucially depend on working memory resources. Despite of the significant differences in the phonological working memory, in fact, no indication of increased processing cost for the interpretation of negative sentences in comparison with affirmative sentences was reported. The analysis of the behavioral data, on the contrary, indicates that dyslexic subjects experienced a more general difficulty in all experimental conditions, very likely deriving from the working memory load associated with the execution of the experimental task. Moreover, the analysis of the ERPs and, in particular, the observation in the dyslexic group of (a) a crucial lack of the N400 effect characterizing the first stage of sentence verification in the control group, and (b) the emergence of an early *polarity* effect, unreported in the control group, suggests that dyslexic adults may rely on different cognitive strategies in the interpretation of both affirmative and negative sentence in sentence-picture verification tasks of the type proposed here. Worth noting, this latter hypothesis is at variance, at least to some extent, with the predictions of the *two-step simulation hypothesis* by Kaup and colleagues, according to which the interpretation of the negative sentences necessarily requires the initial simulation of the negated state of affairs. Further investigation is however needed to better determine the cognitive process underlying the interpretation of negative sentences in adults with developmental dyslexia, especially with reference to a detailed cognitive analysis of the possible strategies that can be adopted for solving tasks of the type implemented here.

Appendix A.
Experimental stimuli

Sentences

For brevity convenience, we report only one of the four lists used in the experiment to counterbalance items and conditions trough the so-called ‘Latin-square distribution’.

<u>Practice trials</u>

Winnie the Pooh non sta portando una torta.	*Winnie the Pooh is not bringing a cake.*
Paperina non sta cuocendo una frittata.	*Daisy is not cooking an omelet.*
Winnie Pooh non sta spedendo una lettera.	*Winnie the Pooh is not sending a letter.*
Paperino non sta guidando un’auto.	*Donald Duck is not driving a car.*
Tigro non sta scavando una buca.	*Tigro is not digging a hole.*
Paperina non sta leggendo un libro.	*Daisy is not reading a book.*
Paperino non sta lanciando un vaso.	*Donald Duck is not throwing a vase.*
Tigro sta guardando una farfalla.	*Tigro is looking at a butterfly.*

<u>Block 1</u>

Alice sta abbracciando una bambola.	*Alice is hugging a doll.*
La Sirenetta non sta acchiappando un pesciolino.	*The Little Mermaid is not catching a fish.*
Lisa sta aggiustando un aereoplanino.	*Lisa is fixing a toy airplane.*
La bambina non sta aprendo un ombrello.	*The girl is not opening an umbrella.*
Paperina sta incollando delle fotografie.	*Daisy is pasting some photos.*
Jasmine non sta attraversando un ponte.	*Jasmine is not going through a bridge.*
Marge sta bevendo una bibita.	*Marge is drinking a soft drink.*
Il poliziotto non sta calciando una sedia.	*The policeman is not kicking a chair.*
La nonna sta chiudendo una porta.	*The grandmother is closing a door.*
Il topo non sta contando le carte.	*The mouse is not counting cards.*
Pippo sta cuocendo del pesce.	*Goofy is cooking some fish.*
Grande Puffo non sta disegnando una principessa.	*Papa Smurf is not drawing a princess.*
Spiderman sta gettando una rete.	*Spiderman is throwing a net.*
Trilli non sta guardando l'orologio.	*Tinker Bell is not looking at the clock.*
Cenerentola sta indossando una collana.	*Cinderella is wearing a necklace.*
Capitan Uncino non sta lavando dei piatti.	*Captain Hook is not washing the dishes.*
Winnie the Pooh sta mangiando del miele.	*Winnie the Pooh is eating some honey.*
L’indiano non sta montando una tenda.	*The indian is not mounting a tent.*
Semola sta perdendo le chiavi.	*Arthur is losing the keys.*
Mike non sta portando un cestino.	*Mike is not carrying a basket.*
Biancaneve sta preparando una torta.	*Snow White is preparing a cake.*
Nonna Papera non sta pulendo gli occhiali.	*Grandma Duck is not cleaning the*

	glasses.
Geppetto sta rompendo un vetro.	*Geppetto is breaking a glass.*
La scimmia non sta sbucciando una banana.	*The monkey is peeling a banana.*
Asterix sta scavando una buca.	*Asterix is digging a hole.*
Titti non sta sognando un'isola.	*Tweety is not dreaming island.*
Duffy Duck sta strappando un cartellone.	*Daffy Duck is ripping a billboard.*
Little John non sta tagliando della legna.	*Little John is not cutting wood.*
Il principe sta tirando una freccia.	*The prince is pulling an arrow.*
Pluto non sta saltando un ostacolo.	*Pluto is not jumping an obstacle.*

<u>Block 2</u>

Bart sta abbracciando un orsacchiotto.	*Bart is hugging a teddy bear.*
Aladdin non sta accarezzando un fiore.	*Aladdin is not caressing a flower.*
Spugna sta alzando le mani.	*Sponge is raising his hands.*
Little John non sta bevendo dell'acqua.	*Little John is not drinking some water.*
Winnie the Pooh sta cancellando un disegno.	*Winnie the Pooh is erasing a drawing.*
Grande Puffo non sta colorando delle uova.	*Papa Smurf is not coloring some eggs.*
La scimmia sta costruendo una capanna.	*The monkey is building a hut.*
Cappuccetto Rosso non sta facendo un panino.	*Little Red Riding Hood is not making a sandwich.*
Pippo sta gonfiando un salvagente.	*Goofy is inflating a life preserver.*
Il gatto non sta guardando la televisione.	*The cat is not watching television.*
Bugs Bunny sta guidando la macchina.	*Bugs Bunny is driving the car.*
Mago Merlino non sta lanciando un sasso.	*Merlin is not throwing a stone.*
Paperina sta lavando i panni.	*Daisy is washing clothes.*
Biancaneve non sta leggendo un libro.	*Snow White is not reading a book.*
Geppetto sta mordendo una mela.	*Geppetto is biting an apple.*
Aurora non sta pestando una pozzanghera.	*Aurora is not stepping on a puddle.*
Titti sta piantando un chiodo.	*Tweety is hammering a nail.*
Il coniglio non sta raccogliendo delle conchiglie.	*The rabbit is not collecting shells.*
Nonna Papera sta riempiendo una bottiglia.	*Grandma Duck is filling a bottle.*
Topolino non sta rincorrendo un aquilone.	*Mickey Mouse is not chasing a kite.*
Obelix sta riparando un arco.	*Obelix is repairing a bow.*
Il pagliaccio non sta saltando una corda.	*The clown is not jumping rope.*
Sebastian sta scrivendo il diario.	*Sebastian is writing the diary.*
L'indiano non sta spegnendo il fuoco.	*The indian is not putting out the fire.*
Spiderman sta spezzando una catena.	*Spiderman is breaking a chain.*
Mike non sta spingendo un pacco.	*Mike is pushing a package.*
Il poliziotto sta strappando un giornale.	*The policeman is ripping a newspaper.*
Trilli non sta suonando dei campanellini.	*Tinker Bell is not playing bells.*
Cenerentola sta tagliando delle carote.	*Cinderella is cutting carrots.*
Marge non sta mostrando una medaglia.	*Marge is not showing a medal.*
Bart sta abbracciando un orsacchiotto.	*Bart is hugging a teddy bear.*
Aladdin non sta accarezzando un fiore.	*Aladdin is not caressing a flower.*
Spugna sta alzando le mani.	*Sponge is raising his hands.*
Little John non sta bevendo dell'acqua.	*Little John is not drinking some water.*
Winnie the Pooh sta cancellando un disegno.	*Winnie the Pooh is erasing a drawing.*

Grande Puffo non sta colorando delle uova.	*Papa Smurf is not coloring some eggs.*
La scimmia sta costruendo una capanna.	*The monkey is building a hut.*
Cappuccetto Rosso non sta facendo un panino.	*Little Red Riding Hood is not making a sandwich.*
Pippo sta gonfiando un salvagente.	*Goofy is inflating a life preserver.*
Il gatto non sta guardando la televisione.	*The cat is not watching television.*
Bugs Bunny sta guidando la macchina.	*Bugs Bunny is driving the car.*
Mago Merlino non sta lanciando un sasso.	*Merlin is not throwing a stone.*
Paperina sta lavando i panni.	*Daisy is washing clothes.*
Biancaneve non sta leggendo un libro.	*Snow White is not reading a book.*
Geppetto sta mordendo una mela.	*Geppetto is biting an apple.*
Aurora non sta pestando una pozzanghera.	*Aurora is not stepping on a puddle.*
Titti sta piantando un chiodo.	*Tweety is hammering a nail.*
Il coniglio non sta raccogliendo delle conchiglie.	*The rabbit is not collecting shells.*
Nonna Papera sta riempiendo una bottiglia.	*Grandma Duck is filling a bottle.*
Topolino non sta rincorrendo un aquilone.	*Mickey Mouse is not chasing a kite.*
Obelix sta riparando un arco.	*Obelix is repairing a bow.*
Il pagliaccio non sta saltando una corda.	*The clown is not jumping rope.*
Sebastian sta scrivendo il diario.	*Sebastian is writing the diary.*
L'indiano non sta spegnendo il fuoco.	*The indian is not putting out the fire.*
Spiderman sta spezzando una catena.	*Spiderman is breaking a chain.*
Mike non sta spingendo un pacco.	*Mike is pushing a package.*
Il poliziotto sta strappando un giornale.	*The policeman is ripping a newspaper.*
Trilli non sta suonando dei campanellini.	*Tinker Bell is not playing bells.*
Cenerentola sta tagliando delle carote.	*Cinderella is cutting carrots.*
Marge non sta mostrando una medaglia.	*Marge is not showing a medal.*

<u>Block 3</u>

Sully sta abbracciando una bambola.	*Sully is hugging a doll.*
Marge non sta accendendo la luce.	*Marge is not turning on the light.*
Little John sta aggiustando un vestito.	*Little John is adjusting a dress.*
Bugs Bunny non sta alzando una bandiera.	*Bugs Bunny is not raising a flag.*
Peter Pan sta aprendo una finestra.	*Peter Pan is opening a window.*
Batman non sta attraversando la strada.	*Batman is not crossing the street.*
Asterix sta bevendo una bibita.	*Asterix is drinking a soft drink.*
Il gatto non sta calciando un pallone.	*The cat is not kicking a ball.*
La bambina sta chiudendo una valigia.	*The little girl is closing a suitcase.*
Il ladro non sta contando delle monetine.	*The thief is counting some pennies.*
Puffetta sta cuocendo del pollo.	*Smurfette is cooking some chicken.*
Winnie the Pooh non sta dipingendo una parete.	*Winnie the Pooh is not painting a wall.*
La Sirenetta sta disegnando una casa.	*The Little Mermaid is designing a house.*
Silvestro non sta gettando la spazzatura.	*Sylvester is not throwing out the garbage.*
Alice sta guardando l'orologio.	*Alice is looking at the watch.*
Paperino non sta incollando delle figurine.	*Donald Duck is not pasting some stickers.*
Mago Merlino sta indossando un cappello.	*Merlin is wearing a hat.*
La nonna non sta mangiando del miele.	*The grandmother is not eating some honey.*

Jasmine sta montando una tenda.	*Jasmine is mounting a tent.*
Aurora non sta perdendo un fazzoletto.	*Aurora is not losing a handkerchief.*
Tarzan sta pestando delle foglie.	*Tarzan is pounding some leaves.*
Cenerentola non sta preparando la tavola.	*Cinderella is not setting the table.*
Brontolo sta pulendo il pavimento.	*Grumpy is cleaning the floor.*
Capitan Uncino non sta sbucciando delle patate.	*Captain Hook is not peeling some potatoes.*
Topolino sta scavando una buca.	*Mickey Mouse is digging a hole.*
Zio Paperone non sta sognando il mare.	*Uncle Scrooge is not dreaming of the sea.*
Lisa sta spegnendo una lampadina.	*Lisa is powering a light bulb.*
Il cow boy non sta tagliando della legna.	*The cowboy is not cutting wood.*
Geppetto sta tirando un carretto.	*Geppetto is pulling a cart.*
Paperina non sta mostrando una coppa.	*Daisy is not showing a cup.*

<u>Block 4</u>

Brontolo sta accarezzando un uccellino.	*Grumpy is caressing a bird.*
Mago Merlino non sta accendendo una candela.	*Merlin is not lightening a candle.*
Grande Puffo sta ascoltando la radio.	*Papa Smurf is listening to the radio.*
Aurora non sta bevendo dell'acqua.	*Aurora is not drinking some water.*
Paperina sta cancellando un disegno.	*Daisy is erasing a drawing.*
Sully non sta colorando un’immagine.	*Sully is not coloring a picture.*
Geppetto sta costruendo un tavolo.	*Geppetto is building a table.*
La bambina non sta dipingendo un quadro.	*The girl is painting a picture.*
Il gatto sta facendo una foto.	*The cat is taking a picture.*
Spugna non sta gonfiando un salvagente.	*Sponge is not inflating a life preserver.*
Obelix sta guidando una nave.	*Obelix is driving a ship.*
Il cow boy non sta lanciando un sasso.	*The cowboy is not throwing a stone.*
La matrigna sta lavando dei piatti.	*The stepmother is washing some dishes.*
Silvestro non sta leggendo un cartello.	*Sylvester is not reading a sign.*
Nonna Papera sta mordendo una ciambella.	*Grandma Duck is biting a donut.*
Cappuccetto Rosso non sta raccogliendo delle fragoline.	*Little Red Riding Hood is not collecting of wild strawberries.*
Robin Hood sta riempiendo un secchio.	*Robin Hood is filling a bucket.*
Alice non sta rincorrendo un aquilone.	*Alice is chasing a kite.*
Paperino sta riparando un motore.	*Donald Duck is repairing an engine.*
Aladdin non sta rovesciando un bicchiere.	*Aladdin is not spilling a glass.*
Il poliziotto sta scavalcando un recinto.	*The policeman is climbing a fence.*
Bart non sta scrivendo il diario.	*Bart is writing the diary.*
Spiderman sta sollevando dei pesi.	*Spiderman is lifting weights.*
La scimmia non sta spezzando un ramo.	*The monkey is not breaking a branch.*
Duffy Duck sta spingendo un’auto.	*Daffy Duck is pushing a car.*
Marge non sta strappando un cartellone.	*Marge is not ripping off a billboard.*
Sebastian sta suonando un tamburello.	*Sebastian is playing a tambourine.*
Peter Pan non sta tenendo una spada.	*Peter Pan is not holding a sword.*
Topolino sta mostrando una medaglia.	*Mickey Mouse is showing a medal.*
Winnie the Pooh non sta acchiappando una farfalla.	*Winnie the Pooh is not catching a butterfly.*

Block 5

Peter Pan sta abbracciando un orsacchiotto.	*Peter Pan is hugging a teddy bear.*
Il gatto non sta acchiappando un pesciolino.	*The cat is not catching a fish.*
Mago Merlino sta alzando una bandiera.	*Merlin is raising a flag.*
Il coniglio non sta aprendo un ombrello.	*The rabbit is not opening an umbrella.*
Il principe non sta attraversa la strada.	*The prince is not crossing the road.*
Pinocchio non sta calciando una sedia.	*Pinocchio is not kicking a chair.*
Spugna sta chiudendo una valigia.	*Sponge is closing a suitcase.*
Titti non sta cuocendo del pesce.	*Tweedy is not cooking some fish.*
Pippo sta gettando la spazzatura.	*Goofy is throwing the garbage.*
Lisa non sta incollando delle fotografie.	*Lisa is not pasting some photographs.*
Nonna Papera sta indossando un cappello.	*Grandma Duck is wearing a hat.*
Homer non sta lavando i panni.	*Homer is not washing clothes.*
Brontolo sta mangiando del pollo.	*Grumpy is eating chicken.*
Grande Puffo non sta montando un mobile.	*Papa Smurf is not assembling a piece of furniture.*
Cenerentola sta perdendo un fazzoletto.	*Cinderella is losing a handkerchief.*
Tigro non sta pestando delle foglie.	*Tigger is not pounding the leaves.*
La scimmia sta piantando un albero.	*The monkey is planting a tree.*
Il pagliaccio non sta portando un regalo.	*The clown is not bringing a gift.*
La Sirenetta sta rompendo un vaso.	*The Little Mermaid is breaking a vase.*
Bugs Bunny non sta saltando un ostacolo.	*Bugs Bunny is not jumping an obstacle.*
La nonna sta sbucciando delle patate.	*The grandmother is peeling potatoes.*
Batman non sta scavando un tunnel.	*Batman is digging a tunnel.*
Robin Hood sta scavalcando un muretto.	*Robin Hood is climbing over a wall.*
Sully non sta spegnendo una lampadina.	*Sully is not turning off a light bulb.*
Il poliziotto sta spezzando una catena.	*The policeman is breaking a chain.*
Topolino non sta strappando un giornale.	*Mickey Mouse is not tearing a newspaper.*
Aladdin sta suonando dei campanellini.	*Aladdin is ringing bells.*
Paperina non sta tagliando delle carote.	*Daisy is not cutting carrots.*
Il cow boy sta tenendo un bastone.	*The cowboy is holding a stick.*
Asterix non sta tirando un carretto.	*Asterix is not pulling a cart*

Block 6

Il principe sta accarezzando un fiore.	*The prince is caressing a flower.*
Biancaneve non sta accendendo una candela.	*Snow White is not lighting a candle.*
Mike sta alzando le mani.	*Mike is raising his hands.*
La Sirenetta non sta indossa una collana.	*The Little Mermaid is not wearing a necklace.*
Lisa sta cancellando la lavagna.	*Lisa is erasing the chalkboard.*
Trilli non sta colorando un'immagine.	*Tinker Bell is not coloring a picture.*
Puffetta sta costruendo un tavolo.	*Smurfette is building a table.*
Geppetto non sta dipingendo una parete.	*Geppetto is not painting a wall.*
Silvestro sta facendo un panino.	*Sylvester is making a sandwich.*
Winnie the Pooh non sta gonfiando un	*Winnie the Pooh is not blowing up a*

palloncino.	*balloon.*
Spugna sta guidando una nave.	*Sponge is driving a ship.*
Il pagliaccio non sta acchiappando una farfalla.	*The clown is not catching a butterfly.*
Il poliziotto sta leggendo un cartello.	*The policeman is reading a sign.*
Marge non sta mordendo una ciambella.	*Marge is biting a donut.*
Pluto sta pestando una pozzanghera.	*Pluto is stepping on a puddle.*
Cappuccetto Rosso non sta pulendo gli occhiali.	*Little Red Riding Hood is not cleaning his glasses.*
Semola sta riempiendo un secchio.	*Arthur is filling a bucket.*
Il topo non sta rincorrendo un topolino.	*The mouse is not chasing a mouse.*
Batman sta rompendo un vetro.	*Batman is breaking a glass.*
Duffy Duck non sta rovesciando una scatola.	*Daffy Duck is not knocking over a box.*
La scimmia sta saltando la corda.	*The monkey is jumping rope.*
Little John non sta disegnando una principessa.	*Little John is not drawing a princess.*
La matrigna non sta scrivendo una lettera.	*The stepmother is not writing a letter.*
Alice non sta sollevando una valigia.	*Alice is picking up a suitcase.*
Asterix sta suonando un tamburello.	*Asterix is playing a tambourine.*
Jasmine non sta chiudendo la porta.	*Jasmine is not closing the door.*
Zio Paperone sta contando delle monetine.	*Uncle Scrooge is counting some pennies.*
Il cow boy non sta attraversando un ponte.	*The cowboy is not going through a bridge.*
Paperino sta lanciando una palla.	*Donald Duck is launching a ball.*
Minnie non sta ascoltando la radio.	*Minnie is not listening to the radio.*

<u>Block 7</u>

Trilli sta aggiustando un vestito.	*Tinker Bell is adjusting a dress.*
Aurora non sta aprendo una finestra.	*Aurora is not opening a window.*
Silvestro sta calciando un pallone.	*Sylvester is kicking a ball.*
Alice non sta contando le carte.	*Alice is not counting cards.*
Marge sta cuocendo del pollo.	*Marge is cooking the chicken.*
Winnie the Pooh non sta disegnando una casa.	*Winnie the Pooh is not drawing a house.*
Spugna sta gettando una rete.	*Sponge is throwing a net.*
Lisa non sta guardando la televisione.	*Lisa is not watching television.*
Grande Puffo sta incollando delle figurine.	*Papa Smurf is pasting some stickers.*
La bambina non sta lanciando una palla.	*The girl is throwing a ball.*
La scimmia sta mangiando del pollo.	*The monkey is eating the chicken.*
Paperino non sta montando un mobile.	*Donald Duck is not assembling a piece of furniture.*
Pinocchio sta perdendo le chiavi.	*Pinocchio is losing the keys.*
L'indiano non sta piantando un albero.	*The indian is not planting a tree.*
Nonna Papera sta portando un regalo.	*Grandma Duck is bringing a gift.*
Cappuccetto Rosso non sta preparando una torta.	*Little Red Riding Hood is not preparing a cake.*
Cenerentola sta pulendo il pavimento.	*Cinderella is cleaning the floor.*
Brontolo non sta raccogliendo delle fragoline.	*Grumpy is not collecting of wild strawberries.*

Il topo sta riparando un motore.	*The mouse is repairing an engine.*
Robin Hood non sta rovesciando un bicchiere.	*Robin Hood is not spilling a glass.*
Mike sta sbucciando una banana.	*Mike is peeling a banana.*
Spiderman non sta scavalcando un muretto.	*Spiderman is not climbing over a wall.*
Bugs Bunny sta scavando un tunnel.	*Bugs Bunny is digging a tunnel.*
Topolino non sta sognando il mare.	*Mickey Mouse is not dreaming of the sea.*
Minnie sta sollevando dei pesi.	*Minnie is lifting weights.*
Obelix non sta spezzando un ramo.	*Obelix is not breaking a branch.*
Il ladro sta spingendo un'auto.	*The thief is driving a car.*
Jasmine non sta tenendo un bastone.	*Jasmine is not holding a stick.*
Semola sta tirando una freccia.	*Arthur is pulling an arrow.*
Sebastian non sta ascoltando un disco.	*Sebastian is not listening to a disc.*

Block 8

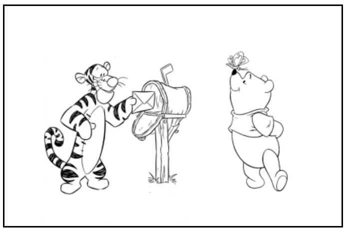
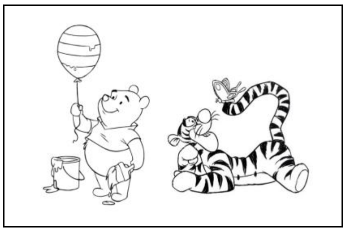
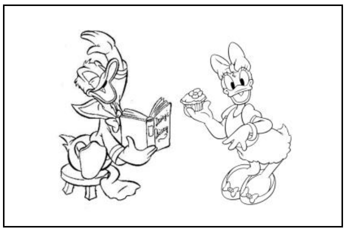
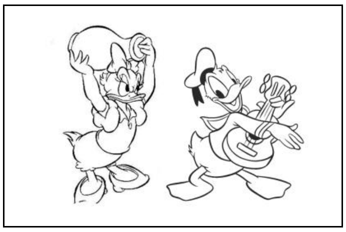
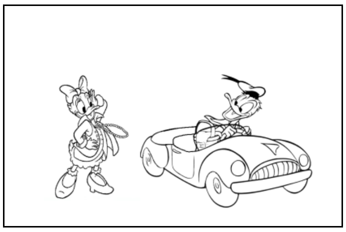
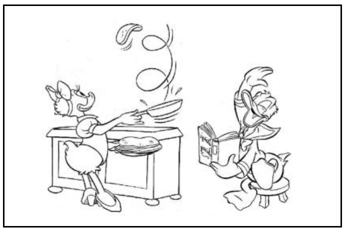
Tarzan sta accarezzando un uccellino.	*Tarzan is caressing a bird.*
Il ladro non sta accendendo la luce.	*The thief is not turning on the light.*
Winnie the Pooh sta aggiustando un aereoplanino.	*Winnie the Pooh is fixing a toy airplane.*
Nonna Papera non sta ascoltando un disco.	*Grandma Duck is not listening to a disc.*
Alice sta cancellando la lavagna.	*Alice is erasing the blackboard.*
Il topo non sta preparando la tavola.	*The mouse is not setting the table.*
Asterix sta costruendo una capanna.	*Asterix is building a hut.*
Sully non sta dipingendo un quadro.	*Sully is not painting a picture.*
Pippo sta facendo una foto.	*Goofy is taking a picture.*
La bambina non sta gonfiando un palloncino.	*The girl is blowing up a balloon.*
Marge sta guidando la macchina.	*Marge is driving the car.*
Paperina non sta colorando delle uova.	*Daisy is not coloring some eggs.*
Bart sta leggendo un libro.	*Bart is reading a book.*
Brontolo non sta mordendo una mela.	*Grumpy is not biting an apple.*
Pinocchio sta piantando un chiodo.	*Pinocchio is hammering a nail.*
Cappuccetto Rosso non sta portando un cestino.	*Little Red Riding Hood is not carrying a basket.*
Sebastian sta raccogliendo delle conchiglie.	*Sebastian is collecting shells.*
La matrigna non sta riempie una bottiglia.	*The stepmother is not filling a bottle.*
Silvestro sta rincorrendo un topolino.	*Sylvester is chasing a mouse.*
Robin Hood non sta riparando un arco.	*Robin Hood is not repairing a bow.*
Aladdin sta rompendo un vaso.	*Aladdin is breaking a vase.*
Peter Pan non sta rovesciando una scatola.	*Peter Pan is not knocking over a box.*
Il cow boy sta scavalcando un recinto.	*The cowboy is climbing over a fence.*
Il principe non sta scrivendo una lettera.	*The prince is not writing a letter.*
Spugna sta sognando un'isola.	*Sponge is dreaming of an island.*
Duffy Duck non sta sollevando una valigia.	*Daffy Duck is not lifting a suitcase.*
Spiderman sta spegnendo il fuoco.	*Spiderman is putting out the fire.*
Topolino non sta spingendo un pacco.	*Mickey Mouse is not pushing a package.*
Grande Puffo sta mostrando una coppa.	*Papa Smurf is showing a cup.*
Semola non sta tenendo una spada.	*Arthur is not holding a sword.*

Pictures

The same 240 pictures were used for the four versions of the experiment. In each of the four lists, however, every picture was associated to a different kind of sentence.

<u>Practice trials</u>



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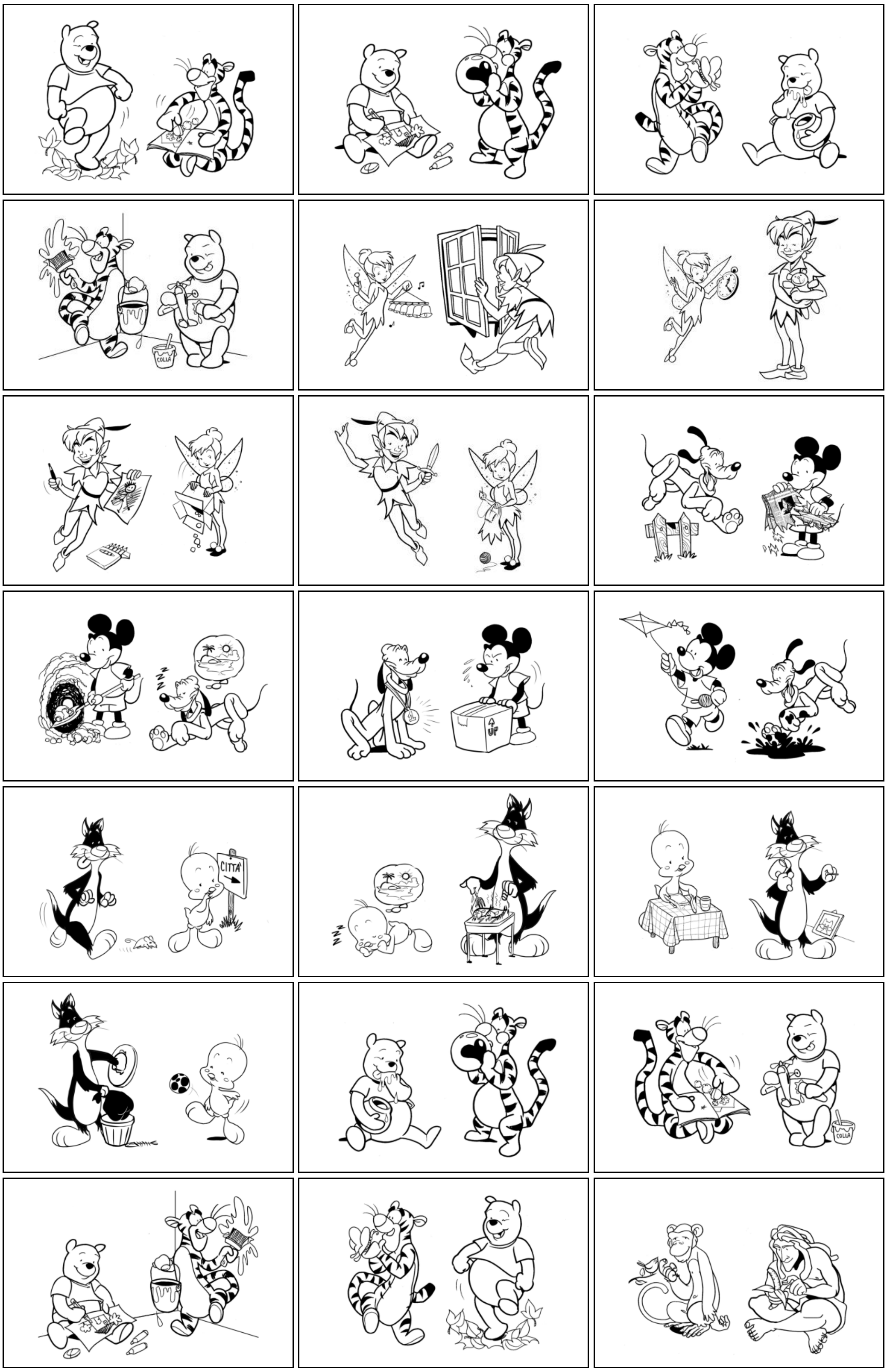


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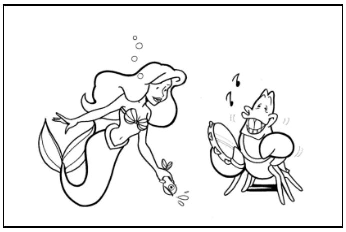
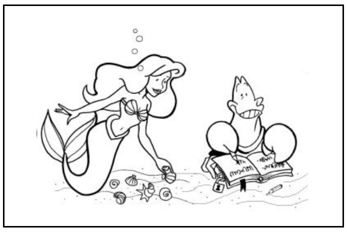
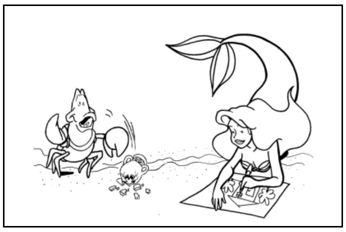
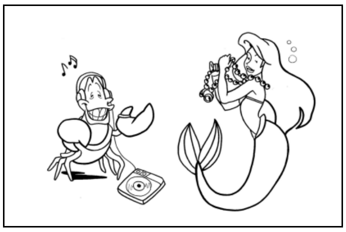



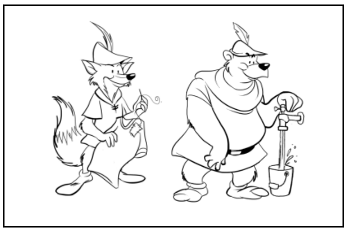
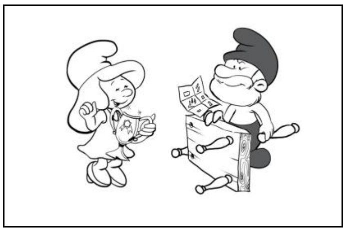
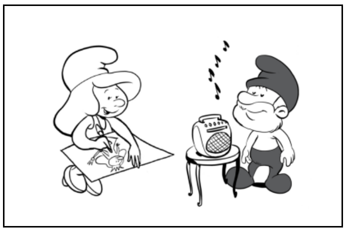
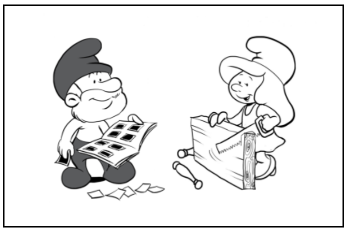
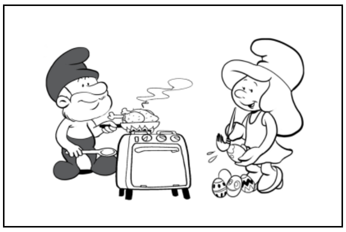
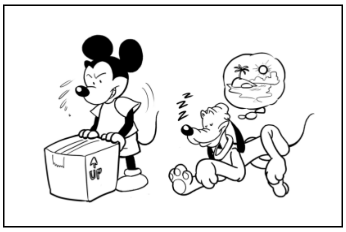
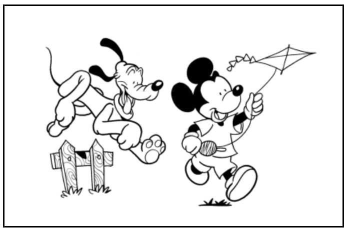
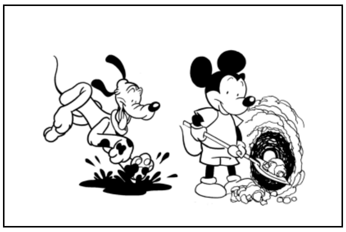
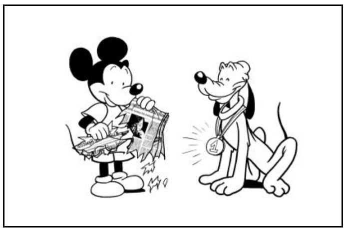
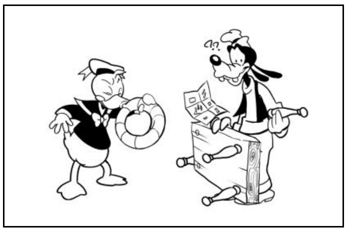
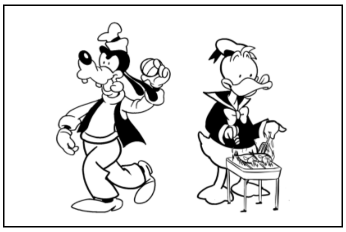


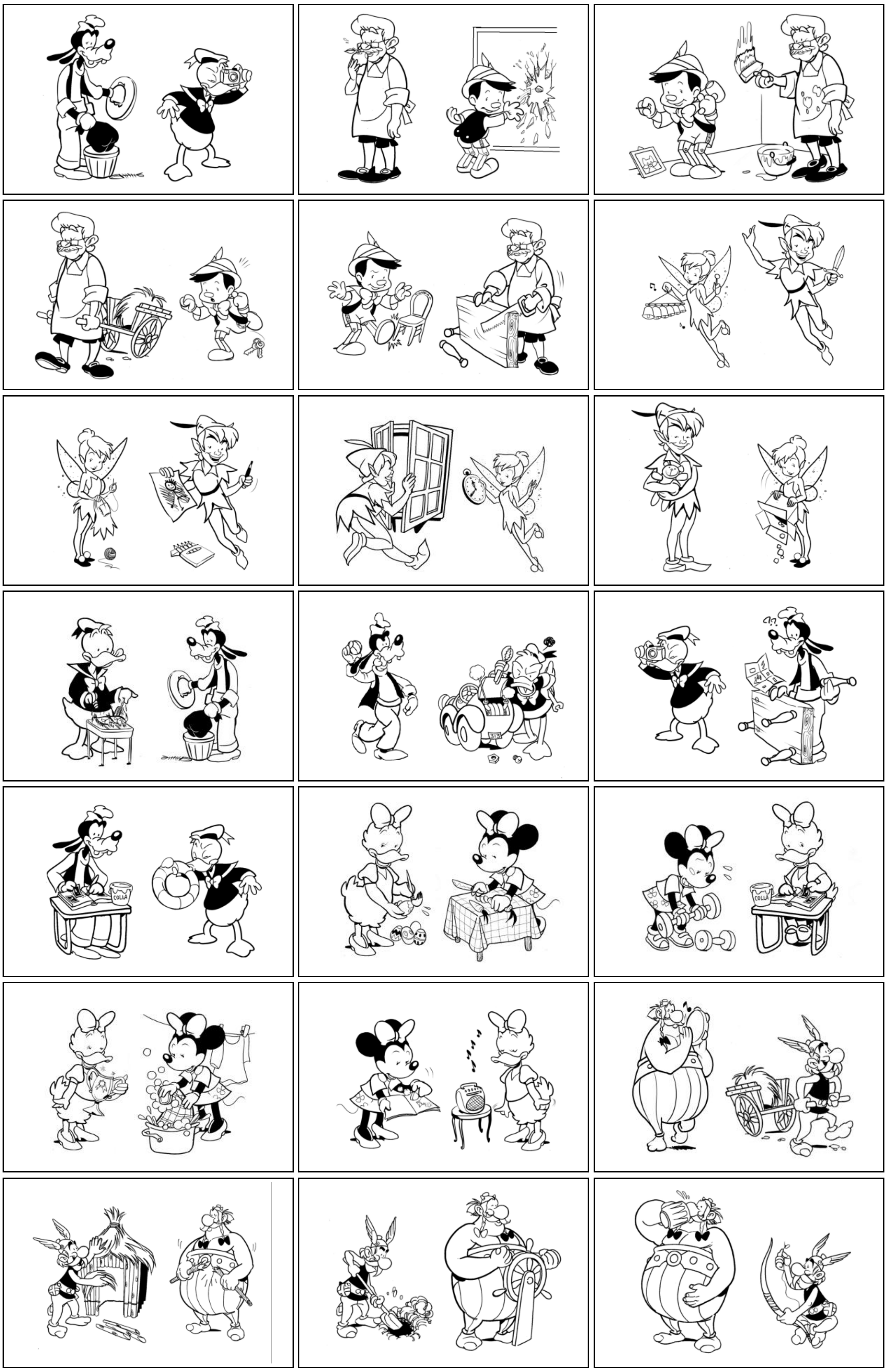

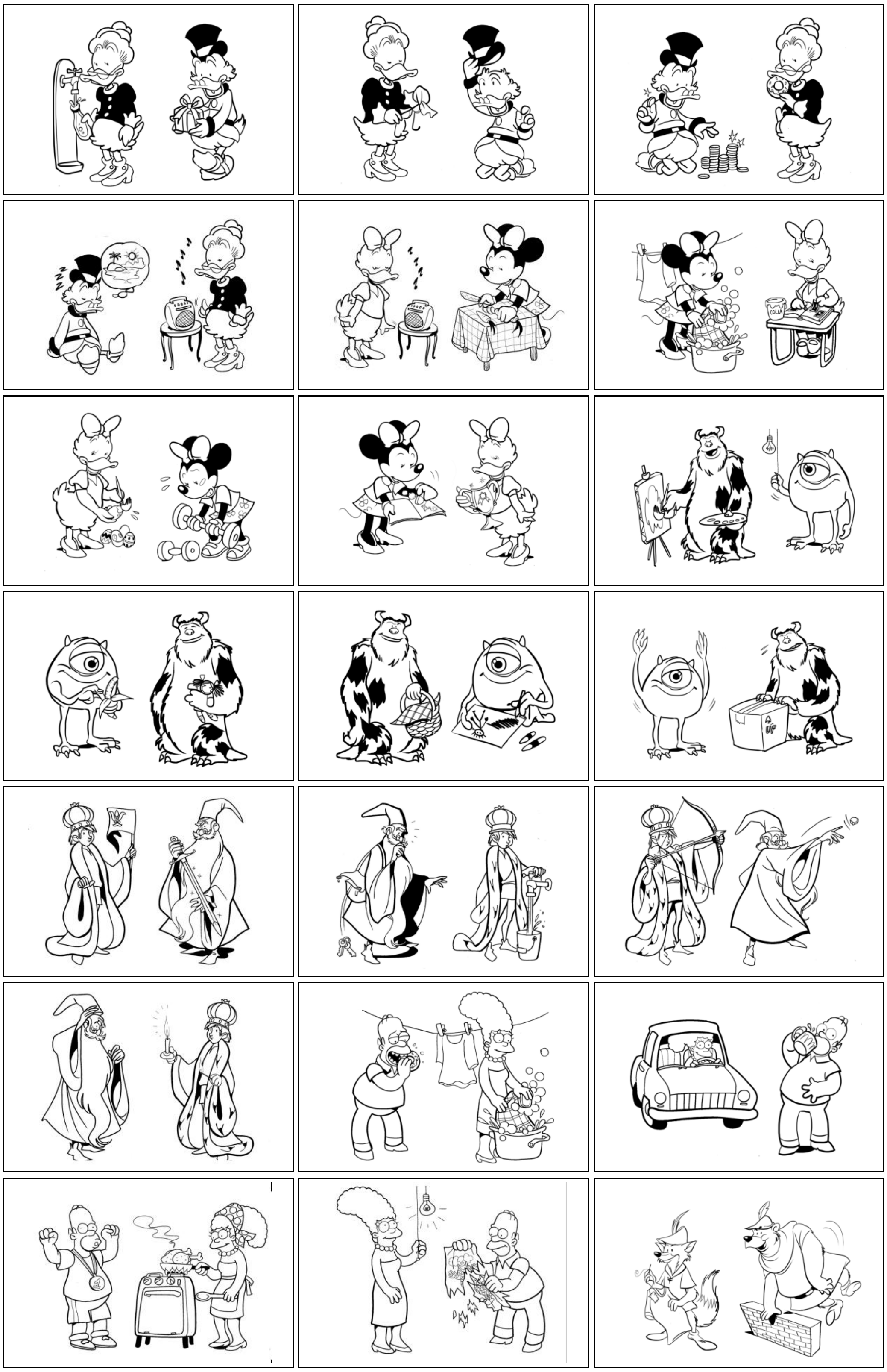




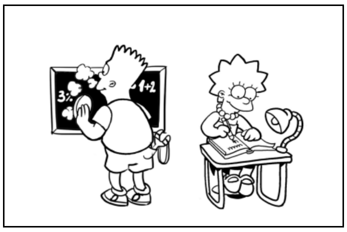
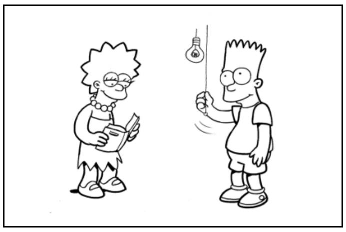
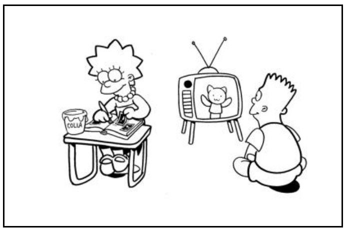
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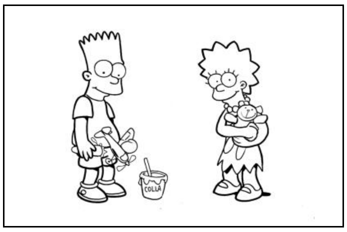
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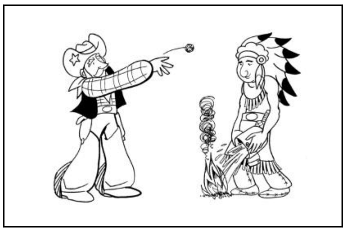
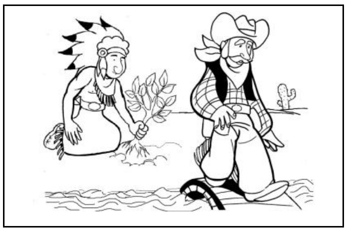
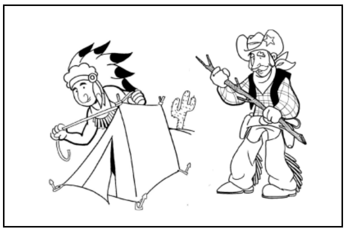
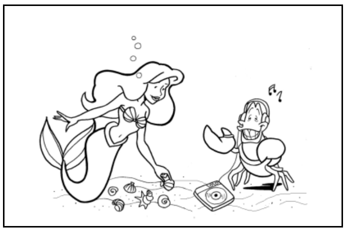
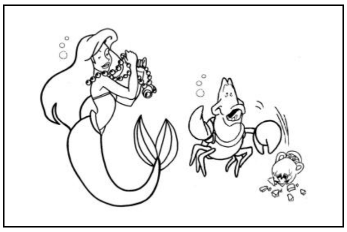
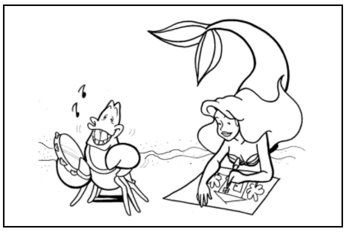
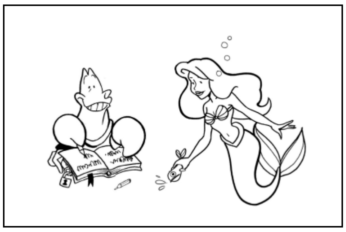
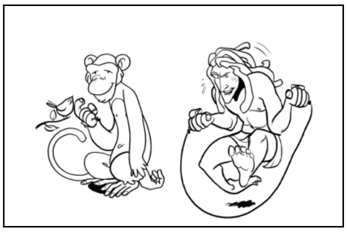
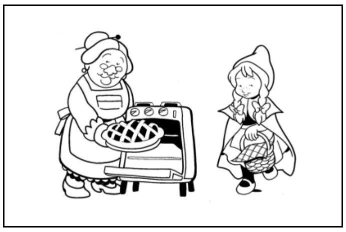














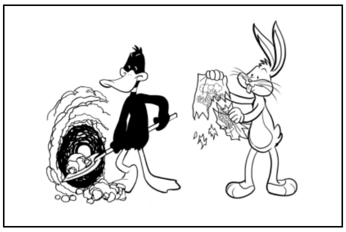
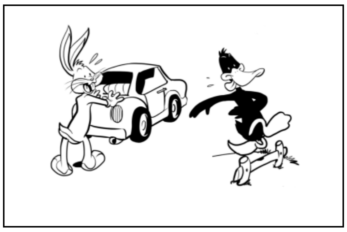
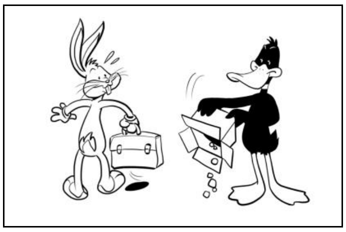
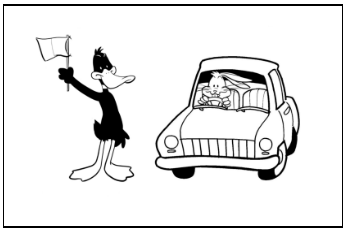
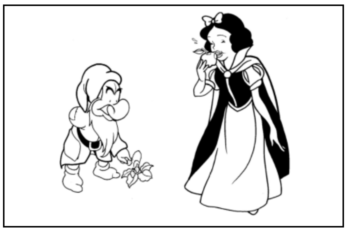




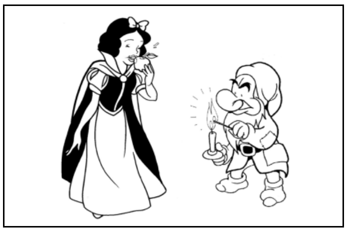


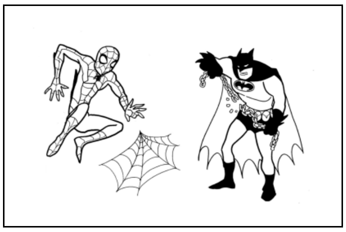
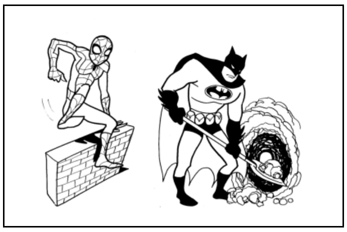
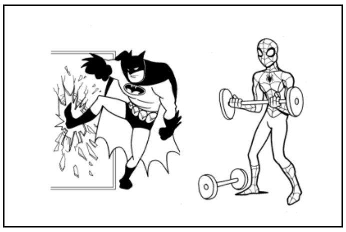


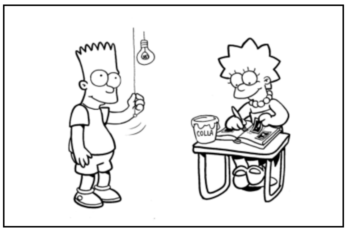
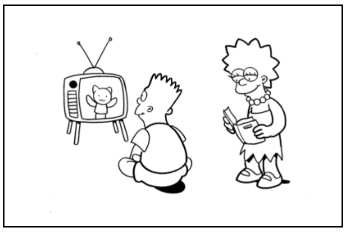
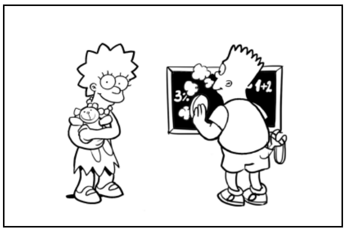
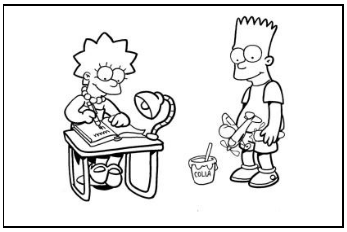


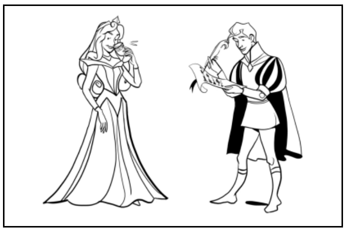
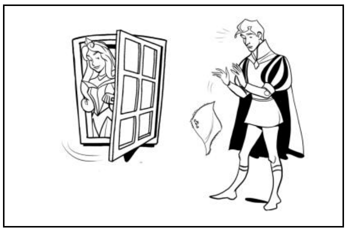
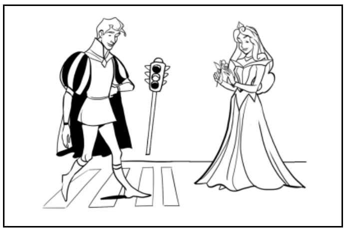
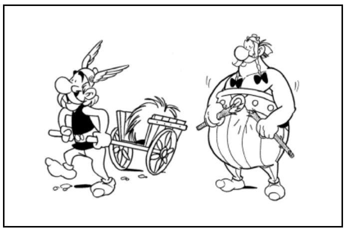
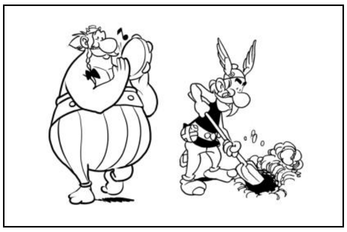
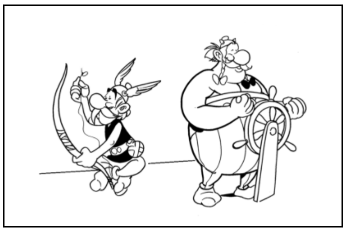
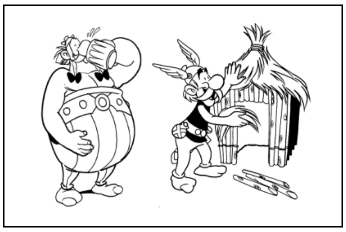
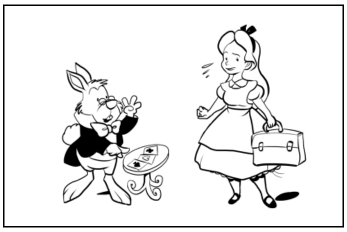







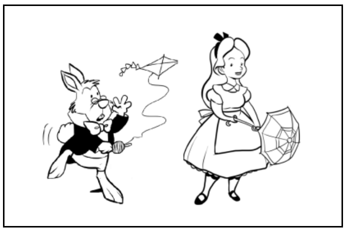





3 = 1+2
5+

Appendix B.
Plots of the EEG grand averages.

In the following pages, the grand averages of all channels and conditions of the three EEG studies performed (the preliminary study with adults, STUDY 1 and STUDY 2) are plotted.

For STUDY 1 and STUDY 2, the grand averages of the three main effects analyzed (*match-mismatch*, *truth-value*, and *polarity*) are also reported.

FIGURE 1(B). EEG grand averages – Preliminary study with adults.

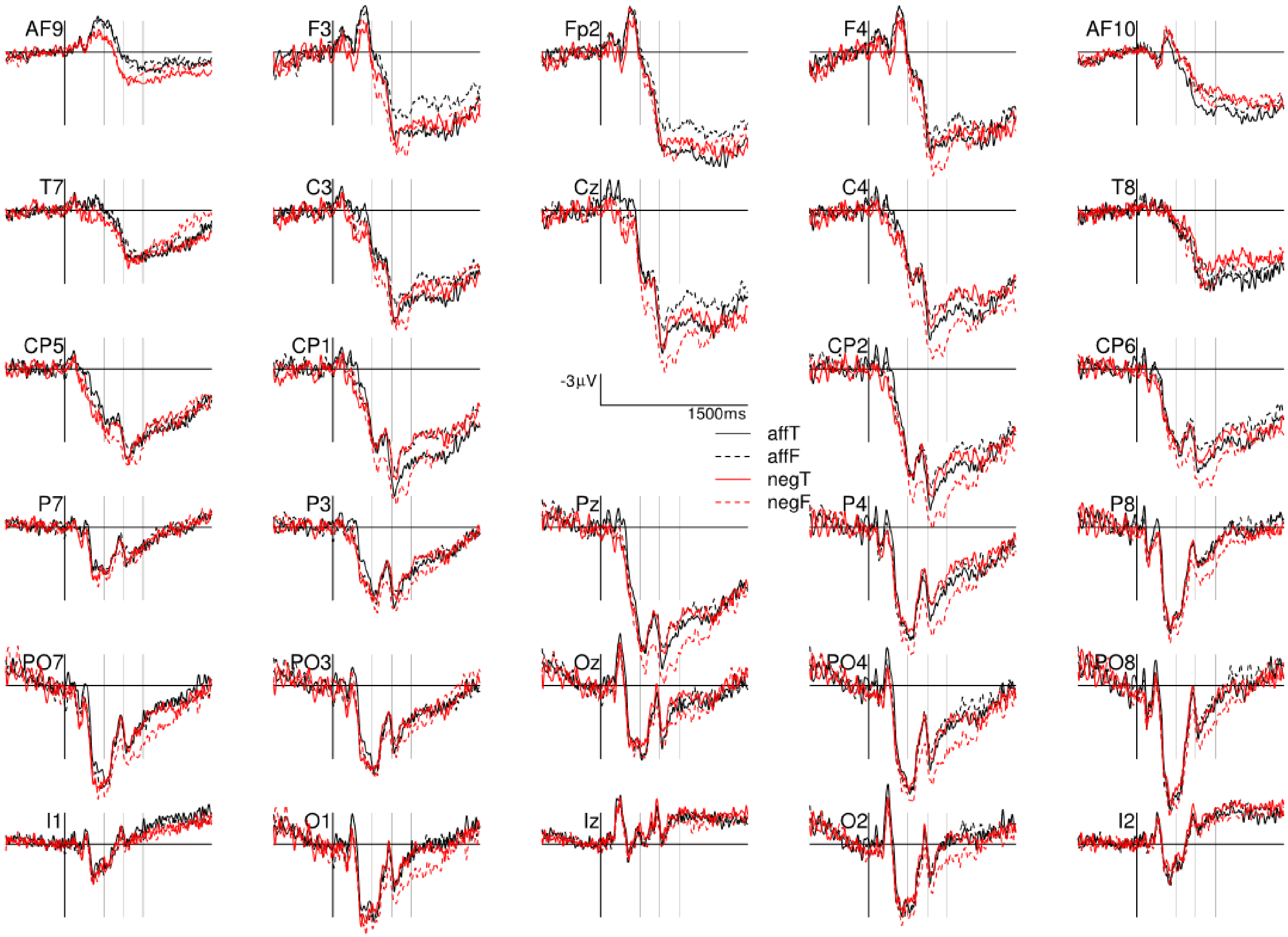


FIGURE 2(B). EEG grand averages – All conditions STUDY 1: Non-dyslexic adults.

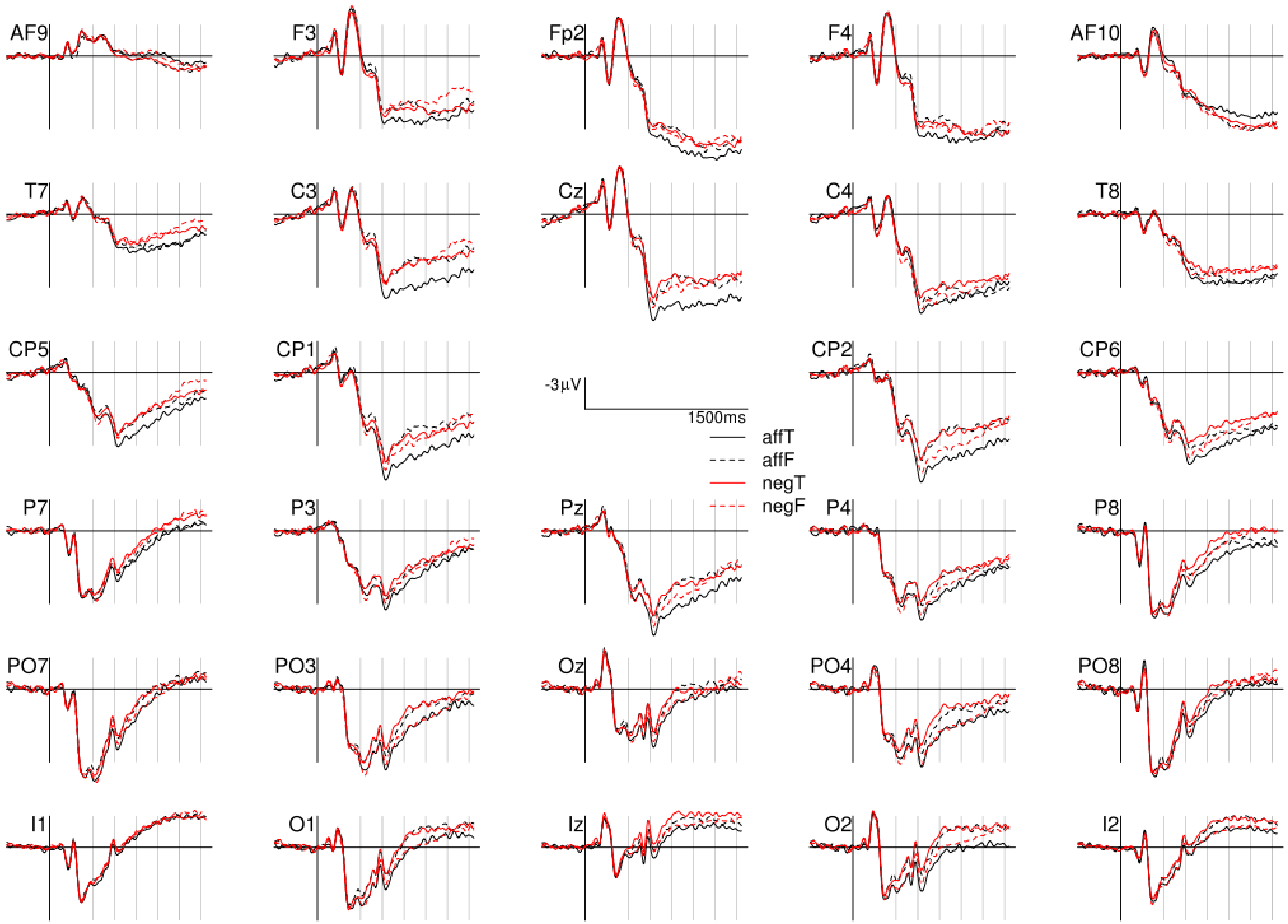


FIGURE 3 (B). EEG grand averages – All conditions STUDY 2: Dyslexic adults.

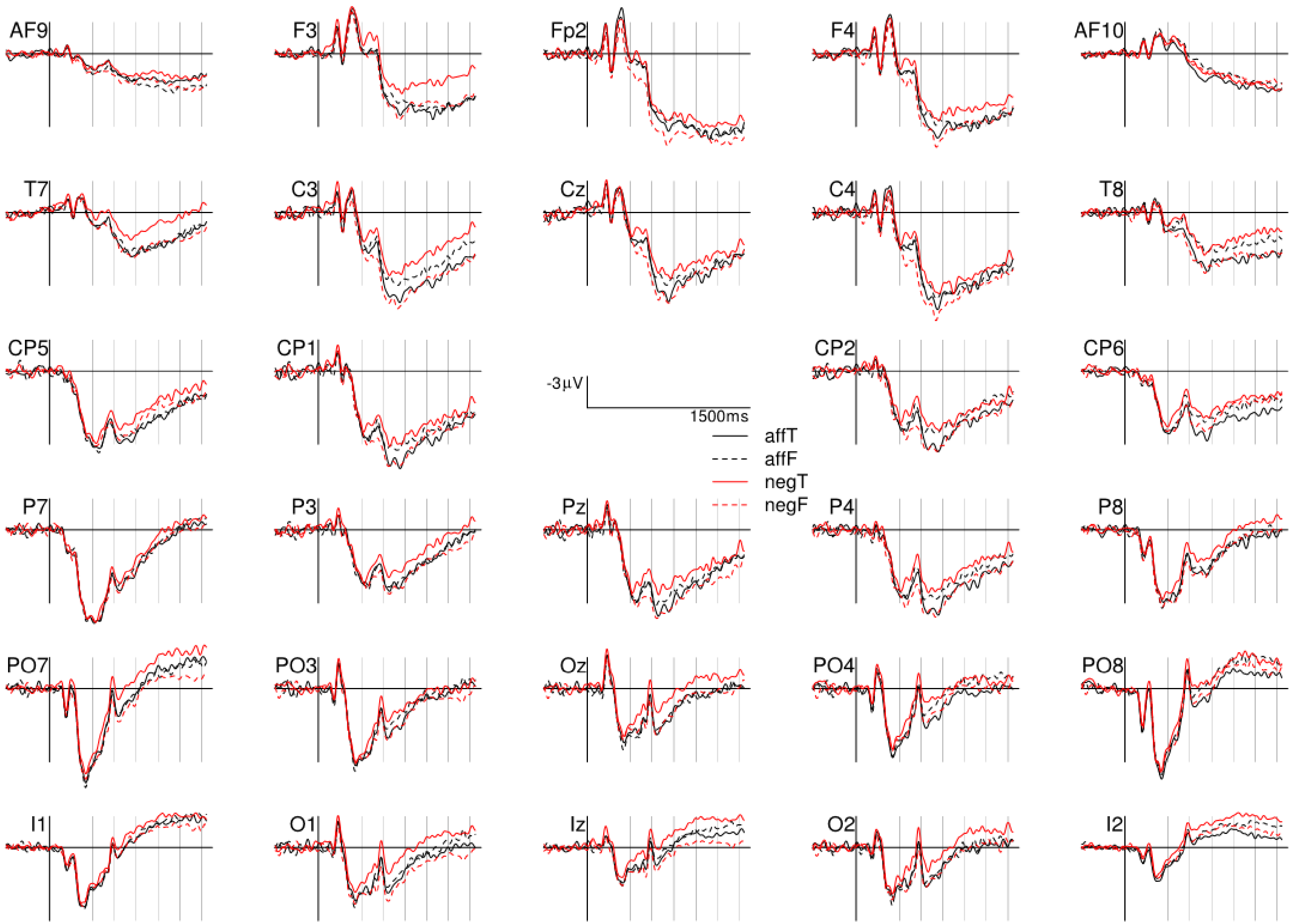


FIGURE 4 (B). EEG grand averages – Main effects STUDY 1: Non-dyslexic adults.

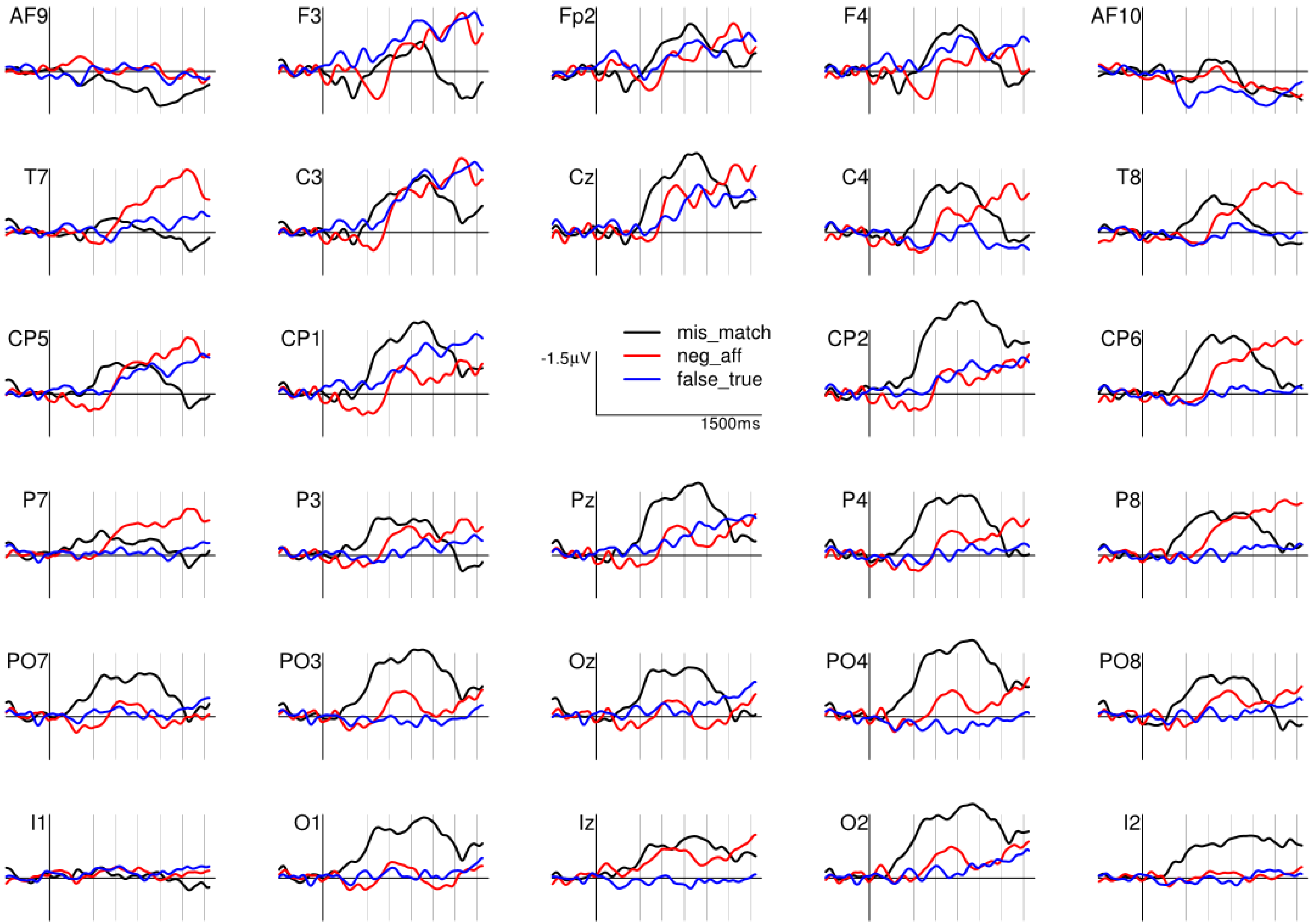
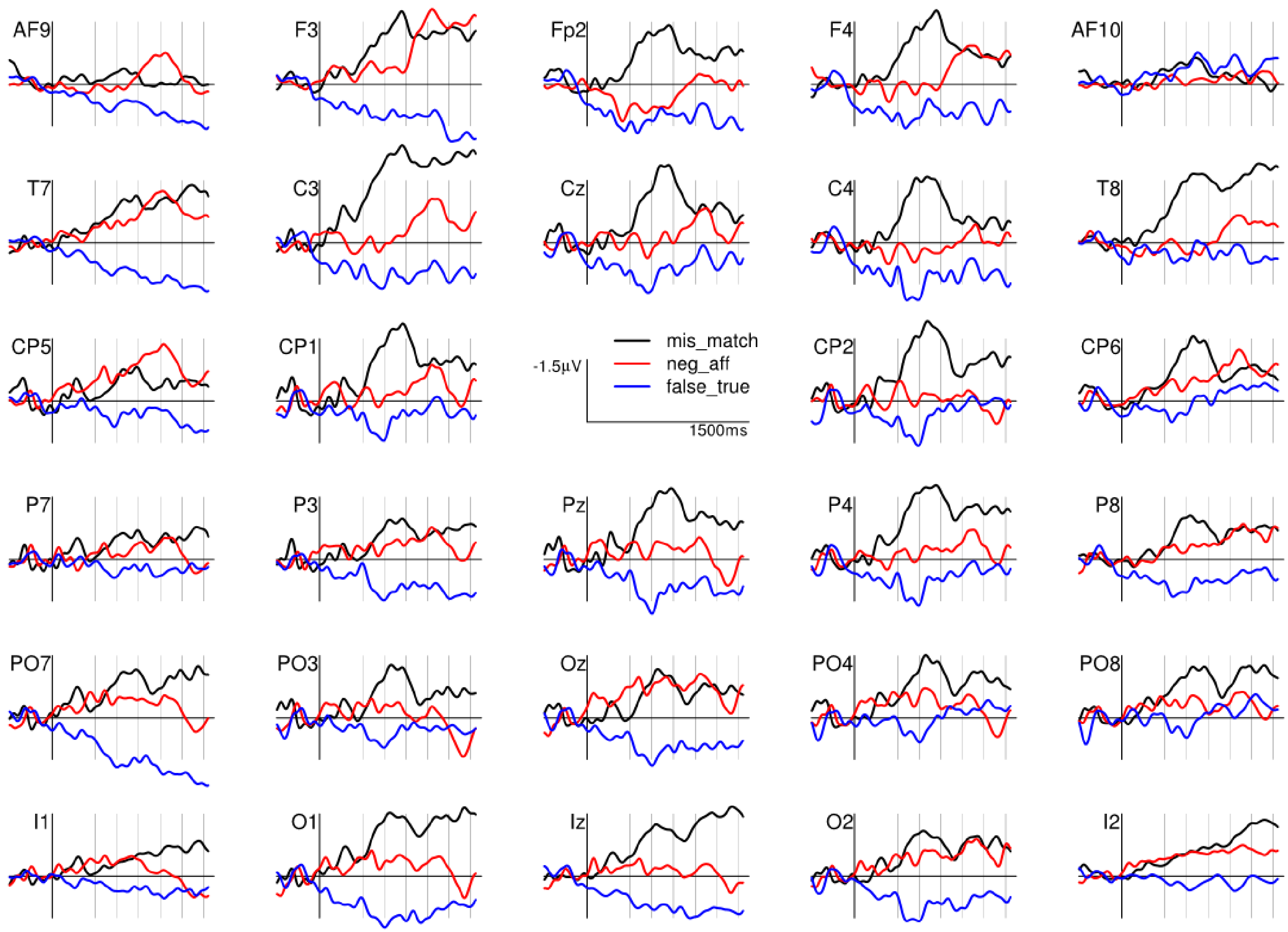


FIGURE 5 (B). EEG grand averages – Main effects STUDY 1: Dyslexic adults.



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