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The processing of negative sentences: neural and behavioral correlates in healthy volunteers and brain-damaged population

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A mio marito.

Contents

Introduction

> "And so, in relation to each of these classes, being is many, and not being is infinite in number."
>
> (Plato, *The Sophist*)[1]

> "Listen, I'm the wrong actor. I don't drive,
> I don't speak English, and I hate
> violence."
> They laughed and said:
> "Maybe that's why we called you."
>
> (Javier Bardem on *No country for old men*)

The possibility of predicating about *what it is not* is a prerogative of human language universally attested across natural languages (Greenberg, 1966; Dahl, 1979; Payne, 1985; Horn, 1989)[2]. Although we efficiently use negative

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[1] H. N. Fowler (1914). *Plato. With an English translation.* London: Heinemann; Cambridge, Mass.: Harvard University Press.

[2] Although it is usually claimed that '*no animal communication system other than human provide a mechanism to negate'* (Horn, 1989; Barwise, 1991; Jackendoff, 2002), some concepts of negation (like refusal and non-existence, but not that of denial) seem actually developed after training by higher animals like birds, dolphin, and primates; see Swartz, Himmanen and Schumaker (2007).

predications to convey meaning, the way negative sentences carry their meaning is quite controversial. An approximate but effective way to approach the problem is by trying to visually represent the semantic content of a negative sentence like (1): the structure is perfectly interpretable, but the attempt to draw its semantic content in a picture inevitably crashes.

(1). Mary does not wear her Rolling Stones sweatshirt while getting to work on rainy mornings.

At a very intuitive level, negative sentences speak of the *absence* of a property or an event ("She does not eat carbohydrates", "The e-mail has not arrived yet", "There were no bananas at the supermarket"). One could thus be tempted to solve the problem by saying that a negative predication denotes *what is missing* in the real world. However, reality is not made by non-facts: we might see people who eat carbohydrates, e-mails in our inbox and bananas at the supermarket, but the 'not-eating' action or non-existing e-mails or bananas are not part of the factual reality (Heinemann, 1944; Quine, 1948; Davidson, 1985; Varzi, 2007; James, 1882 quoted in Dahlstrom, 2010).

This is why, since Aristotle, negation has been included among those operators that do not apply to events or property, but to *propositions* or judgments. Negation has been considered as a feature of the logical domain, namely the function that reverses the truth value of a proposition (Frege, 1891; Wittgenstein, 1954). On this view, the meaning of a sentence like “The e-mail has not arrived yet” is not that the e-mail we were waiting for is not in our inbox, but that the sentence “The e-mail has arrived” is false. This *logical approach* (i.e., the fact of conceiving negation as a truth-value operator on propositions) successfully solves the ontological impasse due to the absence of real-world referents for negative predicates. Furthermore, it also goes hand in hand with the implicit assumption of a secondary status of negation relative to affirmation, since logical connectives combine - by definition - simple units into complex structures and $\neg p$ is a derivation from *p*.

In the early 1960s negative sentences stopped being an exclusive topic of interest for philosophy and formal theories of meaning, and started receiving attention from cognitive research on language processing (Wason, 1959, 1961, 1965; Eiferman, 1961; Miller, 1962; Wason and Jones, 1963; Gough, 1965, 1966; Slobin, 1966; Wales and Grieve, 1969). Since then, the logical definition of linguistic negation (i.e., an operation on statements) has been taken for granted by most of the studies addressing the cognitive and neural correlates of negative sentence processing (Tettamanti et al., 2008; Bahlmann et al., 2011; Dale and Duran, 2011; Alemanno et al., 2012; Aravena et al., 2012; Hald, 2013; Orenes, Beltràn and Santamarìa, 2014). The approach seemed sensible also in light of the analysis provided by linguistic theory. In some languages negation is indeed grammaticalised via morphological markers (particles (2) or affixes (3)) that are attached to same structure of the corresponding affirmative form (Dahl, 1979; Payne, 1985; Miestamo, 2005).

(2). (Italian, Indo-European, personal knowledge)
Il bambino **non** ha mangiato la frutta
DP$_{SUBJ}$ **NEG** VERB DP$_{OBJ}$
'*The child has not eaten his fruit*'

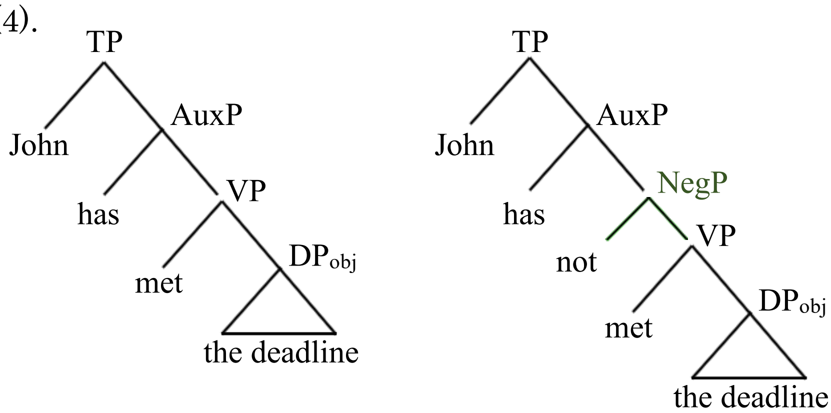
Il bambino ha mangiato la frutta
DP$_{SUBJ}$ VERB DP$_{OBJ}$
'*The child has eaten his fruit*'

(3). (Czech, Indo-European, Miestamo 2017:6)
ne-vol-al
NEGVERB$_{person}$
'*He was not calling/did not call*'

vol-al
VERB$_{person}$
'*He was calling/called*'

As negative particles and affixes are overt markers of *polarity* that are missing in the affirmative forms, in these languages negative sentences appear morphologically marked as compared to their affirmative counterparts. Linguistic theory has assumed that this markedness is pervasive in natural languages and that it is related to an incremental syntactic process which adds a piece of structure (the Negation Phrase, NegP in (4)) to the affirmative version of the sentence (Pollock, 1989; Laka, 1990; Belletti, 1990; Zanuttini, 2001; Khemlani, Orenes and Johnson-Laird, 2012)[3]. On this view, negative sentences formation is basically *logical*, i.e. symmetrical to the mechanism that derives ¬ *p* from *p*.

(4).



The introduction of empirical studies on negation marked a fundamental step in understating our ability to comprehend negative sentences. As it will be discussed extensively in Chapter 1, past research consistently showed that negative sentences increase the difficulty of a behavioral task if compared to their affirmative counterparts. Moreover, the activation of the semantic content in the scope of negation (i.e. 'p' in '¬ p') during the processing of a negated expression was observed in several tasks (Mayo, Schul and Burnstein, 2004; Hasson and Glucksberg, 2006; Kaup, Lüdtke and Zwaan, 2006; Kaup, Lüdtke and Zwaan, 2007). The logical approach was therefore not only strengthened by the data, but also

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[3] The representations via syntactic trees in [iv] are simplifications aimed at stressing the proposed structural asymmetry between affirmative and negative sentences. For an exhaustive introduction to x-bar theory and phrase structure grammar the reader is referred to Harris (1951), Chomsky (1995) and subsequent related works.

extended to a cognitive, 'two-step' model of negation processing (Trabasso, Rollins and Shaughnessy, 1971; van Dijk and Kintsch, 1983; Johnson-Laird, 1983; Zwaan and Radvansky, 1998; Kaup, Lüdtke and Zwaan, 2006; 2007): in other words, it was assumed that the interpretation of a negative sentence is necessarily mediated by the representation of what is negated.

However, the past 120 years of formal theories of meaning and the last 60 years of cognitive research need to face an important aspect of natural languages already raised by Frege: real sentences are not Boolean expressions and the occurrences of negative sentences in everyday communication are not all cases of denial. To make some examples, prohibitions ("Don't park!"), irony ("Kim Jong-Un is not the meekest man on earth") and politeness forms ("The cake was not so bad!") do not mean 'change the truth value of the proposition in the scope of *not*'. Nonetheless, although the marked nature of negation has been taken as a universal feature of natural languages, the 'logical way' is just one of the possible strategies adopted in order to express negation. In some cases, there is no symmetry at all between the affirmative and the negative form (Miestamo 2005, 2017). In others, negation is signaled by changes in verb morphology (Dahl, 1979; Honda, 1996) that do not appear to be more morphologically marked than verbs used in affirmative sentences. Two examples of this last strategy come from Kannada (5) and some super-polite forms of Japanese (6), which express negation on the lexical and the functional morphology of the verb, respectively.

(5). (Kannada, Dravidian language, personal communication)
Bekku meju mele **illa**
DP DP PREP **NEG VERB**
'*The cat is not on the table*'

Bekku meju mele ide
DP DP PREP **AFF VERB**
'*The cat is on the table*'

(6). (Japanese, Japonic language, Nyberg, 2012:17)
sensei ga Mary o mat-are-mas-**en**
DP nom DP acc VERB-..-**tense**$_{\mathbf{NEG}}$
'*The teacher does not wait for Mary*'

sensei ga Mary o mat-are-mas-**u**
DP nom DP acc VERB-..-**tense**$_{\mathbf{AFF}}$
'*The teacher waits for Mary*'

Beyond the inability to account for language use and the typological variation, two important theoretical objections can be leveled against the logical approach to linguistic negation. The first one is well exemplified by sentence (1). If (1) were simply the result of the negation of (1'), then (1') should result from the reverse operation, that is by removing negation from (1).

(1'). Mary wears her Rolling Stones sweatshirt while getting to work on rainy mornings.

(1). Mary does not wear her Rolling Stones sweatshirt while getting to work on rainy mornings.

Nevertheless, (1) has possibly infinite meanings whose negation does not leads to (1') (Wales and Grieve, 1969). Sentences (1.1)-(1.3) below are an example.

(1.1). Mary wears her Rolling Stones sweatshirt while getting to work every morning.
(1.2). Mary wears her Beatles t-shirt while getting to work on rainy mornings.
(1.3). Mary gets to work only on sunny mornings.
…

The second theoretical objection comes from the fact that the meaning conveyed by a negative sentence does not result only in the composition of the meaning of its functional and lexical units. Consider the sentence (7):

(7). I didn't pick up the child from kindergarten!

Sentence (7) does not mean (7.1) nor (7.2):

(7.1). $\neg\exists$ e [pick-up (I, the child, kindergarten, e) $\wedge$ time (e, t)]
'there does not exist a time at which I picked up the child from kindergarten'

(7.2). $\exists$ e [$\neg$pick-up (I, the child, kindergarten, e) $\wedge$ time (e, t)]
'there exists a time at which I did not pick up the child from kindergarten'

It is not the case that I have never picked up my son from kindergarten (which is false), nor do I mean to say that there existed a moment during my lifetime in which I was doing something else (which is trivially true). Sentence [vii] means that there was a time in the past when *I was expected* to pick up my son from kindergarten and I did not. Thus, the correct formalization of sentence (7) meaning is something like (7.3).

(7.3). ∃ e [¬pick-up (I, the child, kindergarten, e) ∧ time (e, t) <u>∧ exp e'[pick-up (I, the child, kindergarten, e)]]</u>

Interestingly, the underlined part of (7.3) is not expressed overtly in sentence (7), but is conveyed by the extra-linguistic context (Partee, 1973). In this view, negation seems to apply to linguistic objects that are made also of *expectations*, more than to pure *propositional contents* (I will return on this in Chapter 1).

The present work integrates cognitive research on negative sentence processing in a twofold way. On one hand it highlights some critical aspects of previous empirical approaches that challenge the logical approach to linguistic negation. On the other hand, it addresses for the first time the comprehension of negative sentences in case of brain injury.

Chapter 1 and 2 provide a critical review of the previous behavioral and neurofunctional literature on negative sentence processing. Two aspects in particular appear critical for the understanding of negative sentence processing:

a) the high probability to confuse task-related effects with true negation effects;
b) the inconclusiveness of previous neuroimaging research, which associated negative sentences either with increased or with decreased BOLD signal as compared to affirmatives.

I addressed these two aspects focusing on the cognitive and neural substrates underlying sentence-picture verification in functional magnetic resonance imaging (fMRI) experiment presented in Chapter 3. Chapter 4 reports data from two studies that investigated sentence-picture verification of affirmative and negative sentences in people with focal and degenerative brain damage.

Chapter 1

A behavioral overview

1. Apology of the *logical approach* to linguistic negation

The analysis of linguistic negation as an operator that applies to sentences has shaped the way cognitive studies on language have addressed negative sentence processing. This approach has been encouraged by three behavioral results in particular:

a) in the experimental environment negation is managed less easily than affirmation (par. 1.1). That is, when people are asked *to do something* with negative sentences, cognitive effort is measurably increased;
b) the so-called *negation-by-truth interaction*, i.e. the fact that, contrary to affirmative sentences, responses to true negative sentences are slower and more error-prone than responses to false negative sentences (par. 1.2);

c) the fact that, in some contexts, negation affects directly the semantic representation of the concept in its scope (par. 1.3).

1.1 Negation is more demanding than affirmation

The very first attempt to address negative sentence processing empirically has been by means of behavioral tasks that required the computation of a truth judgement about sentences. The literature unanimously reports that in this context, negative sentences are associated with longer response times and higher error rates if compared to their affirmative counterparts. After the early works on the completion and construction of true and false statements (Wason, 1959, 1961), *sentence verification* became the leading paradigm in the research on negation processing until the 2000s. In sentence verification tasks participants are asked to judge whether a sentence is true or false relative to a given situation. Both speed and accuracy are lower with negative sentences than with affirmative sentences. This holds regardless of whether the situation given for comparison is provided by a picture (Gough, 1965, 1966; Trabasso, Rollins and Shaughnessy, 1971; Clark and Chase, 1972; Carpenter and Just, 1975; Carpenter et al., 1999; Lüdtke et al., 2008; Kaup, Lüdtke and Zwaan, 2005), by another sentence (Hasegawa, Carpenter and Just, 2002; Christensen, 2009; Bahlmann et al., 2011) or by common world-knowledge (Wason, 1961; Eiferman, 1961; Wason and Jones, 1963; Wales and Grieve, 1969). This effect has been observed also across different manipulations of linguistic variables, such as the place of negation (internal as in "A star is not born" vs. external as in "It is not true that a star is born") and the type of predicate (binary, nominal, event-related or spatial relation). Further evidence of the effort imposed by negation to the verification process was provided by Dale and Duran (2011) who explored the cognitive dynamics of sentence verification via a computer-mouse tracking technique. Participants read simple affirmative and negative statements on world-knowledge (e.g., "Elephants are/are not small") one word a time, in a self-paced reading format. At the top-left and top-right of the interface, two boxes for "TRUE" and "FALSE" judgments were displayed. After the last word of the sentence, participants judged by mouse click on one of the boxes whether the sentence was true or false. The mouse trajectories towards the selected box were analyzed in terms of number of deviations and acceleration/deceleration events, two parameters taken to signal shifts in the dynamics of thought. Response trajectories to negative statements showed more deviations and acceleration/deceleration events as compared to those to affirmative statements, consistent with abrupt changes in the ongoing cognitive process.

Other tasks showed sensitivity to the manipulation of sentence polarity. In MacDonald and Just (1989) participants read at their own pace a stimulus sentence with two direct object phrases. Negation applied either to one of the two direct objects (e.g., "Almost every weekend, Elizabeth bakes *some* *bread* but *no cookies* for the children"/"Almost every weekend, Elizabeth bakes *no bread* but *only cookies* for the children") or to none (e.g., "Almost every weekend, Elizabeth bakes *some bread* and *some cookies* for the children"). After the stimulus sentence, a word corresponding to one of the two direct objects of the sentence (e.g., "cookies"/"bread") was presented. Participants were asked to judge as quickly as possible whether the word had appeared in the preceding statement (exp.1) or to name it aloud (exp. 2). In both tasks, responses to probe words that had been negated in the stimulus sentence were slower than responses to non-negated probes. The same result was found also when nouns semantically related to the direct objects instead of the direct objects themselves were used as probe words (exp. 3). Kaup (1997, 2001) and Kaup and Zwaan (2003) replicated this finding with an experimental design that guaranteed the presence of both the negated and non-negated direct objects in the situation described by the stimulus sentence (e.g. "Elizabeth burns the letters but not the photographs"/"John is building the castle but not the church"). Longer response times and higher errors rates after negative compared to affirmative contexts were found also in lexical decision (Hasson and Glucksberg, 2006; Tomasino, Weiss and Fink, 2010), comprehension (Orenes, Beltràn and Santamarìa, 2014) and probe congruency judgment tasks (Mayo, Schul and Burnstein, 2004).

1.2 The negation-by-truth interaction

In some experimental environments, participants' behavior on true and false sentences changes as a function of sentence polarity. With affirmative sentences, responses to true items are usually faster and more accurate than to false items. By contrast, the reverse pattern is observed with negative sentences – responses to true negative items are slower and more error-prone than to false negative items. This effect was attested for the first time in Wason (1961) via an affirmative-negative sentence construction task. Participants were presented with incomplete statements about numbers of the type "X is/is not an even/odd number". Before the statement, a spoken instruction dictated if the statement had to be true or false, and participants responded by completing the statement with the correct digit. This methodology has been criticized repeatedly (Wales and Grieve, 1969; Horn, 1989). In particular, it has been noted that it is quite unusual and confounding to produce a statement about a "not even" or a "not odd" number when a positive version of both the descriptions ("odd" and "even", respectively) is available and generally adopted. Nevertheless, the negation-by-truth interaction has been observed in two subsequent sentence-picture verification studies (Clark and Chase, 1972; Lüdtke et al., 2008)[4], and has been taken as a substantial confirmation

[4] Two additional studies reported a polarity-by-truth interaction, namely Slobin (1966) and Carpenter and Just (1975), both within a sentence-picture verification paradigm. Nevertheless, since the results are hardly

of the logical approach to negation meaning and the two-step models of negative sentence processing. If it is assumed that negative sentences encapsulate the representation of their scope, false negative items are characterized by a partial match between the meaning of the sentence and that of the picture (see Figure 1.1).

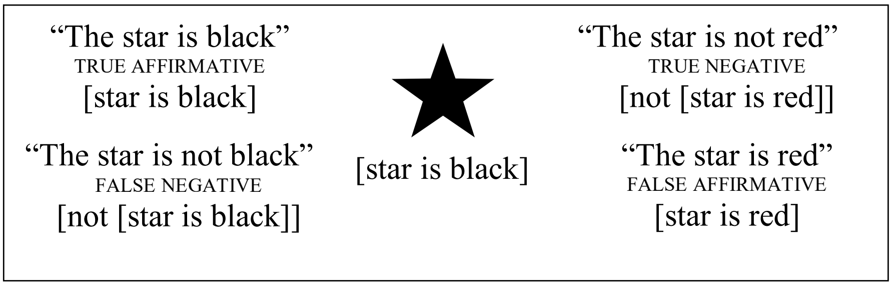

Figure 1.1. Model for sentence-picture verification. For the sake of simplicity, sentences and pictures are coded in terms of elementary propositions (Clark and Chase, 1972).

As exemplified in Figure 1.1, there is a match in the case of true affirmatives and false negatives, and a complete mismatch in true negative and false affirmative items. The complete or partial meaning overlap should facilitate the

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interpretable for the purpose of the present discussion, I will not address them in detail. In Slobin (1966) almost half of the stimulus sentences and thus of the corresponding pictures were odd (e.g. "The flower are/are not watering the girl"). Carpenter and Just (1975) used external negation (e.g. "It is true/not true that ..."), a syntactic structure that forces the interpretation of negation as a tag.

sentence-picture comparison. The negation-by-truth interaction follows from true affirmative and false negative items thus being putatively easier to process than false affirmative and true negative items, respectively.

1.3 Negation entails affirmation

MacDonald and Just (1989), Kaup (1997, 2001) and Kaup and Zwaan (2003) interpreted their results (i.e., the fact that responses to probe words that had been negated in the stimulus sentence were slower than responses to non-negated probes) as consistent with the view that the negation marker reduces the level of activation of the negated concept. This conclusion is questionable. On one hand, the paradigms adopted by these authors did not allow exploring the representation constructed while processing negation (Giora et al. 2004; Giora et al., 2007; Hasson and Glucksberg, 2006). Furthermore, subsequent work revealed that, at some stages of sentence processing, the core meaning in the scope of negation may be active (Mayo, Schul and Burnstein, 2004; Giora et al., 2004; Hasson and Glucksberg, 2006; Kaup, Lüdtke and Zwaan 2007; Orenes, Beltràn and Santamarìa, 2014).

Mayo, Schul and Burnstein (2004) presented participants with a positive or negative description of a person, followed by a probe that attributed a particular behavior to that person. The task required to judge whether or not the probe was congruent with the description. Each trial started with a string of X's shown on a computer screen for 200 ms, followed by a description (e.g., "Tom *is/is not* a tidy person"). When participants pressed a key, the description was replaced by the probe. The probe could be *congruent* with either the positive (e.g., "Tom's clothes are folded neatly in his closet") or the negative version of the description (e.g., "Tom forgets where he left his car keys"), or irrelevant to both (e.g., "Tom likes to have long conversations on the phone"). Clearly, the probe congruent with the positive description was incongruent with the negative description, and vice versa. Interestingly, while responses after positive descriptions were facilitated by congruent probes (i.e., "Tom's clothes are folded neatly in his closet" were judged faster than "Tom forgets where he left his car keys" after the description "Tom is a tidy person"), responses after negative descriptions were facilitated by incongruent probes (i.e. "Tom's clothes are folded neatly in his closet" were judged faster than "Tom forgets where he left his car keys" after the description "Tom is not a tidy person"). In other words, negative descriptions primed the same semantic content as their positive counterparts. This result suggested that the positive content in the scope of negation (e.g., 'tidy person' in "Tom is not a tidy person") is somehow part of the interpretation process of negative sentences.

The result was partially replicated by Giora et al. (2004) and Hasson and Glucksberg (2006) within a lexical decision paradigm. In the first study, participants were presented with short affirmative and negative sentences (e.g., "The instrument is/is not sharp") and they pressed a key after reading. 100 ms after sentence offset, a letter string was displayed, and participants judged by button press whether or not it made up a word. When the letter string made up a word, this was either related to the property mentioned in the sentence (e.g., 'piercing') or not (e.g., 'leaving'). Results showed that both affirmative and negative sentences (e.g., "The instrument *is/is not* sharp") primed related probe words (e.g. "piercing"). Nevertheless, since probe words were lexically related to the predicate of the stimulus sentence, lexical priming could have played a confounding effect. To rule out this possibility, Hasson and Glucksberg (2006) adopted metaphorical statements as stimulus sentences (e.g. "This kindergarten *is/is not* a zoo"). This allowed using probe words related to the metaphorical meaning of the stimulus sentence (e.g. "calm"/"noisy"), and not to its lexical entries. The experimental design was the same adopted by Giora et al. (2004), except for the delay between sentence offset and probe onset, which was 150, 500 or 1000 ms (manipulated across subjects). In contrast to Giora et al. (2004), at a very early stage of processing (150 ms from sentence offset) negative stimulus sentences did not prime related-to-affirmative probes. The facilitation effect appeared only 500 ms after sentence offset and it disappeared later on. Finally, Kaup, Lüdtke and Zwaan (2007) presented participants with negative sentences of the type "There was no X in Y" (e.g., "There was no eagle in the sky") paired with probe pictures that either matched or not the implied shape of the object X in the context Y (e.g. an eagle with its wings outstretched vs. an eagle with its wings folded in). Participants pressed a key after reading the sentence, and the picture appeared after a 250 ms fixation point. The task required to determine whether or not the pictured object had been mentioned in the sentence. Responses were significantly faster and more accurate when the object in the picture had the shape implied by the negated content (e.g., an eagle with its wings outstretched after the sentence “There was no eagle in the sky”).

The content in the scope of negation is clearly active also in sarcasm and politeness negative forms (Colston, 1999; Giora et al., 2004; Giora et al., 2005; Giora, 1995; Giora et al. 2013). Sarcastic negative sentences are negation of an overstatement (e.g., “You are not extremely intelligent” said to someone who made a trivial mistake), while negative politeness forms are negated periphrases that people prefer to more direct (and less complex) affirmative forms when they want to be kind and tactful (e.g., “It was not incredible”, “They are not so boring”). In both cases, the interpretation process needs the meaning expressed by the negated content (i.e., ‘being extremely intelligent/incredible/boring’) in order to formulate the final meaning of the negative expression. This will result from a modulation of the negated content into a concept that stands between it and its antonym (e.g., extremely *intelligent* > final meaning > *stupid*, *incredible* > final meaning > *mediocre*, *boring* < final meaning < *interesting*).

Overall, these findings are compatible with the view that the representation of the negated state of affairs (i.e., the content in the scope of negation) is part of the default processing of the negative sentence and temporally precedes the stage at which negation is elaborated. Nevertheless, further results have shown that the negated state of affairs is not a necessary part of negative sentence interpretation (see par. 2.1), and that negation is immediately incorporated into processing (see Chapter 3, par. 1).

2. Negation in Language

In light of the results summarized in the previous paragraphs, it has been generally assumed that the core of negative sentence processing lies in the representation of the content in the scope of negation. In particular, a large group of theories (such as the *discourse-representation theory*, the *two-step simulation hypothesis*, the *search-for-alternatives* account) suggests that negation operates as an 'a posteriori' tag on the negated situation (Trabasso, Rollins and Shaughnessy, 1971; Clark and Chase, 1972; Kamp, 1981; van Dijk and Kintsch, 1983; Johnson-Liard, 1983; Kintsch, 1988; MacDonald and Just, 1989; Zwaan and Radvansky, 1998; Kaup and Zwaan, 2003; Kaup, Lüdtke and Zwaan, 2006; Kaup, Lüdtke and Zwaan, 2007). On this view, the interpretation process starts with the representation of the negated situation, followed by a shift of focus to an alternative (the 'actual') state of affairs.

The assumption that the interpretation of a negative sentence is necessarily more complex than (and mediated by) the interpretation of its affirmative counterpart is coherent with the behavior observed when negative sentences are managed in the experimental environment. Nevertheless, two important aspects differentiate negative from affirmatives sentences and may have influenced behavioral data on negative sentence processing.

Firstly, negative sentences are strongly *context-dependent*, i.e. they are never uttered out of context, for the mere purpose of introducing a piece of information about the world, as exemplified by sentences [vii] and [viii]. While [vii] could be appropriate is several contexts (e.g., after a solid week of rain, or in Thailand during the monsoons), it is quite sure that statements like [viii], albeit unquestionably true, have never been made entering the office in the morning:

vii. It is not raining today.
viii. The Mad Hatter is not on my desk.

This is because speakers are expected to produce informative and relevant utterances. To accomplish a communicative act, utterances must be as adequate as possible (Grice, 1975; Allwood, 1977; Levinson, 2000). Affirmative sentences meet this requirement just by being true (as in example [vii]), whereas negative sentences need to be both true and non-obvious or non-trivial. More precisely, while affirmative sentences may simply introduce a piece of information into the discourse context, negative sentences are uttered appropriately when they deny something that is taken for granted (Allwood, 1977; Givón, 1978; Horn, 1978; Glenberg et al., 1999). The object of the denial can be an explicit, previously uttered proposition, or an implicit assumption about the world. Sentence [viii] is indeed odd because none would expect to find the Mad Hatter sitting on his desk.

The *context-dependent* nature of negative sentences suggests that if context is insufficient and/or inappropriate, negative sentences are odd and uninformative, and their interpretation demanding. Some studies indeed show that when the context sensitivity of negation is taken into account by the experimental design, the behavioral patterns of affirmative and negative sentences tend to align (par. 2.1).

A second aspect that distinguishes affirmation from negation in language is the fact that while affirmative sentences easily identify a single state of affairs, negative sentences lead to a proliferation of possible worlds. A sentence like "Mary has not bought a complete tea set" results in many – possibly infinite – representations, at least as regards the cardinality of the tea set. In the experimental paradigms presented so far, subjects were forced to build a representation of sentence meaning, which they had to compare to a background situation. As a consequence, the observed behavioral asymmetry between affirmation and negation may be due to an imbalance of the environment created by the experimental stimuli, rather than to a greater complexity of negative sentences. These considerations will be expanded in paragraph 2.2.

2.1 Counter-evidence to 1.1 and 1.3

It has been observed that when negative sentences are introduced by a supporting context, some measures of cognitive effort align to those obtained for affirmative sentences. Glenberg et al. (1999) and Lüdke and Kaup (2006) presented participants with a short story which may or may not provide presuppositions in support of an affirmative or negative target sentence, as shown in [ix] (taken from Glenberg et al., 1999).

> ix. CONTEXT: "Marcy needed a new couch for her family room. (SUPPORTING) *She wasn't sure if a darkly coloured couch would look best or a lighter colour. /* (NON-SUPPORTING) *She wasn't sure what kind of material she wanted the couch to be made of.* She finally picked one out and had it delivered to her home.
>
> TARGET SENTENCE: "The couch *was* black. It looked very nice in her family room."/"The couch *wasn't* black. That probably would have been too dark."

The authors found that with a supporting context, reading times for affirmative and negative target sentences did not differ. Also in Dale and Duran (2011) (see par. 1.1) introducing a supporting context before the stimulus sentences erased the difference between mouse trajectories to affirmative and negative sentences.

Moreover, when the experimental design allows negative sentences to be informative and their meaning to be easily identifiable, the traces of the negated content disappear (Fillenbaum, 1966; Mayo, Schul and Burnstein, 2004; Kaup, Lüdtke and Zwaan, 2005; Kaup, Lüdtke and Zwaan, 2006; Tian et al., 2010; Orenes, Beltràn and Santamarìa, 2014; Orenes et al., 2016; see also Wason, 1965; Nordmeyer and Frank, 2015; Ghiora, 2016). Evidence consistent with this view was first provided by Fillenbaum (1966), who observed that negative statements with contradictory predicates (e.g. "The door is not open") were more likely to be incorrectly recalled as their respective antonym (i.e. "The door is closed") rather than as their affirmative counterpart (i.e. "The door is open"). The result has been substantially replicated in different experimental contexts.

Kaup, Lüdtke and Zwaan (2006) used a probe-recognition task with contradictory predicates (e.g. "The door is/is not open") and pictures that may or not match the state of affairs expressed by the sentence (e.g. a closed/open door). Participants read silently a sentence at their own pace, then pressed a key. A fixation point appeared for 750 or 1500 ms, followed by a picture. Participants were asked to name the object in the picture as quickly as possible. With a 750 ms delay, the picture type had no effect on response times to negative sentences. In the 1500 ms delay condition, responses to negative sentences (e.g., "The door is not open") were faster when followed by a matching picture (e.g., a closed door) compared to mismatching pictures (e.g., an open door). Thus, the representation of the negated state of affairs (e.g., an open door with the sentence "The door is not open") did not facilitate performance on negative sentences. The same result was found in Kaup, Lüdtke and Zwaan (2005) with stimuli that expressed spatial relations. Participants read a sentence of the type "The X is/is not above/below the Y", then pressed a key and a picture was presented with a delay of either 0 or 15000 ms. The picture may represent both the objects mentioned in the sentence, one object that was mentioned and one that was not, or two objects not mentioned in the sentence. In the first case, the objects were represented either in the same spatial relation expressed by the sentence or in the reverse relation. Participants were asked to judge whether the objects presented in a picture had been mentioned in the sentence. Again, response times to negative sentences did not show a main effect of picture type. In other words, after a sentence like "The X is not above the Y", similar RTs were recorded in response to pictures that represented the actual state of affairs (i.e., an Y above an X) and pictures that represented the negated state of affairs (e.g. an X above an Y).

Very similar results were reported in the second experiment by Mayo, Schul and Burnstein (2004). The experimental design was the same as in the first experiment (see 1.3), except that this time person descriptions were made by bi-polar adjectives, i.e. adjectives that contrary to uni-polar ones (e.g., 'creative', 'adventurous', 'charismatic') have a well-defined opposite (as 'rich'/'poor', 'warm'/'cold', 'strong'/'weak'). With bi-polar adjectives, responses after negative descriptions showed the same pattern as responses after affirmative descriptions, namely a facilitation effect for congruent probes against incongruent ones (e.g., after the description "Tom is not a rich person", "Tom does not go on holiday" was judged faster than "Tom has dinner in expensive restaurants").

Bi-polar predications were investigated also by Orenes et al. (2016) via the visual world paradigm. Eye-movements are an index of the ongoing cognitive process (Cooper, 1974; Tanenhaus et al., 1995). In particular, it has been observed that if language processing is accompanied by pictures, the eyes move towards the objects that have been mentioned (Tanenhaus et al., 1995). In the study by Orenes et al. participants were presented with affirmative and negative sentences that contained bi-polar adjectives (e.g., "Her dad was/was not rich") while viewing two images that may or may not match the description (e.g., a rich man or a poor man). Moreover, stimulus sentences were introduced by a context that could be consistent, inconsistent or neutral relative to the description. The authors found that, with negative sentences (e.g., "Her dad was not rich") the fixation time on matching images (e.g. a poor man) was significantly longer when the sentence had been introduced by a consistent context than when the sentence had been introduced by an inconsistent or neutral context.

Another interesting contribution comes from Orenes, Beltràn and Santamarìa (2014), who explored the role of the negated argument during negative sentence interpretation via eye tracking. Participants were presented with a spoken preamble that introduced a binary or a multiple context (e.g., "The figure could be *red or green/red or green or yellow or blue*). The preamble lasted 3500 ms and was followed by a display with four colored figures, that was shown for 5500 ms. After one second of display preview, participants listened to a sentence that mentioned one of the colors either in the affirmative or in the negative form (e.g., "The figure *was/was not* red"). The analysis of eye-movements to negative sentences revealed that participants focused on the negated argument in the multiple context, but moved their gaze toward the alternative in the binary context.

2.2 A closer look at the negation-by-truth interaction

Of particular relevance for the present work is the paradigm developed by Lüdtke et al. (2008). Stimuli are reported in Figure 1.2. It should be noted that the pictures presented in true negative items are somehow similar to the state of affairs negated by the sentence. In particular, the negation scopes over the predicate "to be in front of the tower", and the picture actually represents the state of being in front of the tower. To respond, the participant is induced to a potentially misleading comparison between a negative sentence predicating that a state of affairs is different from being [p] (with p = [to be in front of] + [tower] + [ghost]) and a picture that actually is almost [p] (namely, [to be in front of] + [tower] + [lion]). The same consideration applies to Clark and Chase (1972), who adopted only stimulus sentences with above/below predications ("The X *is/is not above/below* the Y") accompanied by pictures that varied only relative to the vertical axis, namely representing either an X above an Y or an Y above an X.

Sentence	*Picture*	*Condition*
In front of the tower there is a ghost.		True
In front of the tower there is a ghost.		False
In front of the tower there is no ghost.		True
In front of the tower there is no ghost.		False

Figure 1.2. The stimulus adopted by Lüdtke et al. (2008).

The hypothesis that also the *negation-by-truth interaction* effect may be due to task-related issues will be tested in the present study, via an experimental design that tries to overcome some limitations of previous approaches.

3. Interim summary

However intuitive the logical approach to linguistic negation may be, a more in-depth analysis suggests that negative predications are a complex phenomenon which requires careful empirical approaches. Overall, behavioral data collected so far showed that the interpretation of negative sentences is more cognitively demanding than that of their affirmative counterparts, especially when the experimental environment does not provide the adequate context for its interpretation. Moreover, the intermediate representation of the negated concept postulated by the logical approach and the two-step model could represent a task-related effect or a processing step restricted to specific negative forms (e.g., uni-polar predications), rather than the default strategy of negation processing. The study presented in Chapter 3 tests whether even the *negation-by-truth interaction* effect may be ascribed to the task design of previous sentence-picture verification experiments.

Chapter 2

A neurofunctional overview

The study of the neural correlates of negation has followed a path similar to that of the behavioral literature on the same issue. Three main research areas can be identified:

a) studies (essentially based on ERPs) that investigated whether or not negation is processed in a two-step fashion that entails processing the affirmative counterpart (par. 1);
b) fMRI studies supporting the view that comprehending negation is associated with increased processing demands as compared to affirmation (par. 2);
c) studies addressing the effect of negation on semantic representations (par. 3).

1. Testing the two-step model

Event-related potentials (ERPs) are changes in the electrical activity of the brain, that follow specific events or stimuli. In the context of negative sentence processing, studies using the ERP technique have focused on the analysis of the N400 component, a negative event-related potential elicited by content words both in isolation and in sentential context, taken to reflect access to a word's meaning (Kutas and Federmeier, 2000; Lau, Phillips and Poeppel, 2009). The N400 appears between 200 and 600 ms, and peaks around 400 ms after stimulus onset. Its amplitude is inversely modulated by both predictability and context-congruency: the more a target word is predictable by or congruent with a given context (e.g., the sentence), the smaller the N400 amplitude (Federmeier and Kutas, 1999; Hagoort et al., 2004).

Early ERP studies investigated the N400 elicited by the final world of congruous and incongruous affirmative and negative statements (Fischler et al. 1983; Katayama, Miyata and Yagi, 1987; Kounios and Holcomb, 1992). Participants read common-knowledge statements that were either congruous (e.g., "A robin is a bird"/"A robin is not a tree") or incongruous (e.g., "A robin is a tree"/"A robin is not a bird") and were asked to judge whether the statement was true or false. Differently to affirmatives, in negative sentences the final word of semantically congruous stimuli (e.g., "A robin is not a tree") elicited a greater N400 than the final word of semantically incongruous stimuli (e.g., "A robin is not a bird"). This result was deemed consistent with the possibility that, at very early stages of lexical-semantic processing, the negative marker does not affect the electrical activity of the brain, nor the evaluation of the congruency of the target word. Lüdtke et al. (2008) replicated the result with the sentence-picture verification paradigm outlined in Chapter 2 (see par. 2.2). Participants read the target sentence word-by-word. Each word was presented for 300 ms and followed by a 300 ms pause. After the final word, a fixation cross appeared for 250 ms (short delay condition) or 1500 ms (long delay condition). Then the picture was presented for 250 ms and participants indicated whether it was true or false with regard to the sentence. As shown in Figure 1.2, the picture was primed by the sentence in the case of true affirmative and false negative statements (e.g., "In front of the tower there is a/no ghost" + the picture of a ghost in front of a tower) but not in the case of true negative and false affirmative statements (e.g., "In front of the tower there is a/no ghost" + the picture of a lion in front of a tower). In both delay conditions, primed items (true affirmative and false negative) were associated with smaller N400 amplitudes than non-primed items (true negative and false affirmative).

This 'insensitivity' of the N400 to the presence of negation has been taken to show that negation is not integrated immediately during sentence interpretation, but only after some representation of the negated concept has been activated.

In contrast with these findings, Nieuwland & Kuperberg (2008) showed that if negative sentences are licensed by a pragmatic context, the N400 is sensitive to negation. In this study, affirmative and negative sentence stimuli were preceded by a preamble that either created or prevented a licensing context for negation. Participants silently read the stimuli word-by-word. The presentation time of each word was set according to the formula '(number of letters × 27 ms) + 187 ms', and was followed by a 121 ms pause. After the final word, a 500 ms pause was added, followed by a blank screen for 1000 ms. Participants' attention to sentences was ensured via a lexical decision task: after the blank, a word was presented, and participants indicated by button-press whether or not the word was conceptually related to the preceding sentence. The critical words for the N400 analysis are underlined in the example in Table 2.1.

Condition	*Example sentence*
Pragmatically licensed negation	
True affirmative	With proper equipment, scuba-diving is very <u>safe</u> and often good fun.
True negative	With proper equipment, scuba-diving isn't very <u>dangerous</u> and often good fun.
False affirmative	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 negation	
True affirmative	Bulletproof vests are very <u>safe</u> and used worldwide for security.
True negative	Bulletproof vests aren't very <u>dangerous</u> and used worldwide for security.
False affirmative	Bulletproof vests are very <u>dangerous</u> and used worldwide for security.
False negative	Bulletproof vests aren't very <u>safe</u> and used worldwide for security.

Table 2.1. Example sentences of Nieuwland & Kuperberg (2008).

In the pragmatically licensed context, the N400 amplitude elicited by critical words was larger for false affirmative and false negative sentences compared to true affirmative and true negative sentences. By contrast, in the unlicensed context amplitude was larger for false affirmative, false negative and true negative sentences than for true affirmative sentences. Similar results were obtained by Staab et al. (2008) in a sentence verification experiment. Participants were presented with a preamble that remained on-screen until key press (e.g., "During his long flight Joe needed a snack. The flight attendant could only offer him pretzels and cookie."). Immediately after key press, the continuation of the story appeared (e.g., "Joe wanted something *salty/sweet*, so …") and remained on-screen until the next button press. After a 200 ms blank screen, the final sentence of the story (e.g. "he *bought/didn't buy cookies/pretzels*") was presented one word at a time with a word duration of 200ms. Participants were asked to judge whether the final sentence was consistent with the preceding context. Negativity was greater for false than for true final sentences, even though the effect reached significance only for affirmative sentences.

Recent ERP studies on word prediction have shown that even prominent and unambiguous linguistic information such as word order may not immediately affect event-related responses (Chow & Phillips, 2013; Chow, et al., 2016; Chow et al., 2018). For example, in verb final constructions like [ix] and [x], the verb elicits the same N400, even if it is more predictable when the subject is "cop" than when it is "thief" (Chow et al., 2018).

ix. jingcha ba xiaotou zhua-le
cop BA thief arrest
'The cop arrested the thief'

x. xiaotou ba jingcha zhua-le
thief BA cop arrest
'The thief arrested the cop'

These results suggest that the N400 may follow lexical association more than higher-level computations. N400 amplitude modulation is therefore not a good predictor of the time window at which the negative particle is integrated during interpretation.

The two-step model was recently challenged by the first experiment of a transcranial magnetic stimulation (TMS) study by Papeo, Hochmann and Battelli (2016). Several studies showed that the motor portion of the left precentral gyrus (LPCG) is recruited in the earliest stage of semantic access during action-related words processing (Papeo et al., 2014). Papeo, Hochmann and Battelli (2016) measured LPCG activity when reading affirmative and negative sentences to investigate whether and when negation changes the neural representation of word meaning. Stimuli consisted of simple affirmative and negative first-person sentences describing a manual action (e.g., "Now I write"/"I don't write") or a psychological state (e.g., "Now I wonder"/"I don't wonder").

Since the experiment was run in Italian, which is a null-subject language, the subject was omitted in both the affirmative and the negative form (e.g., "Ora/Non scrivo/mi stupisco"). Stimulus presentation began with the adverb ("Ora/Non", *'now/don't'*) presented for 250 ms, followed by a 200 ms blank and then by the verb, presented for 700 ms. TMS was delivered over the left precentral gyrus, and the activity of the muscle responding to the stimulated area (the right first dorsal interosseous, rFDI) was recorded via motor-evoked potentials (MEPs). MEP amplitude with action verbs was modulated by polarity already at 250 ms after word onset (the effect is addressed in detail in par. 3 of the present chapter), suggesting that negation is integrated at an early stage during semantic processing.

2. Negation increases the computational load

The fMRI technique measures the blood flow to brain regions as a function of the neural activity in those regions (Turner and Jezzard, 1994). Blood flow is measured using blood oxygenation level-dependent (BOLD) contrast. Early fMRI studies on negative sentence processing adopted a sentence verification paradigm. They found increased activation with negative stimuli in the left superior and middle temporal gyrus (Carpenter et al, 1999; Hasegawa et al., 2002), two brain areas typically engaged by complex linguistic structures (Just, Carpenter and Keller 1996). Similar results were obtained by two subsequent fMRI studies using similar paradigms (Christensen, 2009; Bahlmann et al., 2011). These observations were interpreted as showing that processing negative sentences poses greater computational demands than processing affirmatives.

Carpenter et al. (1999) used affirmative and negative sentences in spatial relations of the type "It *is true/is not true* that the star is above the plus". Participants read the sentence, then pressed a button to get to the picture (e.g., a star above or below a plus sign) and were asked to judge by button press whether the sentence was true or false relative to the picture. The functional activation was assessed in two major regions of interest (ROIs), one including the posterior superior and the middle temporal gyrus, the other including the superior parietal lobule, the posterior supramarginal gyrus and the angular gyrus. Functional images were acquired during three acquisition intervals with a mean elapsed time of 940 ms (defined "sentence processing phase"), 2440 ms (defined "picture processing phase") and 3940 ms from the sentence onset. BOLD signal changes were significantly larger in the negative than in the affirmative condition in the left temporal and left parietal ROIs during sentence processing, and in the right and left parietal ROIs during picture processing.

Stimulus sentences with external negation were adopted by Bahlmann et al. (2011), but in stimuli that also contained an affirmative or negative subordinate clause (e.g., "It *is true/is not true* that Peter *visited/did not visit* Hans"). Thus, four sentence types were tested: double affirmation, single negation in the main clause, single negation in the subordinate clause and double negation. The experiment was run in German, where double negation is used quite frequently, and is interpreted as an affirmation. Sentences were presented phrase-by-phrase, each phrase being shown at the center of the screen for 800 ms (+200 ms blank). After the last phrase, an ISI of 3000 ms intervened, followed by a target sentence. Participant judged via button press whether the target sentence was true or false relative to the stimulus sentence. Negative sentences were associated with higher hemodynamic responses in left inferior frontal gyrus and left inferior parietal lobule.

Hasegawa et al. (2002) tested Japanese speakers with moderate fluency in English in a probe-to-target task with Japanese and English sentences. Participants read a two-clause target sentence (e.g., "The worker read a magazine and showed some pictures to the brother") followed by a one-clause probe sentence (e.g., "The worker read a magazine"), and judged whether the probe was true or false relative to the target. Negation could apply to either the first or the second clause of the target sentence (e.g., "The worker read a magazine and didn't show the pictures to the brother"/"The worker didn't read a magazine and showed some pictures to the brother"). The functional activation was assessed in three main ROIs. The fronto-temporal ROIs included the superior and middle temporal gyrus and the pars opercularis and triangularis of left inferior frontal gyrus. The parietal ROI included the angular and supramarginal gyrus. Other ROIs included the superior portion of the precentral sulcus and its posterior branches, the juxtaparacentral lobule and, bilaterally, Heschl's gyrus. Negative sentences correlated with larger volume and higher intensity of BOLD signal changes in left temporal regions, but only for English.

Christensen (2009) adapted the experimental design of Hasegawa et al. (2002) to a monolingual study on Danish. Affirmative and negative target sentences were presented visually for 5000 ms, followed after a 1000 ms pause by affirmative or negative probes for 3000 ms. Participants judged within the 3000 ms whether the probe was true or false relative to the target. Imaging data were recorded only during the presentation of the target sentences. The negative>affirmative contrast showed activation in a cluster with local maxima in the left premotor cortex, whereas the affirmative>negative contrast showed activation in the bilateral anterior and posterior cingulate and in the right supramarginal gyrus. The working memory engagement was attributed to additional syntactic computation imposed by negative sentences.

A very important issue in the neuroimaging studies presented so far lies in the choice of sentence stimuli. Whether sentences like "It *is true/is not true* that …" adopted in Carpenter et al. (1999) and in Bahlmann et al. (2011), contrast affirmation versus negation rather than truth versus falsity predication is open to question. Moreover, subjects were asked to decide if a sentence was *true* or *false*. Thus, they had to judge true states of affairs as false (if X is true, the sentence

"It is not true that X" is false), and false states of affairs as true (if X is false, the sentence "It is not true that X" is true). Therefore, the experimental paradigm was strongly biased against correct responses to negative sentences. This may have affected Bahlmann's results, as sentence processing and sentence verification stages were not kept distinct in the analysis. The paradigm adopted by Hasegawa et al. (2002) was also unbalanced, as affirmative target sentences were followed by affirmative probes only, whereas negative target sentences were followed by either negative or affirmative probes. This drawback is not present in Christensen (2009), who however found stronger activations to negation than to affirmation in areas involved in rule-based and cognitive manipulation of representations, but not in those typically engaged by complex sentence processing.

3. Negation reduces access to semantic information

Tettamanti et al. (2008) and Tomasino, Weiss and Fink, (2010) conducted studies with simple affirmative and negative action-related sentences. They found an activation pattern opposite to that presented in par. 2, namely an overall *decrease* of the BOLD signal with negative compared to affirmative sentences in brain areas commonly engaged by action-verb processing (Hauk, Johnsrude and Pulvermüller, 2004; Tettamanti et al., 2005; Tomasino et al., 2008). They proposed that the effect of sentential negation on sentence processing consisted of *reduced access* to semantic information, more than increased processing load.

Tettamanti et al. (2008) adopted a passive listening paradigm with a 2x2 factorial stimulus design, the two factors being sentence polarity (affirmative or negative) and predicate type (abstract or action-related). The four experimental conditions were: action-related affirmative sentences (e.g. "Now I push the button"), action-related negative sentences (e.g. "Now I do not push the button"), abstract affirmative sentences (e.g. "Now I appreciate the loyalty"), abstract negative sentences (e.g. "Now I do not appreciate the loyalty"). Sentences were spaced by a varying period of silence, so that each stimulus lasted 4000 ms. Stimuli were presented auditorily in 9 separate sessions of 26/27 stimuli each. Immediately after fMRI data acquisition, participants were asked to recall as many sentences or parts of sentences as possible. While no greater signal was found for negative compared to affirmative sentences, affirmative sentences were associated with increased brain activity as compared to negative sentences in the right middle frontal and occipital gyrus and in the left pallidum. More in detail, activation was greater for affirmative than for negative action-related sentences in the left inferior frontal gyrus (pars opercularis and triangularis), the left inferior parietal lobule and the left posterior inferior temporal gyrus. These activations fall within the network involved in the execution/observation of the corresponding actions. Since the same network showed greater BOLD signal changes in response to action-related than abstract sentences (Tettamanti et al. 2005), Tettamanti et al. (2008) proposed that negation reduces access to the motor component of the semantic representation engaged by action-sentence processing.

The study by Tettamanti et al. (2008) was run in Italian, a null-subject language that omits subject pronouns (especially first-person pronouns), unless specific pragmatic requirements are to be met. The unmarked way to express a first-person action or state in Italian is thus [xi], whereas [xii] is a marked structure, used to highlight the subject.

xi. Ora premo il bottone
ADV VERB1**st-person-sing** DPobj
'Now I push the button'

xii. Ora io premo il bottone
ADV PRONsubj VERB1**st-person-sing** DPobj
'Now ***I*** *push the button'*

In order to control for the unavoidable length imbalance introduced by negation (negative sentences have necessarily an extra word), Tettamanti and colleagues contrasted affirmative sentences of the type [xii] (i.e., with overt subject pronoun) with negative sentences of the type [xi] (i.e., with omitted subject). As a consequence, stimuli were pragmatically unbalanced, as affirmative sentences were topicalized structures (i.e., they were appropriate in contexts where the speaker wishes to put the stress on the subject), whereas negative sentences were neuter, unmarked statements. Nevertheless, results were confirmed by

Tomasino, Weiss and Fink, (2010) who ran the study in English, circumventing the difference in the number of words by using imperatives, which require the auxiliary in both the affirmative and the negative form. Participants silently read affirmative and negative action-related imperatives (e.g., "*Do/Don't* grasp!") interspersed with affirmative and negative meaningless sentences with pseudo-verbs (e.g., "*Do/Don't* gralp!") and decided whether or not the sentence made sense by pressing a pedal with their foot. Functional activation was assessed in the left and right primary motor cortex and in the left and right premotor cortex. All ROIs showed deactivation in the negative compared to the affirmative form of action verbs.

Comparable results were obtained by Foroni and Semin (2013) and Papeo, Hochmann and Battelli (2016) who addressed the effect of negation on the neural activity of the motor system with different techniques. Foroni and Semin (2013) measured the activity of the left zygomatic muscle during the reading of affirmative and negative statements on emotional states. The emotional state either involved the relevant facial muscle (e.g., "I *am/am not* smiling") or not (e.g., "I *am/am not* frowning"). Following a 500 ms fixation point and a 3000 ms baseline interval, the stimulus sentence was presented for 4000 ms. After a 500 ms interval, an arrow appeared at the center of the screen and the participant reported whether it pointed left or right. Zygomatic muscle activity was measured continuously. Mean activity over a 500 ms period before stimulus presentation was considered as the baseline. Relevant affirmative sentences activated the zygomatic muscle significantly more than their negative counterparts.

Papeo, Hochmann and Battelli (2016) measured motor excitability/inhibition during affirmative and negative sentence reading in two TMS experiments. In both experiments participants read word-by-word affirmative and negative sentences describing a hand action or a psychological state (see par. 1 of the present chapter), while TMS was delivered over the left precentral gyrus, and the activity of the rFDI was recorded via MEPs. In Experiment 1, TMS was delivered 200 ms after adverb onset ("Ora/Non") and at 250, 400 or 550 ms after verb onset. In Experiment 2, TMS was delivered 200 ms after adverb onset and 250 ms after verb onset, and participants were instructed to maintain the rFDI muscle contracted throughout the experiment. This offered a measure of the inhibitory activity of the motor cortex: indeed, when a muscle targeted by TMS is contracted voluntarily, the MEP is followed by a suppression of EMG activity, whose duration correlates positively with the activity of GABAergic inhibitory neurons. Results of Experiment 1 showed that the motor excitability (i.e., the MEP amplitude) of the rFDI muscle for action verbs was lower in the negative than in the positive context. Experiment 2 showed that also the inhibitory activity of the motor cortex is modulated by polarity, and in particular that it is reduced in positive compared to negative contexts.

3.1 Some puzzling issues posed by the reduced access hypothesis

The *reduced access hypothesis* is questionable. Firstly, the inhibition exerted by negation on the semantic content in its scope is not supported by behavioral studies (see Chapter 1, par. 1.3). Secondly, the functional results provided so far are contrasting.

Alemanno et al. (2012) measured via electroencephalography (EEG) the activity of the motor cortex during silent reading of affirmative and negative sentences with hand-action verbs (e.g., "I brush/do not brush"). The analysis was performed on the event-related desynchronization (ERD) of the μ rhythm. The ERD is defined as an amplitude decrease compared to a resting state. It is associated with activation of the corresponding cortical areas involved in sensory or cognitive information processing. ERD decreases when a task requires increasing processing resources (Neuper et al., 2005). In Alemanno et al. (2012) hand-action related sentences induced a greater μ ERD over the left premotor and motor hand areas than abstract sentences. Moreover, desynchronization was greater and occurred at a later time window when hand-related verbs were presented in the negative vs. affirmative form, suggesting that negation induces a greater cortico-thalamo-cortical neuronal activity. Similar results were obtained by Liuzza et al. (2011), who measured the reactivity of the motor system during the reading of affirmative and negative, hand action-related sentences. They applied paired-pulse TMS to the left motor cortex and recorded MEP amplitude from the FDI in healthy participants who silently read affirmative and negative hand action-related and abstract sentences (e.g., "I *dream/do not dream* the peace"/"I *squeeze/do not squeeze* the lemon"). Differently to negative hand action-related sentences and affirmative abstract sentences, affirmative hand action-related sentences suppressed cortico-spinal reactivity. Finally, Aravena et al. (2012) investigated language-induced motor activity via a grip-force sensor held by participants during passive listening. Affirmative and negative sentences were presented auditorily via headphones to participants who held a grip-force sensor with the thumb, index and middle fingers of their right hand. All the verbs in stimulus sentences denoted actions performed with the hand or arm (e.g., "At the gym, Fiona lifts the dumbbells"/"In the plane, Laure doesn't lift her luggage"). A significant increase of grip force relative to the baseline was recorded only for affirmative sentences. Nevertheless, the effect became significant only 320 ms after verb onset, suggesting that the engagement of the motor system is not a mandatory part of the network for action word representation.

The results of Tettamanti and Tomasino, Weiss and Fink's studies are also puzzling. In Tettamanti et al. (2008), the posterior cingulate cortex (which is part of the default mode network and is deactivated by goal-directed actions) was more deactivated by abstract negative than by abstract affirmative sentences. In Tomasino, Weiss and Fink pseudo-sentences yielded the reverse pattern to real sentences, i.e. a significant decrease of beta values for affirmatives compared to negatives in the left premotor cortex. Unless it is assumed that abstract negative sentences and negative pseudo-sentences are more semantically accessible than their affirmative counterparts, a direct correlation between amount of brain activity and accessibility to semantics should be taken carefully.

Finally, the effects discussed so far were restricted to the domain of *actions*. Thus, the inhibition effect attributable to negation may be relative to linguistic features specifically engaged by action words that go beyond semantic processing *per se*. For the sake of clarity, consider the stimuli adopted by Tomasino, Weiss and Fink (2010). Positive and negative imperatives are orders and prohibitions, more than simple affirmative and negative sentences. Modulation of brain activity in motor areas may be due to the participants' attitude towards the speech act of order/prohibition, more than to access to semantics.

4. Interim Summary

The neurofunctional literature on negative sentences leaves unsolved several issues regarding the neural and functional processing of negation. In particular, available data do not allow establishing if the affirmative counterpart of a negative sentence must be computed during the interpretation process, nor if negative sentences actually recruit greater computational resources than affirmative sentences. Tettamanti et al. (2008) and Tomasino, Weiss and Fink (2010) challenged the *increased processing load hypothesis*, and more in general the idea that processing negation is intrinsically more demanding than processing affirmation. Their results showed that, when the effort imposed by the task is limited (as is the case with passive listening and lexical decision vs. explicit sentence-picture verification tasks), negative sentences do not yield greater perisylvian activation than affirmatives. An intriguing question arises at this point: does the behavioral and functional 'effort' observed with negative sentences reflect a complexity intrinsic to negation, or is it due to extrinsic, non-linguistic task demands?

The fMRI study in the next chapter addresses this question.

Chapter 3

The cognitive and neural correlates of negative sentence verification

Behavioral experiments show that negative sentences are managed less easily than affirmatives in the experimental environment: when compared to their affirmative counterparts, negatives are associated with longer reaction times and higher error rates in sentence verification, lexical decision and probe recognition tasks, and with abrupt changes in thought processes during decision making (see Ch. 1, par. 1.1). Furthermore, some sentence-picture verification studies have reported an effect known as *negation-by-truth interaction*. With affirmative sentences, responses to true items are typically faster and more accurate than responses to false items. By contrast, responses to true negative sentences are slower and more error-prone than responses to false negative sentences (see Ch. 1, par. 1.2). This effect has been accounted for by assuming that the interpretation of a negative sentence is mediated by that of its affirmative counterpart. On this view, the processing of a sentence like

"The star is not black" entails a step in which the content in the scope of negation (e.g., 'the star is black') is represented (see Figure 1.1). Greater difficulty in behavioral tasks, along with the negation-by-truth interaction effect, have been interpreted as a consequence of greater computational demands imposed in sentence processing by negation as compared to affirmation.

Neuroimaging data on this issue are controversial. Four functional neuroimaging studies based on sentence verification found increased activation to negative stimuli in left hemisphere language areas, in particular the left superior and middle temporal gyrus in Carpenter et al. (1999) and Hasegawa et al. (2002), the pars triangularis and opercularis of the left inferior frontal gyrus [LIFG] in Bahlmann et al. (2011) and the left premotor cortex in Christensen (2009) (see Ch. 2, par. 2). By contrast, Tettamanti et al. (2008) and Tomasino, Weiss and Fink (2010), who adopted a passive listening and a lexical decision task respectively, found the opposite pattern, i.e. an overall decrease of the BOLD signal with negative as compared to affirmative sentences. More in detail, negative action-related sentences yielded a signal reduction in left fronto-parieto-temporal regions commonly associated with action-related sentence processing (see Ch. 2, par. 3).

In the first group of studies, increased activation was attributed to a putatively greater computational demand posed by negative sentences. In the second, greater activation to affirmative sentences was ascribed to reduced access to semantic information in the case of negative stimuli. Specifically, negation would reduce access to the motor component of the semantic representation engaged by action-sentence processing.

Leaving aside the contrasting results and interpretations, other aspects of neuroimaging studies are problematic.

On one hand, there are issues related to stimulus design. Carpenter et al. (1999) and Bahlmann et a. (2011) used a sentence-picture verification paradigm with affirmative and negative sentences of the type "It is true that…"/"It is not true that…", that actually contrast truth versus falsity predication and not affirmation versus true sentential negation. Hasegawa et al. (2002) adopted a probe-to-target task: participants read a target sentence (e.g., "The worker read a magazine and showed some pictures to the brother") followed by a probe (e.g., "The worker read a magazine"), and judged the probe relative to the target. Unfortunately, however, the experimental design was unbalanced, as affirmative target sentences were followed by affirmative probes only, whereas negative target sentences were followed by either negative or affirmative probes. Stimuli were carefully balanced in the study by Christensen (2009), in which both affirmative and negative target sentences were followed by affirmative and negative probes. This author found stronger activation in response to negation than affirmation in brain areas involved in the rule-based and cognitive manipulation of representations, but not in areas typically engaged by complex sentence processing.

On the other hand, the reduced access hypothesis is also questionable. In the first place, the inhibitory effect of negation on the semantic content in its scope is not supported either in the behavioral literature (see Ch. 1, par. 1.3) or in neurophysiological studies (see Ch. 2, par. 3.1). Secondly, the correlation between the intensity of the BOLD signal and the accessibility of semantic representations is not unproblematic. In the fMRI study by Tettamanti et al. (2008) the posterior cingulate cortex (which is part of the default mode network and is deactivated by goal-directed actions) was more deactivated by abstract negative sentences than by abstract affirmative sentences. Tomasino, Weiss and Fink (2010) interspersed affirmative and negative sentences with affirmative and negative pseudo-sentences made up of pseudo-words. Pseudo-sentences yielded a pattern opposite to that of real sentences, i.e. a significant decrease of beta values for affirmatives compared to negatives in the left premotor cortex. Unless one is willing to conclude that negative pseudo-word and abstract sentences are more semantically accessible than their affirmative counterparts, the neural correlates of negative sentence processing require further investigation.

Importantly, the results from Tettamanti et al. (2008) and Tomasino, Weiss and Fink (2010) question the '*increased processing load*' hypothesis, and the broad idea that the processing of negation is intrinsically more demanding than that of affirmation. Their results show that, when the effort imposed by the task is limited (as is the case with passive listening and lexical decision tasks), negative sentences are not associated with increased left perisylvian activation as compared to affirmatives.

In the present study, we used a written sentence-picture verification paradigm (Carpenter and Just, 1975) to examine brain activity during affirmative and negative sentence verification. In a fMRI experiment, Spanish-speaking subjects were asked to judge whether simple subject+verb affirmative and negative sentences were true or false with respect to a picture. We created one-clause sentences with internal negation, of the type "The child eats"/"The child does not eat" ("El niño come"/"El niño no come"). Our aim was to understand whether the greater behavioral and neural demand previously reported for negative sentences is due to the computation of negation *per se*, or to a language-aspecific computational demand introduced by the sentence-verification process. To this end, the analysis of neural activity was not limited to the overall contrast between affirmative and negative items, but was extended to the computation of the contrasts within affirmative and negative items (i.e., true affirmative vs. false affirmative, and true negative vs. false negative items).

1. Material and Method

1.1 Subjects

Twenty healthy, right-handed undergraduate students took part in the experiment. They were all native speakers of Spanish with normal or corrected-to-normal vision. None reported history of psychiatric or neurological disorders. The data of one subject were excluded from analysis due to chance performance in the sentence-picture verification task. Therefore, the final sample consisted of 19 subjects (6 males, mean age = 20.3 ±3.3). All participants were fully informed about the study and signed a written consent form. This study followed the principles of the Declaration of Helsinki and was approved by the Ethics Committee of the University of La Laguna (La Laguna, Spain).

1.2 Stimuli

Twenty subject-verb sentences balanced for length (6-8 syllables) and frequency of written usage were created; subjects were singular lexical determiner phrases (DPs) with human referents; verbs (half transitive, half intransitive) were in the 3rd person singular of the present indicative; both subject DPs and verbs were unique across all items. By manipulating the polarity of each structure, 20 experimental pairs of affirmative (A) and negative (N) sentences were created ("The child eats"/"The child does not eat"). Each sentence was then combined with a picture that represent either the action mentioned (M) in the sentence (e.g. <to eat>) or another action (NM); when the action represented in the picture was not mentioned in the sentence, it could be either an action semantically related (rNM, e.g. <a child drinking>) or semantically unrelated (uNM, e.g. <a child playing>) to the verb in the written sentence. The complete set of sentences and pictures is reported in Appendix 1. Each sentence+picture pair had the same subject, the only variation being on the verb. By combining polarity (A/N) and picture type (M/rNM/uNM), six types of items were created: true affirmative (aff. sentence + picture with a mentioned action, or TA), false related affirmative (aff. sentence + picture with a not-mentioned related action, or FrA), false unrelated affirmative (aff. sentence + picture with a not-mentioned unrelated action, or FuA), false negative (neg. sentence + picture with a mentioned action, or FN), true related negative (neg. sentence + picture with a not-mentioned related action, or TrN), and true unrelated negative (neg. sentence + picture with a not-mentioned unrelated action, or TuN). Examples of the experimental stimuli are reported in Figure 3.1. Three pseudo-randomized blocks of 40 stimuli each were prepared (see Appendix 2). Within each block, no more than two consecutive sentence/picture pairs had the same truth value and each picture appeared only once. Both polarity and polarity × picture type were balanced across blocks. Stimuli were presented as white line drawings on a black background. The picture was presented at the center of the screen and the sentence on a single line above the picture. Subjects had to judge as accurately and quickly as possible whether the sentence was true or false in relation to the picture.

Sentence	Picture	Picture Type	Truth Value	Item Type
"El niño come" *'The child eats'*		M	T	TA
"El niño come" *'The child eats'*		rNM	F	FrA
"El niño come" *'The child eats'*		uNM	F	FuA
"El niño no come" *'The child does not eat'*		M	F	FN
"El niño no come" *'The child does not eat'*		rNM	T	TrN
"El niño no come" *'The child does not eat'*		uNM	T	TuN

Figure 3.1. Sample Material (M = picture with an action mentioned in the sentence, rNM = picture with an action not mentioned in the sentence but related to it, uNM = picture with an action not mentioned in the sentence and unrelated to it).

Semantic closeness was calculated by combining a distributional semantic approach with data from native speakers. The analysis was run on the Italian translation of Spanish verbs. The distributional approach to semantics is based on the assumption that words with a similar meaning occur in similar context (Harris, 1970; Rubenstein and Goodenough, 1965). Distributional semantic models represent word meaning in a multi-dimensional fashion, by using algebraic vectors that encode the pattern of co-occurrence of that word with other expressions in a large corpus of language (Turney and Pantel, 2010). The more two words have a similar meaning, the higher the value of the vector that encodes their co-occurrence. Co-occurrence vectors were calculated with the neural net Word2Vec (Mikolov et al., 2013) over an Italian lemmatized corpus from the entire Wikipedia. An internet-based questionnaire was then administered to 20 students from the University of Trento. Participants were presented with the infinitive form of the verbs included in the stimulus sentences and were asked to list 3 actions semantically related and 3 actions semantically unrelated to each verb. The actions included in the related and unrelated stimulus pictures were selected by integrating co-occurrence vectors with the information provided by native speakers.

1.3 Procedure

The experiment took place in two sessions: a practice behavioral session and the experimental fMRI session, during which the behavioral task was also carried out. During practice, participants received instructions for the behavioral task and completed a training session (practice material is presented in Appendix 2). The task consisted of looking at a stimulus and then judging whether the sentence was true or false with reference to the picture. Given the number of experimental conditions and the large number of stimuli, a rapid event-related fMRI design was adopted (Burock et. al., 1998). Stimulus presentation times were determined using the optseq2 script (Dale, 1999). Parameters for the optseq scripts were such that stimulus presentation was set to 4 seconds, the Post Stimulus Delay was set to 16 s, and the sequence was optimized for a general True versus False contrast. The picture+sentence stimuli were accompanied by 20 randomly interspersed NULL events (a simple fixation point) per run, with an average duration of 8.1 s (range 2 - 24 s). Each pseudo-randomized block lasted 5 min 45 sec. A one-minute pause between blocks was included to allow data download. Stimuli were displayed in a rapid event-related mode with Presentation V14.05 (Neurobehavioral Systems, Albany, CA, USA). Participants read the stimuli in the fMRI scanner with VisuaStim Goggles 800 × 600 pixel resolution at 60 Hz (Resonance Technologies, Inc.). They held a controller in each hand and responded by pressing a button with the right or the left index finger, corresponding to True or False, respectively. RTs and accuracy were registered using the VisuaStim controllers (Resonance Technologies, Inc.). The visual component was not explicitly controlled, but since each picture was presented both in affirmative and negative, true and false conditions, there is no principled reason to expect visual processing to affect results differently across conditions.

1.4 Statistical analyses of behavioral data

The behavioral data of 6 participants were not recorded by the software due to a malfunctioning of the response button. Therefore, the final sample for behavioral data analysis consisted of 13 subjects. For each participant, we deleted those trials in which the RT was two standard deviations (sd) above or below that participant's mean RT for the condition in which the trial occurred (Ratcliff, 1993). Individual accuracy in each subject was within 2 sd from the group mean. Data were analyzed via the RStudio software (Version 1.1.442 for Macintosh, RStudio Team (2015). RStudio: Integrated Development for R. RStudio, Inc., Boston, MA, http://www.rstudio.com/). A two-way repeated-measure analysis of variance (ANOVA) was performed on RT and accuracy, the two factors being polarity and picture type. Post-hoc Tukey's multiple comparison tests (Tukey, 1949) were calculated to inspect how behavior on each of the three different picture types interacted with polarity.

1.5 MRI Data Acquisition

MR imaging data was acquired on a 3 T Signa EXCITE MRI whole body scanner (General Electric Healthcare, Milwaukee, WI, USA) using an 8-channel head coil. Head movement was avoided using sponge pads inside the coil. Earplugs were used to reduce noise in the scanner. Functional T2*-weighted images were obtained using gradient recalled echo, echoplanar imaging (EPI) sequences. Every participant underwent 3 functional scanning runs (one for each session) each lasting 5 min and 45 s. In each run, 165 volumes were collected; each volume contained 36 axial slices (TR = 2000 ms, TE = 22.5 ms, FOV = 256 mm, matrix size: 64 × 64, slice thickness of 4 mm, 75° flip angle, voxel size = 4 × 4 × 4 mm) and was preceded by ten dummy volumes that allowed for steady-state tissue magnetization. Following the acquisition of the functional data, a high-resolution T1 scan (1 mm resolution isomorphic) was acquired using the 3D FSPGR with ASSET sequence.

1.6 fMRI Data Processing

Each participant's dataset from each run was processed using the standard FSL pipeline (v5.0.9) at default settings (Woolrich, 2008). Images were motion-corrected using FSL MCFLIRT (Jenkinson et. al., 2002). Low-frequency oscillations were removed with a high-pass filter at 0.01 Hz. Images were spatially smoothed with a Gaussian filter at 5 mm Full Width Half Max (FWHM). As per default settings, no slicetime correction was applied, and small deviations from the expected signal were accounted for in the statistical model (see below). Registration to standard space involved the standard two-step procedure with default settings where functional data was linearly registered to the standard space by means of the linear registration of the participant's structural scan to the standard space.

1.7 fMRI Data Analysis

The analysis followed the standard two-level statistical analysis as implemented in FSL FEAT (FMRI Expert Analysis Tool) Version 6.00 (FMRIB's Software Library, www.fmrib.ox.ac.uk/fsl). Images were thresholded using clusters determined by $Z>2.3$ and a cluster probability of $p < 0.05$ corrected for multiple comparisons (Worsley, 2001). The exact stimulus onsets and their durations were extracted from the Presentation log files. At the first level, the design matrix included individual variables modeling the onset of each stimulus in each stimulus condition. These variables were modeled using a double gamma function. To account for small deviations in the timing of the onset the design matrix also included the double gamma's first temporal derivative. Statistical modeling was based on the General Linear Model. For each participant we computed the contrasts resulting from polarity and picture type across polarity (TA vs. FA and TN vs. FN and vice versa). Moreover, in order to focus on the dynamic of sentence-picture verification, the TA condition (where "The child eats" is paired with <a child eating>) was considered the baseline for the process, and FA (where "The child eats" is paired with <a child drinking/playing>), TN (where "The child does not eat" is paired with <a child drinking/playing>) and FN (where "The child does not eat" is paired with to <a child eating>) items provided all the possible variations from baseline. Thus, we computed also the activations relative to the contrasts of TA versus TN and FN. The contrast images obtained from each participant in each individual run were then combined across runs using a fixed-effect analysis. Finally, group level images were obtained using FSL FLAME (FMRIB's Local Analysis of Mixed Effects) with automatic outlier detection (Woolrich, 2008; Woolrich et al., 2004; Beckmann, Jenkinson, and Smith, 2003) and a mixed-effect analysis in which participants were included as random variables. We will report here the results of an exploratory whole-brain analysis.

2. Results

2.1 Behavioral Results

RT Data. Mean RT data are reported in Table 3.1. The ANOVA revealed two main effects of *polarity* ($F(1,12)=138.8$, $p<.001$) and *picture type* ($F(2,24)=17.7$, $p<.001$), and a significant polarity × picture type interaction ($F(2,24)=4.06$, $p<.05$). Post hoc analyses showed that the main effect of *picture type* was restricted to affirmative items

($F(2,24)=46.84$, $p<.001$). TA items were verified significantly faster than both FrA ($p<.001$) and FuA items ($p<.001$), and FrA items were verified significantly faster than FuA ($p<.05$), whereas RTs to true and false negative items did not differ significantly.

	Picture Type			
Polarity	**M**	**rNM**	**uNM**	mean
A	(TA) 1761.097	(FrA) 2126.919	(FuA) 2002.155	**1963.39**
N	(FN) 2386.992	(TrN) 2541.573	(TuN) 2391.325	**2439.963**
mean RT variation	**625.895**	**414.654**	**389.170**	

Table 3.1. Mean RTs in ms.

In general, negation significantly slowed RTs. Moreover, the RTs increase (Δ) due to negation was significantly greater in the case where the picture represents the action mentioned in the sentence, than in the case where the picture represents an action that was not mentioned in the sentence ($p_{(\Delta M\text{-}\Delta rMS)}=.05$; $p_{(\Delta M\text{-}\Delta uMS)}<.05$; $p_{(\Delta rMS\text{-}\Delta uMS)}>.05$; see Figure 3.2).

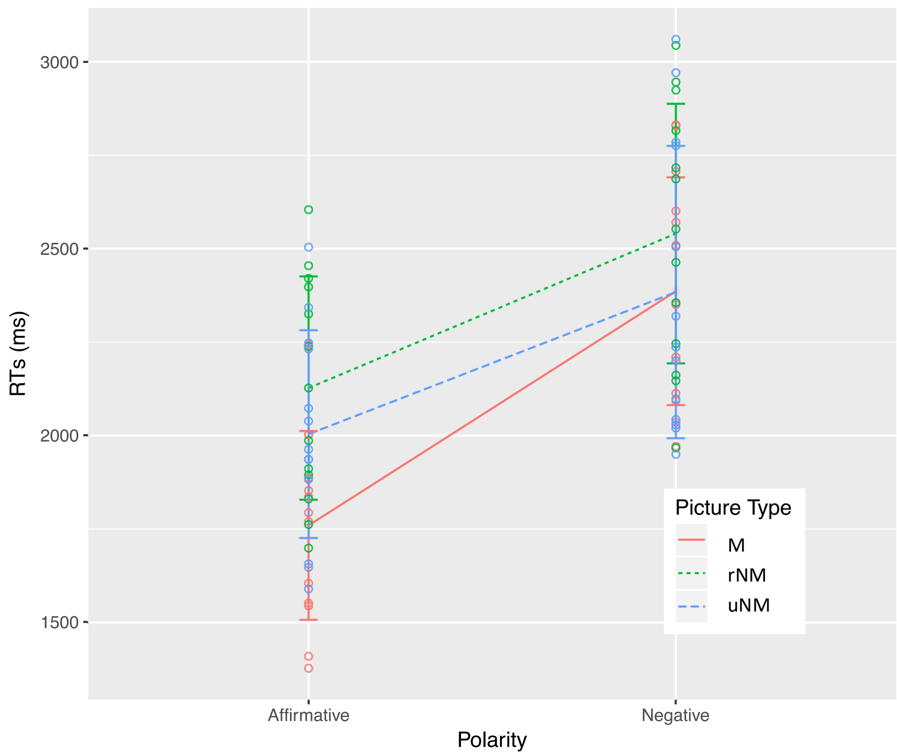

Figure 3.2. The *Polarity* × *Picture type* interaction plot for RTs. As shown by the slope of the lines corresponding to the three picture types (M, rNM and uNM), RTs to negative sentences increase significantly more in the the case where the picture represents the action mentioned in the sentence, than in the case where the picture represents an action that was not mentioned in the sentence (M is more sloped than uNM and rNM, which have the same slope).

Accuracy Data. Accuracy data are reported in Table 3.2. The ANOVA revealed both a main effect of *polarity* ($F(1,12)=10.81$, $p<.01$) and a main effect of *picture type* ($F(2,24)=7.068$, $p<.01$). As for RTs, the post-hoc analysis showed picture type to affect performance on affirmative but not on negative sentences. Overall, responses to negative sentences were significantly less accurate than to affirmative sentences. While accuracy on negative sentences held constant across the three picture types, responses to affirmative sentences were less accurate with FrA items than with both TA (p<.01) and FuA (p<.01) items, whereas responses to TA items were as accurate as responses to FuA items.

	Picture Type			
Polarity	**M**	**rNM**	**uNM**	**mean**
A	(TA) 0.98	(FrA) 0.90	(FuA) 0.99	**0.95**
N	(FN) 0.95	(TrN) 0.86	(TuN) 0.91	**0.91**

Table 3.2. Accuracy data.

2.2 fMRI Results

Polarity. The verification process yielded two distinct activation patterns, depending on sentence polarity (Figure 3.3 and Appendix 3). The verification of affirmative sentences was characterized by stronger activations than that of negative sentences in the right precuneus and in the posterior cingulate gyrus (Figure 3.3a). In contrast, as compared to affirmative sentences, the verification of negative sentences was associated with activity in a left-lateralized frontal cluster with local maxima in the LIFG (pars opercularis and triangularis) and the left middle frontal gyrus (Figure 3.3b).

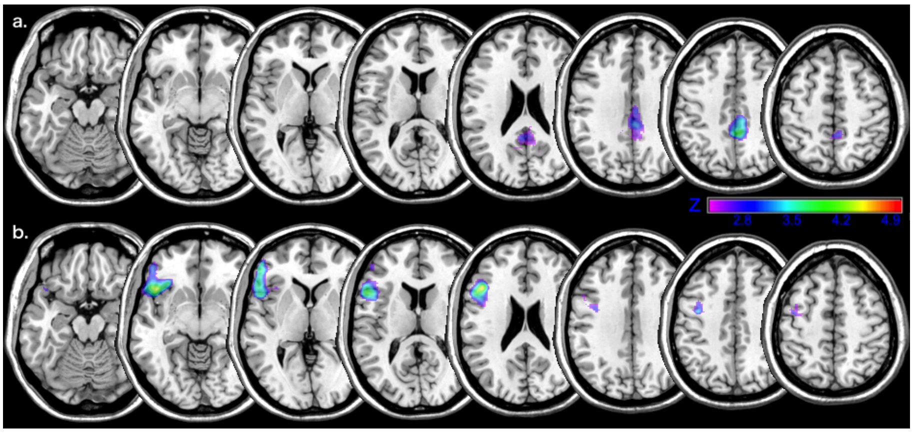

Figure 3.3. The activation patterns of the *polarity* contrasts: in a) regions significantly more active with affirmative compared to negative items and in b) regions significantly more active with negative compared to affirmative items.

Picture Type across Polarity. Picture type affected sentence verification differently, depending on polarity. True affirmative items activated the left postcentral gyrus and superior parietal lobule more than false affirmative items. In the reverse contrast, false affirmatives showed greater activation in the right precentral and postcentral gyrus, in the LIFG (pars opercularis and triangularis) and in the left middle frontal gyrus (Figure 3.4a and Appendix 3). True negative items activated the left precentral and postcentral gyrus more than false negative items, whereas the reverse contrast activated homologous areas on the right (Figure 3.4b and Appendix 3). The contrast between related and unrelated pictures did not yield significant differences in brain activation, regardless of sentence polarity. Since the experimental design was not optimized to inspect this kind of semantic features, this result will not be discussed further.

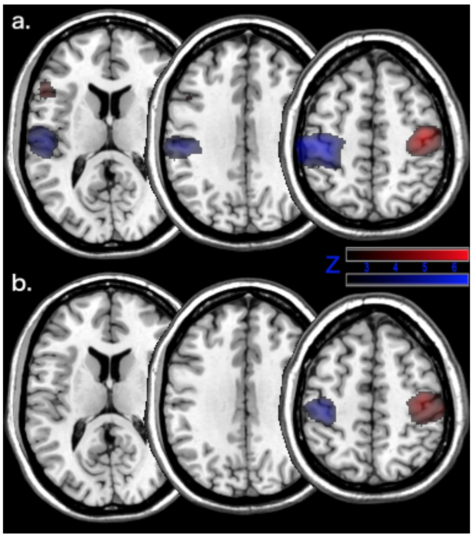

Figure 3.4. The activation patterns of *picture type* across affirmative (in a) and negative items (in b). Regions significantly more activated with true as compared to false items (i.e. TA>FA in a, TN>FN in b) are reported in blue, regions significantly more activated with false as compared to true items (FA>TA in a, FN>TN in b) are reported in red.

TA versus FN and TN. When compared to true affirmative items, false negative and true negative items yielded significantly greater activation of the LIFG (pars opercularis and triangularis) and the left middle frontal gyrus. In contrast, true affirmative items were associated with greater activation than false negative items in the left precuneus and the posterior cingulate gyrus, but with greater activation than true negative items in three clusters (one including the right posterior and anterior cingulate gyrus and the precuneus; one including the left central opercular cortex, the postcentral and precentral gyrus, the planum polare and temporale and Heschl's gyrus; one including the posterior and anterior supramarginal gyrus, the parietal operculum cortex and the angular gyrus) (see Appendix 3).

3. Discussion

3.1 Not all that complicates is complex: new insights into old (and new) behavioral data

Previous studies on sentence-picture verification reported two main results: i) longer RTs and lower accuracy in negative than affirmative sentence verification (Wason, 1961; Gough, 1965, 1966; Just and Carpenter, 1971; Clark and Chase, 1972; Carpenter and Just, 1975; Cheng and Huang, 1980; Carpenter et al., 1999; Kaup, Lüdtke and Zwaan, 2005; Lüdtke et al., 2008); ii) a negation-by-truth interaction (Clark and Chase, 1972; Lüdtke et al., 2008). The present study replicated the first result but found comparable RTs and accuracy with false and true negative items.

An increase in RTs and error rates with negative compared to affirmative sentences has been reported systematically in the literature on negation, across several linguistic tasks. Ever since the cognitive studies in the 60s, this finding has been putatively ascribed to an intrinsic complexity of sentential negation. Nevertheless, at least two additional differences between affirmatives and negatives should be considered. In the first place, affirmative sentences are descriptive of reality, in the sense that they allow identifying/representing a property or an event; whereas negative sentences speak of the absence of properties or events, and thus prevent the identification/representation of a precise state of affairs (Wales and Grieve, 1969; Apostel, 1972; Leech, 1981; Horn, 1989). For example, "Mary is not walking" tells us what is not happening, not what is happening, and the events compatible with 'not walking' are many (drinking/driving/swimming/…). Secondly, and contrary to affirmatives, negative sentences are never uttered out of a precise discourse context: they accomplish the communicative purpose of denying an explicit, previously uttered proposition or an implicit assumption that is taken for granted (Allwood, 1977; Givón, 1978). The few investigations that addressed this issue suggest that, in the presence of sufficient and appropriate context, integrating negation in sentence interpretation is significantly facilitated and the behavioral difference between affirmative and negative sentence processing tends to disappear (see Ch. 1, par. 2.1).

Both the 'semantic indefiniteness' (i.e. the impossibility of representing a precise state of affairs) and the context-dependency are particularly challenging in a sentence verification task, in which sentences are given out of a context and the participant is forced to represent a single state of affairs that must be compared to another semantic content. These considerations allow to suppose that the computational demands posed by negation processing during sentence verification tasks is not necessarily due to its cognitive complexity, but rather to task-related issues.

This idea is suggested also by a careful analysis of the experimental paradigms that attested the *negation-by-truth interaction*. In Lüdtke et al. (2008) stimuli were composed of an affirmative or negative sentence of the type "In front of the tower there is a/no ghost" and a picture that represented either a ghost or a lion in front of a tower. This means that in true negative items (i.e., "In front of the tower there is no ghost" + the picture of a lion in front of a tower) the picture resembles to some extent the state of affairs negated by the sentence (see Figure 1.2). In particular, the negation scopes over the predicate "to be in front of the tower", and the picture represents the state of 'being in front of the tower'. To respond, the participant is induced to a potentially misleading comparison between a negative sentence predicating that a state of affairs is different from being [p] (with p = [to be in front of] + [tower] + [ghost]) and a picture that actually is almost [p] (namely, [to be in front of] + [tower] + [lion]). The same objection applies to Clark and Chase (1972), who adopted stimulus sentences with above/below predications ("The X is/is not above/below the Y") accompanied by pictures that varied only relative to the vertical axis, namely representing either an X above an Y or an Y above an X.

Our experimental paradigm avoided this possible task-related bias and failed to replicate the *negation-by-truth interaction*. We used simple subject+verb sentences in which the scope of negation was restricted to the verb, and created the pictures for true negative items by manipulating the entire semantic content in the scope of negation and not just part of it (see Figure 3.1). As a consequence, in true negative items the only component shared by the semantic contents of the sentence and the picture was the agent, which was unambiguously not part of the scope of negation. The fact that, with a balanced paradigm that avoids scope ambiguity, performance on true and false negative items was indistinguishable, suggests that the negation-by-truth interaction results from task-related issues, more than from the computations specifically involved by negation processing. Furthermore, the RTs increase due to negation was significantly larger in the case where the picture represents the action mentioned in the sentence (i.e., between TA and FN items), than in the case where the picture represents an action that was not mentioned in the sentence (i.e., between FA and TN items, see Figure 3.2). This last result is also not accounted for by the previous two-step models of negative sentence processing (Clark and Chase, 1972; Kaup, Lüdtke and Zwaan, 2006; Kaup, Lüdtke and Zwaan, 2007). According to this view, TA and FA items are equally different to FN and TN items respectively, and thus a facilitation for FN items due to the partial match between sentence and picture is expected (see Figure 1.1). For the negative sentences in our experiment, the comparison with a picture representing the negated state of affairs is like the comparison with a picture representing any other possible state of affairs. If the sentence verification paradigm is deemed as a reliable measure of sentence interpretation, this result should be taken as evidence against a sequential, two-step model of negation processing where the affirmative counterpart is represented before negation is integrated in the meaning.

3.2 The role of the LIFG in sentence verification and in negative sentence processing

The fMRI experiment was designed to explore the activation patterns elicited by affirmative and negative sentences in the context of a sentence-picture verification task. In agreement with previous fMRI studies on sentence verification (Carpenter et al., 1999; Bahlmann et al., 2011), increased activation was found in the LIFG and in the left middle frontal gyrus when all negative sentences were contrasted with all affirmative sentences. These areas are typically associated with increased syntactic and working memory demands (e.g., Just, Carpenter and Keller, 1996; Makuuchi et al., 2009; Vigneau et al., 2006), and with the retrieval of semantic information (e.g., Wagner et al., 2001; Tettamanti et al., 2005; Grindrod et al., 2008), and thus a stronger engagement with negative as compared to affirmative sentence verification was attributed to greater computational demands specific to negation processing. Nevertheless, our results revealed that the same left frontal network showed stronger activation also with FA items (along with TN and FN items) as compared to TA items (see Figure 3.5). This result contrasts with the idea that the modulation of neural activity in the LIFG during sentence verification is due to structural computations specific to negation processing. Neuroimaging data also fail to support the possibility that differences between affirmative and negative sentences result merely from the unavoidable length imbalance introduced by the negative marker, as the very same sentence yielded greater activations in the FA than in the TA condition.

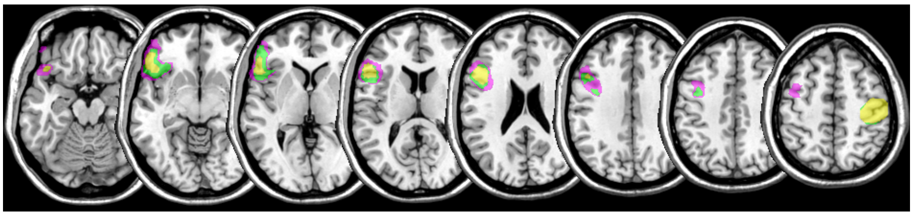

Figure 3.5. Overlap of the contrasts TN>TA (violet), FN>TA (green) and FA>TA (yellow).

A possible interpretation comes from an analysis of the experimental items (see Figure 3.1). A feature shared by FA, FN, and TN items, that sets them apart from TA items, is that the sentence and the picture express two different states of affairs. The engagement of the LIFG may be due to a general cognitive demand – i.e., the need to encode competing representations and then select among them (Thompson-Schill et al., 1997; Kan and Thompson-Schill, 2004). On this view, the interpretation of negative sentences would not be intrinsically more complex and cognitively costly than that of affirmative sentences, but simply more challenging in the context of a task that requires comparing semantic contents – a process much less demanding in the case of affirmative sentences. Consistent with this possibility, the cumulative contrast between affirmative vs. negative items yielded activations in the default mode network (Mantini et al., 2007; Christensen, 2009; van den Heuvel et al., 2009), which typically occur during rest and tend to decrease during goal-directed tasks (Raichle et al., 2001; Raichle and Snyder, 2007). Finally, if the activations in the motor areas are ignored[5], no differences are found between true and false negative items. This means that, at the level of brain activity and consistent with behavioral data, the verification of negative sentences is indifferent to the presence of the negated state of affairs in the picture.

4. Conclusion

The present fMRI experiment explored the nature of the computational demands posed by negation in sentence verification tasks. The experimental paradigm allowed focusing on two features described in previous studies based on sentence-verification paradigms, i.e. the negation-by-truth interaction effect on RTs and accuracy, and the stronger engagement of the LIFG with negative as compared to

[5] The engagement of motor areas in the contrasts between true and false is attributable to the motor component of the task. In the face of the bias linked to the hand response (participants always responded 'True' and 'False' with the right and the left index finger, respectively) further speculations are unwarranted.

affirmative sentences. Results showed that both these effects might be due to the experimental design or to the cognitive mechanisms recruited by sentence verification *per se*, more than to an intrinsic complexity of negation processing. Moreover, neither the behavioral nor the neuroimaging data found evidences in support of the idea that negation is integrated in the meaning via a two-step model where the affirmative counterpart of the sentence is represented. Our results are compatible with the idea that the 'effort' attested in experiments on negation might result from task-specific cognitive mechanisms (e.g., the need to encode competing representations and to select among them, or to compare target sentences with misleading pictures) which put negative sentences to a disadvantage. We suggest that negation in language cannot be ultimately reduced to logical negation. This conclusion is also in line with the real use and meaning of negative sentences, since negative linguistic acts are not always acts of denial (i.e., intended to change the truth value of a proposition). Negative sentences are used to forbid, make irony or correct the expectations/beliefs of our interlocutor, and they need an adequate context to be interpreted (see Introduction and Ch 1, par. 2). More precisely, they refer to an implicit amount of information that is provided by the *conversational context* and exceeds the affirmative content in the scope of *not*.

Chapter 4

Sentence-picture verification applied to language impairment: a study on Aphasia and degenerative dementia

Language comprehension is the process of assigning a meaning to a linear sequence of linguistic signs. Albeit effortless for an intact cognitive system, sentence comprehension is a complex phenomenon that requires the integration of strictly linguistic knowledge with more general cognitive abilities such as attention monitoring and memory recall. In particular, beyond the retrieval of the semantic content associated with the lexical units, meaning must also be extracted by the way in which words are combined. For example, the sentence "The girl hits the boy" is correctly interpreted only if we know that the verb "to hit" needs an entity performing and another undergoing the action, and that canonically the two are placed before and after the verb, respectively.

The complexity of this largely unconscious and usually accurate system becomes obvious when its functions are disrupted by brain damage. Depending on the kind of injury (focal vs. diffuse), its nature (vascular vs. neoplastic vs. inflammatory vs. traumatic), mode of onset (abrupt vs. gradual), location and size, the spectrum of symptoms that may emerge as a consequence of damage to the language areas is extremely diversified. In addition, the complexity of the cognitive mechanisms underlying normal and pathological language processing often makes it hard to identify the locus of damage.

The present study adopted the sentence-picture verification task presented in Chapter 3 to explore language comprehension in thirty-one individuals with aphasia and thirty-seven individuals with diagnosed degenerative dementia.

Aphasia is an acquired language disorder typically resulting from damage to perisylvian areas of the left hemisphere. Language comprehension in case of focal brain injury has been frequently addressed in research on aphasia (e.g., Caramazza and Zurif, 1976; Schwartz, Saffran and Marin, 1980; Grodzinsky, 1989; Caplan and Evans, 1990; Caramazza and Miceli, 1991; Bastiaanse and van Zonneveld, 2006; Caplan et al., 2007; Sheppard et al. 2015). Overall, following brain damage, comprehension accuracy decreases with increasing syntactic complexity (e.g., passive structures are comprehended less accurately than actives, object relatives less accurately than subject relatives, wh-questions with object extraction less accurately than wh-questions with subject extraction), and when the event referred to in the sentence is semantically reversible (i.e., “The horse kicks the cow” is usually understood with greater difficulty than “The horse kicks the fence”). Nevertheless, the across-subject variation in comprehension patterns is quite large (Badecker, Nathan and Caramazza, 1991), and it has not licensed a unitary explanation able to fully account for patients’ performance (Caplan, Baker and Dehaut, 1985; Caramazza, and Miceli, 1991; Berndt et al., 1997; Linebarger, Schwartz and Saffran, 1983; Caramazza and Hillis, 1989; Nespoulous et al., 1988; Caplan and Waters, 1990). Furthermore, it is often difficult to associate the attested deficits to the failure of one or the other component of language processing. Several studies reported agrammatic speakers with asyntactic comprehension who were quite good in judging the grammatical well-formedness of sentences (Linebarger, Schwartz and Saffran, 1983; Schwartz et al. 1987). In addition, the same deficit may have different degrees of severity: some patients understand very little in conversational settings and fail in simple tests of comprehension of single word, others show difficulties only in tests that require the ability to compute structural information (Berndt, Mitchum and Wayland, 1997).

Degenerative dementias include a broad range of conditions characterized by neuronal degeneration. Overall, their main feature is the slow decrease of cognitive skills. Depending on the cause of the neurodegeneration, there exist different kinds of degenerative dementia syndromes, whose early symptoms may vary. Language deficits in dementia are quite pervasive (Kempler and Goral, 2008). In particular, sentence comprehension is impaired in Frontotemporal Dementia (Grossman et al., 1996; Hodges and Patterson, 1996; Mesulam, 2001; Snowden, Neary and Mann, 1996; Thompson et al., 1997; Grossman, Rhee and Moore, 2005) and Alzheimer's disease (Emery, 1983, 1988; Kempler et al., 1998; Tomoeda et al., 1990; Rochon, Waters and Caplan, 2000). In aphasic patients, comprehension accuracy tends to decrease with increasing syntactic complexity (Emery, 2000; Grossman, Rhee and Moore, 2005).

The investigation of sentence comprehension in focal and diffuse brain injury must face several problems. The most obvious difficulty is that, beyond single-word comprehension, sentence interpretation requires understanding how words are combined. Furthermore, studies frequently adopted stimulus sentences with a minimum of three constituents (the verb plus two arguments) and complex syntactic structures, such as passives, wh-questions or subject and object relatives (Caramazza and Zurif 1976; Grossman, Rhee and Moore, 2005; Schwartz, Saffran and Marin, 1980; Grodzinsky, 1989; Kempler et al., 1998; Grober and Bang, 1995; Grossman et al., 1996; Caplan and Evans, 1990; Bastiaanse and van Zonneveld, 2006; Caplan et al. 2007; Sheppard et al. 2015; Linebarger, Schwartz and Saffran, 1983). Failure to match a complex sentence like "The boy that the girl is hitting cries" to the corresponding picture could be due to a difficulty with any of a number of dimensions of the stimulus, such as object fronting, long-distance syntactic dependencies and thematic role assignment. Another major problem is that the experimental paradigms adopted more commonly do not allow disentangling damage to language-specific vs domain-general mechanisms. As a result of these drawbacks, the cause of the poor sentence comprehension problem is not easily identifiable, as damage may affect lexical semantics, syntactic ability or memory.

The sentence-picture verification task presented in Chapter 3 is a promising tool for the assessment of language and cognitive impairment in case of brain damage. By using very simple, monoargumental sentence structures as “The child eats”, it addresses the basic steps of sentence processing and reduces the syntactic mechanisms under investigation to a minimum. Moreover, the experimental design allows focusing on different cognitive mechanisms at the same time. The verification paradigm requires participants to answer “false” to positive sentences (the case of false affirmatives) and “true” to negative sentences (the case of true negatives), and thus it stresses the decision-making process. The *picture type* manipulation allows investigating subtle semantic processing. Finally, it is possible to study how patients with brain damage deal with negation, a linguistic feature almost ignored by studies on acquired language disorders.

To our knowledge, only three studies addressed negation processing in brain injury, with unsatisfactory results. Juncos-Rabàdan (1992) tested fluent aphasics and subjects with right temporal lobe damaged by means of a sentence-picture verification paradigm. Aphasic participants differed significantly only for RTs, while error rates were almost comparable to those of the other groups. Nevertheless, results are puzzling, as in some tasks the control group fared worse than brain-damaged patients. Rispens et al. (2001) tested comprehension and production of negation in Dutch, English and Norwegian agrammatic speakers with a sentence-picture verification task and two sentence-anagram tasks. Negative sentences were significantly more impaired than affirmatives only in the anagram task in English speakers, but strong conclusions on negation processing are prevented by the use of complex and ambiguous stimulus sentences. The study from Fyndanis et al. (2006) on the production and comprehension of negation in Greek agrammatic speakers found a significant effect of negation only in production, but an in-depth analysis is not possible, as testing materials are described in insufficient detail.

1. Material and Method

1.1 Subjects

Focal Group. Thirty-one patients with damage to the left hemisphere participated in this study (15 males). Lesions were caused by stroke (n = 27), tumor (n = 3) or head trauma (n = 1). Participants were all native speakers of Italian. Age ranged between 32 and 87 years (Mean = 65.6, SD = 12.4) and education between 3 and 16 years (Mean = 8.8, SD = 3.8). Patients were recruited via speech and language therapy services based on biographical information (age between 18 and 90 years; good linguistic performance before the brain lesion), neuropsychological profile (a diagnosis of aphasia) and lesion location (a single lesion in the left hemisphere). Exclusion criteria included the presence of additional right hemispheric damage and/or clear signs of dementia. Participants were clinically stable throughout the testing phase. They signed a written consent form approved by the Ethics Committee of the University of Trento (Trento, Italy).

Degenerative Group. Thirty-seven patients with a diagnosis of degenerative dementia participated in this study (16 males). Participants were all native speakers of Italian. Patients were included on the basis of neuroradiological and cognitive criteria. For all subjects, MRI showed signs of cortical and subcortical atrophy, in the absence of signs of vascular damage other than those compatible with age. They had a history of slow progressive deterioration of cognitive skills, ranging in age between 60 and 95 years (Mean = 75.9, SD = 6.8) with at least 5 years of education (Mean = 7.5, SD = 3.6). The Mini Mental State Examination (MMSE, Folstein, Folstein and McHugh, 1975) corrected scores (Magni, 1996) ranged between 6.3 and 28 (Mean = 22.2, SD = 4.8). Patients were included if they achieved a score lower than x on the MMSE (Magni et al., 1996), or if their performance on a battery sensitive to diffuse cognitive damage (MDB, Carlesimo, Caltagirone and Gainotti, 1996) showed poor performance on tasks tapping at least two cognitive areas. In all subjects the most likely diagnosis was Alzheimer Disease, as in all cases MRI and clinical criteria failed to show the typical signs of Frontotemporal Dementia or Lewy body Disease. Participants were recruited via care homes for the elderly, therapy services and hospitals based on biographical information (age between 18 and 95 years), neuropsychological profile (medical history compatible with a neurodegenerative syndrome; absence of lateralized sensory and motor deficits) and neuroradiological data (cortical and/or subcortical atrophy without signs of vascular disease other than those compatible with age). Since the data collected for each participant did not include biological markers, it is not possible to reliably differentiate different types of degenerative dementia. Participants signed a written consent form approved by the Ethics Committee of the University of Trento (Trento, Italy).

Control Group. Normative data for the sentence-picture verification test were collected from 53 healthy participants. Data from 3 subjects were removed due to low accuracy on the Sentence-Picture Verification Test (2 SD below the group mean). The effective number of control subjects was thus 50 (19 males, mean age = 68±7.5, mean education = 12±4.1). They were native speakers of Italian with no history of neurological or psychiatric condition or brain injury, and their scores on the MMSE were above 26 (29±1). Participants signed a written consent form approved by the Ethics Committee of the University of Trento (Trento, Italy).

1.2 The Sentence-Picture Verification Test

The experimental material of the Sentence-Picture Verification Test was the same adopted for the fMRI experiment presented in Chapter 3 (see Ch. 3, par. 1.2). The three pseudo-randomized blocks (n=40 stimuli each) where administered in three separate sessions in order to avoid fatigue or the development of response strategies. The experimental session was preceded by a training session. Participants sat in front of a laptop screen. A stimulus sentence was read aloud by the experimenter and a picture was presented on a laptop screen immediately after the sentence. During sentence reading a fixation cross was shown on-screen. After reading the sentence the experimenter pressed a key and the picture appeared (see Figure 4.1). Participants listened to the sentence, then looked at the picture and were asked to judge if the sentence was true or false in relation to the picture. Sentences could be repeated once, upon request.

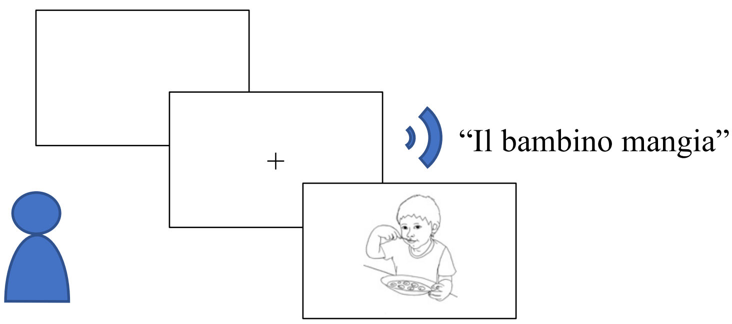

Figure 4.1. The experimental set of the Sentence-Picture Verification Test.

1.3 Procedure

Before engaging in the Sentence-Picture Verification Test, participants completed standardized neuropsychological tests intended to assess their general cognitive status and ensure they would be able to complete the Test. In particular, we addressed:

-nonverbal intelligence with Raven's Coloured Progressive Matrices (CPM, Raven, 1962);
-phonological, visuospatial and episodic working memory with the forward digit span, Corsi blocks (Monaco et al., 2013) and the immediate and delayed story recall (Mondini et al., 2011);
-executive functions with the backward digit span (Monaco et al., 2013).

Language was evaluated by means of auditory and visual single-word (nouns and verbs) and sentence comprehension tasks from the Batteria per l'Analisi dei Deficit Afasici, BADA (Miceli et al., 1994) and by noun and verb naming tasks (Rofes, Capasso and Miceli, 2015). Participants were tested individually. Healthy volunteers completed testing in three sessions; some patients were tested in more than three sessions.

1.4 Statistical Analysis of Sentence-Picture Verification Test

Participants' performance was analyzed by computing the accuracy (A) in the entire test and in all the conditions resulting from the manipulation of *polarity* (Affirmative/Negative) and the combination of *polarity* with *picture type* (TA/FrA/FuA/FN/TrN/TuN). Responses to two sentences ("The man slips/does not slip" and "The athlete jumps/does not jump", see Appendix 1) were ignored, as these stimuli yielded a sizeable number of incorrect responses in control subjects. Given that both the assumptions of normality and homogeneity of variance were violated, a logit transformation was applied to the proportion of correct responses (Targher et al., 2017). A three-way repeated measure ANOVA was performed with *group* as fixed factor and *polarity* and *picture type* as random factors in order to compare Control Group with Focal Group, Control Group with Degenerative Group and Focal Group with Degenerative Group. Both the ANOVA between the Control and Focal Group and the ANOVA between the Focal and Degenerative Group revealed a significant *group* × *polarity* × *picture type* interaction ($F(2,138) = 5.045$, $p = .01$; $F(1,96) = 4.63$, $p = .02$), whereas the ANOVA between the Control and Degenerative Group revealed a significant *group* × *polarity* and *group* × *picture type* interaction ($F(1,64) = 15.077$, $p < .001$; $F(2,73) = 23,94$, $p < .001$). A further two-way repeated measures ANOVA with *polarity* and *picture type* as factors was performed on Control, Focal and Degenerative Group, along with paired and independent post-hoc t-tests to inspect each experimental condition both between and within groups. The Bonferroni correction was applied to the significance cut-off for the post-hoc tests (Dunnett, 1955).

The performance of brain-damaged participants was further analyzed in two independent directions. In patients with focal damage, Fisher's exact test was used to investigate the presence of common error patterns (Fisher, 1954). This strategy was selected because in populations with focal damage, heterogeneous error profiles are often observed, which may reveal theoretically interesting functional dissociations. In patients with degenerative dementia, performance in the Sentence-Picture Verification Test was involved in additional statistical analyses: Pearson's *r* correlations with scores in other neuropsychological tests (Katz, 2006), and the Crawford & Garthwaite test for comparisons between single cases and Control Groups (Crawford and Garthwaite, 2004). This approach was chosen because in dementia a test investigating the processing of negation may be of diagnostic interest, and measuring the sensibility of the test and its correlation with standardized tests would help establishing its merits in this regard. All the analyses were performed with the IBM SPSS Statistics software (IBM Corp. Released 2016. IBM SPSS Statistics for Windows, Version 20.0, Armonk, NY: IBM Corp.).

2. Results

2.1 Between Groups Analysis

Results are reported in Table 4.1 and Figure 4.2. Post-hoc independent t-tests revealed that in all the experimental conditions the Control Group performed significantly better than both the focal (TA: $t_{(33)} = 5.14$, $p < .001$; FrA: $t_{(37)} = 7.17$, $p < .001$; FuA: $t_{(33)} = 4.37$, $p < .001$; FN: $t_{(37)} = 5.97$, $p < .001$; TrN: $t_{(44)} = 9.48$, $p < .001$; TuN: $t_{(36)} = 7.9$, $p < .001$) and the degenerative group (Affirmative: $t_{(133)} = 9.29$, $p < .001$; Negative: $t_{(172)} = 12.75$, $p < .001$; M: $t_{(94)} = 5.48$, $p < .001$; rNM: $t_{(116)} = 10.9$, $p < .001$; uNM: $t_{(102)} = 10.18$, $p < .001$).

	Group		
Condition	Control	Focal	Degenerative
TA	.99±.01	.92±.09	.98±.04
FrA	.98±.03	.78±.18	.83±.17
FuA	.99±.01	.88±.15	.90±.09
FN	.97±.03	. 76±.23	.85±.16
TrN	.94±.07	.5±.26	.67±.18
TuN	.96±.04	.54±.32	.73±.2
mean	.97±.02	.73±.14	.83±.1

Table 4.1. Control, Focal and Degenerative Groups' accuracy and SD in each experimental condition.

Overall, participants with degenerative disease performed better than focal patients, although the difference between the two groups reaches significance only for TA ($t_{(54)} = 2.6$, $p < .05$), TrN ($t_{(51)} = 2.47$, $p < .05$) and TuN items ($t_{(51)} = 2.19$, $p < .05$).

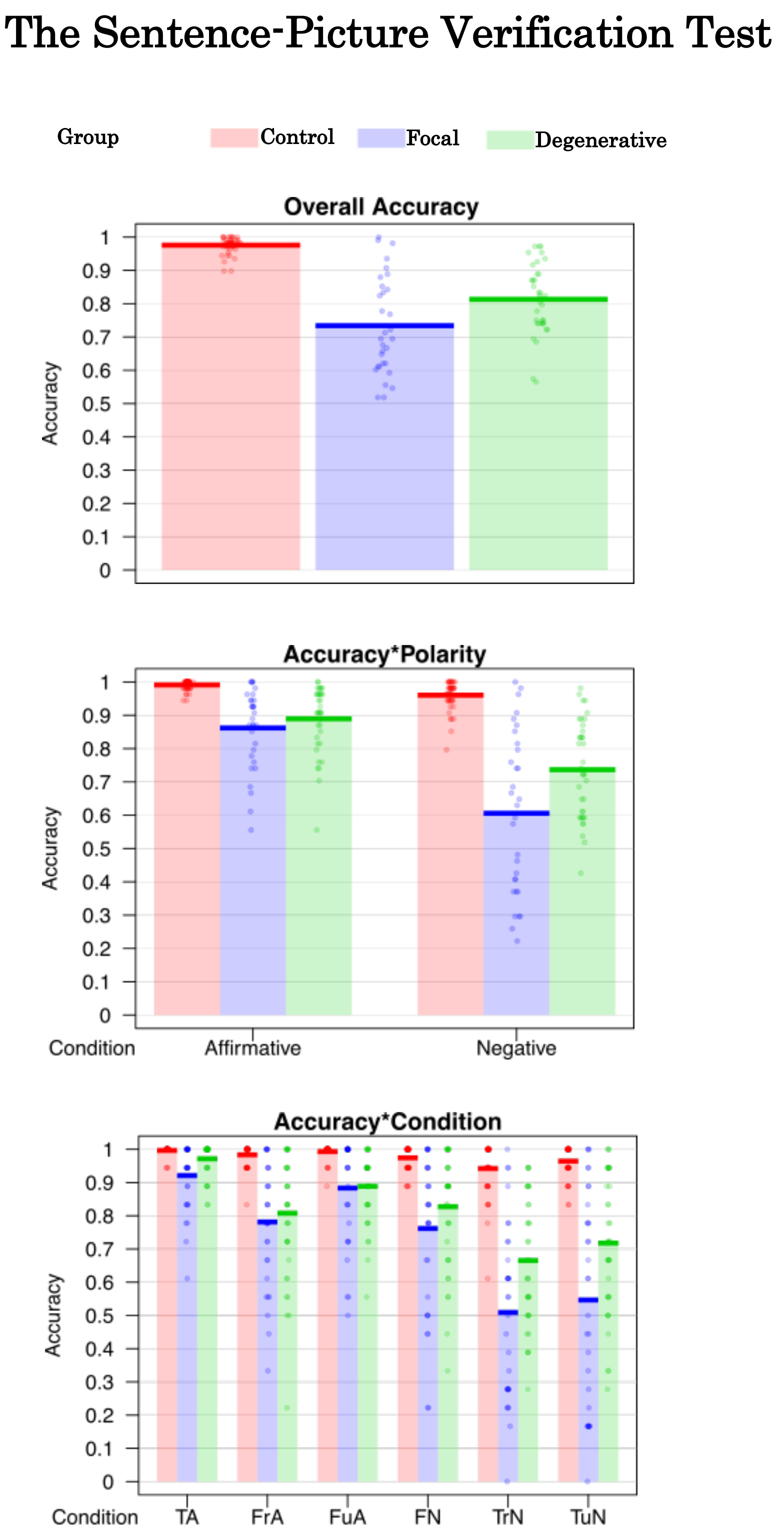

Figure 4.2. Control (in red), Focal (in blue) and Degenerative (in green) Group's accuracy by comparison.

2.2 Within Groups Analysis

Control Group. The ANOVA on Control Group's accuracy data revealed a main effect of *polarity* ($F_{(1,49)} = 38.61$, $p < .001$) and *picture type* ($F_{(2,98)} = 8.69$, $p < .001$). Responses to negative sentences were significantly less accurate than responses to affirmative sentences ($A_{Aff.} = .99 \pm .01$, $A_{Neg.} = .96 \pm .04$, $t_{(149)} = 7.61$, $p < .001$). Responses to items with pictures that represent the action mentioned in the sentence (M) were as accurate as responses to items with picture that represent an unrelated action (uNM). Both M and uNM items were responded to more accurately than items with pictures that represent a related action (rNM) ($t_{(99)} = 4.15$, $p < .001$ and $t_{(99)} = 3$, $p < .01$ respectively).

Focal Group. The ANOVA on Focal Group's accuracy data revealed a significant *polarity* × *picture type* interaction ($F_{(2,48)} = 5.1$, $p < .05$). Post-hoc t-tests showed that response accuracy was higher on affirmative than on negative items ($A_{Aff} = .86 \pm .12$, $A_{Neg.} = .6 \pm .24$, $F_{(1,30)} = 42.003$, $p < .001$). While affirmative items with M and uMM pictures were more accurate than items with rMM pictures ($t_{(30)} = 3.74$, $p = .001$ and $t_{(30)} = 4.11$, $p < .001$), with negative sentences performance with uMM and rMM pictures was undistinguishable and in both cases less accurate than performance with M pictures ($t_{(30)} = 4.5$, $p < .001$ and $t_{(30)} = 5.9$, $p < .001$). Inspection of individual performance profiles allowed identifying three specific behavioral patterns (see Figure 4.3):

1. patients whose performance was particularly impaired with true negative sentences (Pattern 1, n=5);
2. patients who fared poorly on negative sentences regardless of their truth value (Pattern 2, n=5);
3. patients with particularly poor scores when judging pictures semantically related to the verb of the sentence (Pattern 3, n=3).

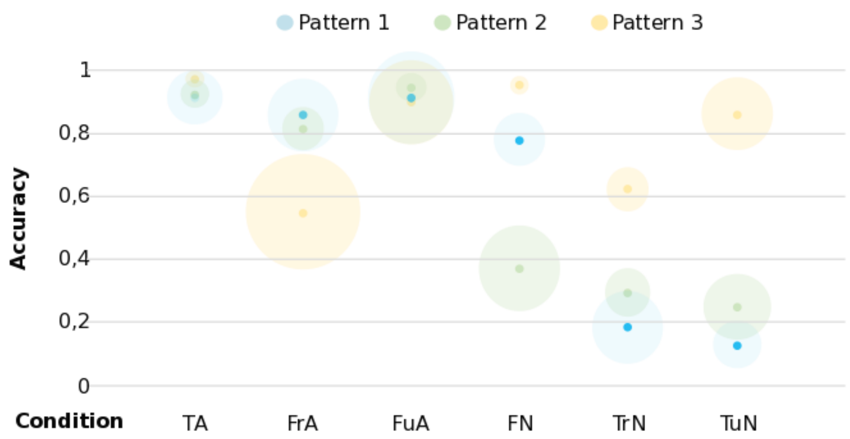

Figure 4.3. The three behavioral patterns identified via the Fisher's exact test on the performance of individual subjects. The graph represents the mean (smaller and darker dots) and standard deviation (larger and lighter circles) of each group of subjects.

Data distribution of focal patients' performance did not reveal significant correlations between the Sentence-Picture Verification Test and any other neuropsychological tests.

Degenerative Group. The ANOVA revealed main effects of *polarity* ($F_{(1,36)}$ = 56,97, $p < .001$) and *picture type* ($F_{(2,71)}$ = 50.009, $p < .001$). Responses to negative sentences were significantly less accurate than responses to affirmative sentences ($A_{Aff.}$ = .88±.1, $A_{Neg.}$ = .73±.14, $t_{(110)}$ = 8.41, $p < .001$). Items with M pictures were verified more accurately than items with rMM ($t_{(73)}$ = 8.34, $p < .001$) and with uMM pictures ($t_{(73)}$ = 6.05, $p < .001$), and items with uMM pictures were verified more accurately than items with rMM pictures ($t_{(73)}$ = 3.69, $p < .001$).

The Pearson correlation coefficient revealed a moderate positive correlation at the group level both between overall performance in the Sentence-Picture Verification Test and the rough scores in the MMSE (r = .605, $p < .01$), and between performance with TrN items and the scores on the CPM (r = .506; $p < .01$).

The comparison between single cases and the Control Group revealed that 29 patients out of 37 (78.4%) fared significantly worse than control subjects on the overall test and on FA and FuA items ($p < .05$). Thirty patients out of 37 (81.1%) were significantly different from controls on affirmative items as a whole ($p < .05$).

3. Discussion

3.1 Performing tasks with language is not (just) comprehending language

Control Group data showed that the presence of negation in the sentence and semantic similarity between sentence and picture strongly interfere with the comprehension of negative sentences in a sentence-picture verification paradigm. This finding is in line with previous behavioral studies (Clark and Chase, 1972; Wason, 1961; Gough, 1965; Cheng and Huang, 1980; Kaup, Lüdtke and Zwaan, 2005; Lüdtke et al., 2008).

Negative sentences challenge the sentence-picture verification process because, differently to affirmatives, their semantic content does not result in a one-to-one mapping of words to meanings (the core meaning of "not to eat" extends to *the entire set* of all the actions different from 'to eat') and cannot be translated in representational terms (a picture cannot possibly represent an exhaustive disjunction of possibilities). Thus, while the verification of an affirmative sentence allows comparing two well-defined semantic contents (one activated by the sentence, one activated by the picture), the verification of a negative sentence forces the listener to compare the semantic content activated by the picture to a set of contents activated by the sentence. Such a set of contents is more difficult to retrieve and to maintain active than a single content.

The difficulty increases also when the state of affairs represented in the picture is semantically related (i.e., similar) to the verb of the sentence. If a similarity occurs between the sentence and the picture (as in the cases of "The child eats"/"The child does not eat" paired with the picture of a child seated at the table and drinking a glass of water), the comparison is potentially misleading, as the subject has to judge a sentence about [p] or [not [p]] relative to a picture that is almost [p]. In other words, what becomes difficult it is not language processing *per se* (in TA, FrA and FuA the sentence is the same as in FN, TrN and TuN), but one of the cognitive steps that involved in the verification process, i.e. the sentence-picture comparison.

This last result has important implications for the study of language impairment, which typically investigates language comprehension through linguistic tasks. When participants are asked to do something with a sentence they hear or read, several cognitive processes beyond pure language processing are involved. Thus, failure to respond correctly may not lie necessarily in a difficulty with language, but might result from damage to a cognitive, but non-linguistic process needed to accomplish the task.

The present study shows that sentence-picture comparison is inherently difficult when the semantic contents to be compared are quite similar. This fact has at least two important implications. On one hand, it stresses the need for experimental paradigms that use simple linguistic structures and allow isolating the different cognitive components involved by a task. On the other hand, it suggests caution when analyzing the performance of brain-damaged participants on tasks that require the ability to manage several semantic contents (as sentence-picture matching tasks), as poor performance may not necessarily be the result of pure language impairment.

3.2 The Spanish and the Italian Group by comparison

The study with patients required the intermediation of the experimenter in stimuli presentation, with the resulting loose of reliability of RTs data. In order to maintain an homogeneous data acquisition, the same design was adopted for Control Group, and thus RTs have not been recorded for both patients and control subjects. For what concerns the accuracy, Control Group results in the Sentence-Picture Verification Test partially replicated the behavioral data of the fMRI experiment presented in Chapter 3. Both Italian control subjects and Spanish students performed more accurately with affirmative as compared to negative sentences, and with TA and FuA items as compared to FrA items. Nevertheless, while the Spanish Group did not show significant differences among FN, TrN and TuN items, the Control Group performed more accurately with FN and TuN items as compared to TrN items. Interestingly, the same pattern is observed in the degenerative group. This results strengthen the idea that the comparison between similar semantic contents is a critical computation for our cognitive system.

3.3 Impaired performance results from selective disruptions of linguistic and cognitive mechanisms

A first relevant result of the present study is that even simple, monoargument structures that do not involve long-distance dependencies or possible errors of thematic role assignment (as "The child eats/does not eat") may be challenging for patients with brain damage. Another interesting result is that the sentence-picture verification paradigm is problematic for subjects with left brain damage and, just as in control subjects, its difficulty increases with negation.

Group-level analyses demonstrate that patients do not simply fare worse than controls, but also show performance profiles different to those observed in controls, as shown by the different ways in which the *picture type* variable affects performance in the three groups. This result suggests that poor performance in patients does not result from an aspecific difficulty with complexity, but rather from the disruption of specific linguistic/cognitive mechanisms.

Overall, patients with neurodegenerative diseases performed slightly better than focal patients in the Sentence-Picture Verification Test. The results of the analyses conducted on the two groups require separate considerations.

Performance of patients with neurodegenerative diseases. The most interesting result in patients with degenerative diseases is that the Sentence-Picture Verification Test is sensitive to cognitive impairment (up to 81% of the participants in this group). The moderate correlation with only two of the standardized tests typically adopted in the diagnosis of dementia diseases (MMSE; CPM) suggests that our experimental task and standard batteries measure partly independent skills. For this reason, interesting cues come from the performance of the three subjects excluded from the Control Group. Their data are reported in Table 4.2.

Subj.	**Age**	**Edu.**	**MMSE score**	**Sentence-Picture Verification Test Accuracy**						
				Tot.	**TA**	**FrA**	**FuA**	**FN**	**TrN**	**TuN**
LV	74	17	28	0.79	1.00	0.84	0.74	0.63	0.74	0.79
GV	76	18	28	0.85	0.74	0.79	0.89	0.95	0.89	0.84
GC	79	8	29	0.89	1.00	0.95	0.95	0.95	0.63	0.84

Table 4.2. The healthy participants tested as controls and removed from the group.

The performance of LV, GV and GC in the Sentence-Picture Verification Test was seriously damaged in comparison with that of other controls, notwithstanding intact general cognitive skills. This result is compatible with the idea that language may be affected even in the very first stages of a neurodegenerative diseases, and that linguistic tasks may be promising tools for early diagnosis.

Performance of patients with focal damage. The identification of specific error profiles suggests that focal brain damage can selectively disrupt cognitive or linguistic abilities, and specific processing stages of such abilities can be affected. Impaired performance can result from damage to language-specific processes (Pattern 2), from the inability to deal with related semantic contents (Pattern 3), or from the disruption of more general cognitive process such as decision making and truth value assignment (Pattern 1, resulting in the inability to assign a positive truth-value to negative sentences). Sentence-picture verification is a complex process that requires extracting the semantic contents of the sentence and the picture, comparing the two and formulating a truth judgment. Nevertheless, the experimental design proposed here is a promising tool for the identification of the different levels at which cognitive and linguistic mechanisms may be disrupted. Figure 4.4 reports two answers from patients PLG and AD. The item is of the same FN type in the two cases and the outcome is the same (both answers are wrong). PLG correctly processes the negative sentence and the comparison with the picture (indeed he corrects the experimenter), but fails in formulating the truth judgement. By contrast, AD completely neglects the negative marker, processing the sentence as if it were affirmative, and consequently gives an incorrect truth judgment.

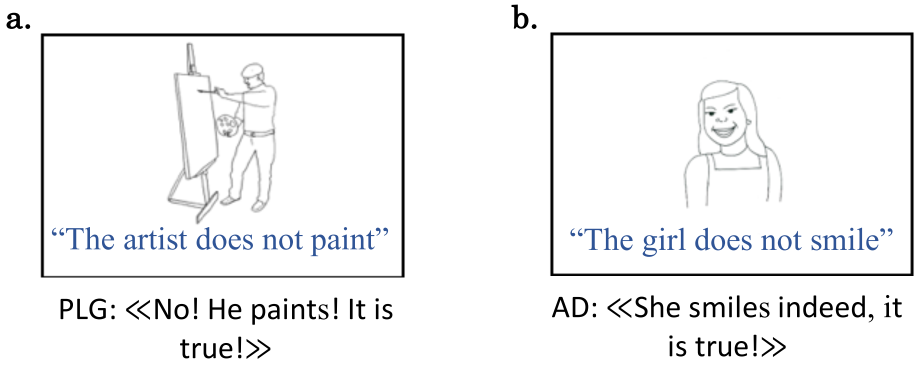

Figure 4.4. An example of how the same superficial phenomenon (e.g. an error in truth value assignment) may result from the failure of different cognitive mechanisms.

These examples show that the same data (i.e., an incorrect response to a FN item) may be due to the failure of completely different mechanisms – the formulation of a truth judgement (in a) or the processing of the negative marker (in b).

4. Conclusions

Language comprehension is a multifaceted phenomenon effortlessly performed by healthy cognitive systems. In the presence of brain damage, linguistic performance may be accessed indirectly through behavioral tasks. While offering a window on language impairment, linguistic tasks engage cognitive mechanisms that go beyond pure language processing. Thus, if carefully designed and analyzed, behavioral language tasks may focus on several high-level cognitive processes, allowing one to identify the cause of impaired performance, or to highlight an otherwise subclinical or undetected cognitive deterioration.

The data presented in this chapter show that damage to language areas yields impaired performance in sentence-picture verification, especially if sentences contain negation. The analysis on the Focal Group revealed that the damage may selectively affect negation processing, semantic processing or truth judgments assignment/decision making. Results from the Degenerative Group showed that sentence-picture verification may help identify cognitive deterioration due to neurodegeneration.

Overall, a sentence-picture verification task with simple affirmative and negative sentences is a promising tool for the investigation of language impairment. Moreover, the lack of strong correlation with other neuropsychological tests suggests that the experimental task and standard batteries measure partly independent skills, and provides useful insights for the investigation of acquired language disorders.

Conclusions

The present work set out to deal in greater depth with some critical aspects of the traditional approach to Negation and to pave the way for the use of negative sentences in the study of acquired language impairment.

According to received knowledge, negation in language is a logical function which operates on affirmative propositions by changing their truth-value. On this view, negative sentences (e.g., "This book is not interesting") result from applying the logical truth-value operator (*not*) to affirmative contents ("This book is interesting"). Behavioral research on negative sentence processing has reported two main results: a) the processing of negative sentences is typically associated with longer response times and higher error rates if compared to that of affirmative sentences (see Ch. 1, par. 1.1), and b) the representation of the affirmative content in the scope of negation is a step of negative sentence processing (see Ch. 1, par. 1.2 and 1.3). The theoretical analysis provided by logic has thus been converted into the cognitive hypothesis that negative sentences are more complex structures than affirmatives and that their processing requires greater computational resources.

Nevertheless, neurofunctional results on negative sentence processing are sparse and inconclusive. On one hand, ERP studies reported contrasting results about whether the affirmative counterpart is engaged during negation processing or not (see Ch. 2, par. 1). On the other hand, previous fMRI studies have not arrived at a coherent comprehension of the neural and cognitive correlates of negative sentence processing. The increased BOLD signal with negative compared to affirmative sentence verification in left hemisphere language areas has been attributed to greater computational demands posed by processing negation (see Ch. 2, par. 2). The decreased BOLD signal with negative compared to affirmative sentence listening in brain areas engaged by action-verb processing has been interpreted by proposing that negation reduces access to semantic information (see Ch. 2, par. 3).

The study presented in Ch. 3 was designed to further explore the neural and cognitive correlates associated with negative sentence verification. On one hand, the stimuli design avoided possible task-related bias involved by the studies attesting the negation-by-truth interaction effect. On the other hand and differently to previous fMRI experiments based on sentence verification, the analysis of neural activity has not been limited to the overall contrast between affirmative and negative items, but has been extended to the computation of the contrasts within affirmative and negative items (i.e., true affirmative vs. false affirmative, and true negative vs. false negative items). The analysis of these contrasts has allowed to explore the role of the LIFG during sentence verification, and to attribute to the verification task the cognitive demands previously ascribed to negation processing. Previous fMRI studies based on sentence verification found increased activation in the LIFG and in the left middle frontal gyrus with negative as compared to affirmative sentence verification, and attributed this to greater computational demands specific to negation processing. In the present work increased activity in the left inferior frontal gyrus was observed with negative vs affirmative sentences, but also with false vs true affirmative sentences, suggesting that the modulation of neural activity in the LIFG during sentence verification is not due to structural computations specific to negation processing (see Ch 3., par. 2.2). Moreover, no differences were found in terms of RTs, accuracy and activation patterns between true and false negative items. This last result is compatible with the idea that the intermediate representation of the negated concept postulated by the logical approach and the two-step models is a task-related effect or a processing step restricted to specific negative forms (e.g., uni-polar predications, see Ch. 2, par. 2.1), rather than the default strategy of negation processing. Our results are in line with the idea that the 'effort' observed in linguistic tasks with negative sentences may be due to extrinsic, non-linguistic task demands, rather than to a complexity intrinsic to negation. On this account, negative sentences would not be intrinsically more complex than affirmatives, but would be at a disadvantage during tasks, such as sentence-picture verification, that involve competing semantic representations.

The complexity engaged by linguistic tasks with negative sentences was used in Chapter 4 to asses acquired language impairment. The main idea was to test whether a linguistic task that engages cognitive abilities that exceed pure language processing (such as sentence verification with affirmative and negative sentences) may help identify the cause of poor sentence comprehension in individuals with brain damage. Thirty-one individuals with aphasia and thirty-seven individuals with diagnosed degenerative dementia were tested with an adaptation of the sentence-picture verification paradigm presented in Ch. 3. The comparison between patients and the control group revealed that sentence-picture verification is overall problematic for people with brain injury, especially if sentences contain negation. However, the most interesting data come from the analysis of performance within the two groups of brain-damaged participants. Analyses on focal patients showed that the sentence-picture verification test allows identifying at least three distinct cognitive domains that may be selectively interested by the damage, i.e. pure language (negation) processing, semantic processing and truth judgment assignment/decision making. The results of the Degenerative Group showed that the Sentence-Picture Verification Test is highly sensitive to cognitive impairment and that it measures partly independent skills in relation to standard batteries. We suggest that sentence-picture verification tasks are a promising tool in the assessment of language impairment, since they allow to disentangle pure language processing from domain-general cognitive mechanisms and may help identifying cognitive decline due to neurodegeneration.

The experimental paradigms that ask people 'to do something' with sentences (as verification, probe matching, lexical decision, congruency judgement, and so on) entail cognitive resources that exceed pure sentence comprehension. The data obtained from this kind of tasks thus provide information about how people verify, make semantic judgements or lexical choices with sentences, rather than a direct access to the way sentences are processed.

The cognitive effort observed with negative sentences in several linguistic tasks has been traditionally attributed to greater processing demands of negative as compared to affirmative sentences. The present work has pointed out that the behavioral and neuroimaging results observed during sentence-picture verification, and putatively ascribed to an intrinsic complexity of negation, may not concern negation processing *per se*. Sentence-picture verification is indeed demanding for healthy subjects and brain damaged patients also in the case of false affirmative items, and the same (left frontal) network is engaged by false affirmative, true negative and false negative items as compared to true affirmative items. Moreover, data from patients showed that poor performance in this kind of task may result from disruptions that do not concern negation processing *per se*, and that sentence verification may be impaired also with an intact sentence comprehension. Taken together, these results suggest that task performance on different types of linguistic structure may diverge for reasons other than pure linguistic complexity. As regard to the sentence-picture verification paradigm, two aspects in particular put negative sentence processing at disadvantage as compared to affirmative sentence processing: 1) the semantic indefiniteness of negation (i.e. the fact that, differently to affirmatives, negative sentences do not allow to identify/represent a precise state of affairs) and 2) the absence of an adequate context that prevents negative sentence interpretation from being odd. On one hand, the semantic indefiniteness challenges sentence verification as participants are forced to compare the semantic content of the sentence with that of the picture. On the other hand, the fact of being pragmatically unlicensed increases the processing cost of negative sentences, that differently to affirmatives are not uttered appropriately without a context to deny (see Ch. 1, par. 2). These two aspects could be at the basis of the main effect of *polarity* found for both RTs and accuracy data (i.e., negative items always slower and less accurate than affirmative items). In other words, negative sentence processing would not be intrinsically more complex than that of affirmatives, but more disadvantaged by the specific task adopted. The fact that, at the level of brain activity, false affirmative items showed an activation pattern comparable to that of false and true negative items as compared to true affirmative items may be due to our fMRI setting being insensitive to these fine-grained aspects of language processing. Our experimental design indeed failed to find any difference also between related and unrelated semantic contents.

Future attempts at understanding pure negation processing should adopt experimental designs that reduce to a minimum the task computations that yield confounding effects of language processing. A very suitable option is given by passive listening paradigms, possibly with control tasks that ensure participants process the sentences they hear (e.g., comprehension questions interspersed among stimuli). Context-dependency and semantic indefiniteness may be addressed using world-knowledge based sentences. Consider sentence (8):

(8). The epidemy has not spread among those below 10 years old.

The meaning of sentence (8) is clearly much more circumscribable and identifiable than that of any of the negative sentences proposed throughout the present work. It is indeed easily paraphrased in one single positive state of affairs sounding as "Children below 10 years old have some sort of resistance to the virus" or "Children below 10 years old stay healthy so far". This is basically because there is a common knowledge of the world that tells us that epidemies usually affect the population regardless of the age, and that children and elders are actually the weakest subjects. Since it goes against shared presuppositions, sentence (8) is highly informative and its interpretation allows to select one more salient state of affairs. In cases like (8) negative sentences are licensed by the context provided by common world-knowledge. This context is implicitly carried by words, and thus sentences of this type may be feasible candidates for passive listening paradigms that try to create balanced environments for affirmative and negative sentence processing.

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Appendix 1

Experimental Stimuli

1. Sentences

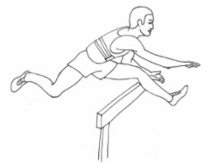
Verb ID	Polarity	Italian version	Spanish version
1	A(ffirmative)	L’uomo scivola	El hombre resbala
	N(egative)	L’uomo non scivola	El hombre no resbala
2	A	La ragazza piange	La chica llora
	N	La ragazza non piange	La chica no llora
3	A	La bambina ride	La nina ríe
	N	La bambina non ride	La nina no ríe
4	A	La donna telefona	La mujer llama
	N	La donna non telefona	La mujer no llama
5	A	Il contadino semina	El agricultor siembra
	N	Il contadino non semina	El agricultor no siembra
6	A	Il marinaio rema	El marinero rema
	N	Il marinaio non rema	El marinero no rema
7	A	Il pilota gareggia	El piloto conduce
	N	Il pilota non gareggia	El piloto no conduce
8	A	L’atleta salta	El atleta salta
	N	L'atleta non salta	El atleta no salta
9	A	Il medico scrive	El medico escribe
	N	Il medico non scrive	El medico no escribe
10	A	Il bambino mangia	El niño come
	N	Il bambino non mangia	El niño no come
11	A	Il ragazzo fuma	El chico fuma
	N	Il ragazzo non fuma	El chico no fuma
12	A	Il vigile legge	El vigilante lee
	N	Il vigile non legge	El vigilante no lee
13	A	Il cuoco cucina	El chef cocina
	N	Il cuoco non cucina	El chef no cocina
14	A	La signora spazza	La señora barre

	N	La signora non spazza	La señora no barre
15	A	L'artista dipinge	El artista pinta
	N	L'artista non dipinge	El artista no pinta
16	A	Il signore beve	El señor bebe
	N	Il signore non beve	El señor no bebe
17	A	La ballerina danza	La bailarina baila
	N	La ballerina non danza	La bailarina no baila
18	A	Il principe cavalca	El príncipe cabalga
	N	Il principe non cavalca	El príncipe no cabalga
19	A	La maestra parla	La maestra habla
	N	La maestra non parla	La maestra no habla
20	A	Il pompiere dorme	El bombero duerme
	N	Il pompiere non dorme	El bombero no duerme

2. Pictures

Verb ID	**Mentioned**	**Not mentioned - Related**	**Not mentioned - Unrelated**
1	 1.1	 1.2	 1.3
2	 2.1	 2.2	 2.3

3	 3.1	 3.2	 3.3
4	 4.1	 4.2	 4.3
5	 5.1	 5.2	 5.3
6	 6.1	 6.2	 6.3
7	 7.1	 7.2	 7.3

8	 8.1	 8.2	 8.3
9	 9.1	 9.2	 9.3
10	 10.1	 10.2	 10.3
11	 11.1	 11.2	 11.3
12	 12.1	 12.2	 12.3

13	 13.1	 13.2	 13.3
14	 14.1	 14.2	 14.3
15	 15.1	 15.2	 15.3
16	 16.1	 16.2	 16.3
17	 17.2	 17.2	 17.3

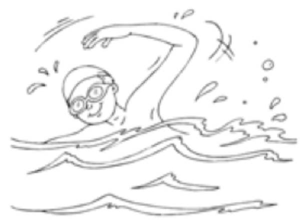
18	 18.1	 18.2	 18.3
19	 19.1	 19.2	 19.3
20	 20.1	 20.1	 20.3

Appendix 2

Experimental Material fMRI Experiment

1. Practice material

El niño escribe

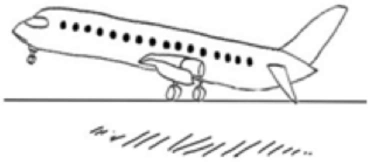


El chico no nada

El ladrón anda

El chico no nada

2. Items



El avión no vuela

El chico resbala

2. Items

Block 1

Verb ID	Condition	Sentence	Picture
1	TA	El hombre resbala	1.1
2	FrA	La chica llora	2.2
13	TrN	El chef cocina	13.2
11	TuN	El chico no fuma	11.3
3	FN	El niña no ríe	3.1
4	TA	La mujer telefonea	4.1
7	TrN	El piloto no conduce	7.2
15	FuA	El artista pinta	15.3
8	FrA	El atleta salta	8.2
19	TA	La maestra habla	19.1
17	FrA	La bailarina baila	17.2
10	TA	El niño come	10.1
1	TrN	El hombre no resbala	1.2
18	FuA	El príncipe cabalga	18.3
12	FuA	El vigilante lee	12.3

20	TuN	El bombero no duerme	20.3
16	TA	El señor bebe	16.1
9	FN	El médico no escribe	9.1
19	TrN	La maestra no habla	19.2
13	TA	El chef cocina	13.1
15	FN	El artista no pinta	15.1
14	FrA	La señora barre	14.2
3	FuA	La niña ríe	3.3
10	TrN	El niño no come	10.2
6	FuA	El marinero rema	6.3
4	TrN	La mujer no telefonea	4.2
9	FuA	El medico no escribe	9.3
35	TuN	El agricultor no siembra	5.3
16	TrN	El señor no bebe	16.2
7	TA	El piloto conduce	7.1
11	FrA	El chico fuma	11.2
17	TuN	La bailarina no baila	17.3
8	TuN	El atleta no salta	8.3
20	FrA	El bombero duerme	20.2
14	TuN	La señora no barre	14.3
12	FN	El vigilante no lee	12.1
6	FN	El marinero no rema	6.1
5	FrA	El agricultor siembra	5.2
2	TuN	La chica no llora	2.3
18	FN	El príncipe no cabalga	18.1

Block 2

Verb ID	Condition	Sentence	Picture
11	FuA	El chico fuma	11.3
3	TA	La niña ríe	3.1
5	FuA	El agricultor siembra	5.3
20	FN	El bombero no duerme	20.1
16	TuN	El señor no bebe	16.3
2	FuA	La chica llora	2.3
9	TrN	El médico no escribe	9.2
4	FrA	La mujer telefonea	4.2
10	TuN	El niño no come	10.3
18	TA	El príncipe cabalga	18.1
14	FN	La señora no barre	14.1
5	FN	El agricultor no siembra	5.1
8	FuA	El atleta salta	8.3
15	TA	El artista pinta	15.1
17	FN	La bailarina no baila	17.1
12	TrN	El vigilante no lee	12.2
14	FuA	La señora barre	14.3
1	TuN	El hombre no resbala	1.3
13	TuN	El chef no cocina	13.3
20	FuA	El bombero duerme	20.3
6	TrN	El marinero no rema	6.2
8	FN	El atleta no salta	8.1
19	FrA	La maestra habla	19.2
18	TrN	El príncipe no cabalga	18.2
16	FrA	El señor bebe	16.2
12	TA	El vigilante lee	12.1
7	TuN	El piloto no conduce	7.3

13	FrA	El chef cocina	13.2
3	TrN	La niña no ríe	3.2
10	FrA	El niño come	10.2
11	FN	El chico no fuma	11.1
17	FuA	La bailarina baila	17.3
15	TrN	El artista no pinta	15.2
9	TA	El médico escribe	9.1
1	FrA	El hombre resbala	1.2
2	FN	La chica no llora	2.1
4	TuN	La mujer no telefonea	4.3
6	TA	El marinero rema	6.1
7	FrA	El piloto conduce	7.2
19	TuN	La maestra no habla	19.3

Block 3

Verb ID	Condition	Sentence	Picture
8	TA	El atleta salta	8.1
13	FN	El chef no cocina	13.1
7	FuA	El piloto conduce	7.3
18	FrA	El príncipe cabalga	18.2
12	TuN	El vigilante no lee	12.3
1	FuA	El hombre resbala	1.3
6	TuN	El marinero no rema	6.3
11	TA	El chico fuma	11.1
3	TuN	La niña no ríe	3.3
15	FrA	El artista pinta	15.2
14	TrN	La señora no barre	14.2
13	FuA	El chef cocina	13.3
20	TrN	El bombero no duerme	20.2

16	FuA	El señor bebe	16.3
2	TrN	La chica no llora	2.2
6	FrA	El marinero rema	6.2
8	TrN	El atleta no salta	8.2
10	FuA	El niño come	10.3
19	FN	La maestra no parla	19.1
17	TA	La bailarina baila	17.1
9	TuN	El médico no escribe	9.3
5	TrN	El agricultor no siembra	5.2
3	FrA	La niña ríe	3.2
2	TA	La chica llora	2.1
11	TrN	Il chico no fuma	11.2
12	FrA	El vigilante lee	12.2
4	FN	La mujer no telefonea	4.1
20	TA	El bombero duerme	20.1
17	TrN	La bailarina no baila	17.2
9	FrA	El médico escribe	9.2
14	TA	La señora barre	14.1
1	FN	El hombre no resbala	1.1
19	FuA	La maestra parla	19.3
18	TuN	El príncipe no cabalga	18.3
10	FN	El niño no come	10.1
5	TA	El agricultor siembra	5.1
7	FN	El piloto no conduce	7.1
15	TdN	El artista no pinta	15.3
4	FdA	La mujer telefonea	4.3
16	FN	El señor no bebe	16.1

Appendix 3

Activated Brain Regions when contrasting Affirmative and Negative items, TA and F, TN and FN, TA and FN, TA and TN.

Region	Z	MNI coordinates		
		x	y	z
Affirmative vs. Negative				
L/R Precuneus	4,05	4	-42	44
L/R Cingulate Gyrus				
Negative vs. Affirmative				
L Inferior Frontal Gyrus, pars opercularis	4,66	-46	20	24
L Middle Frontal Gyrus				
L Inferior Frontal Gyrus, pars triangularis				
L Frontal Orbital Cortex	4,44	-44	20	-6
L Frontal Operculum Cortex				
L Insular Cortex				
L Frontal Pole	3,91	-54	42	2
TA vs. FA				
L Postcentral Gyrus	6,30	-46	-28	62
L Superior Parietal Lobule				
L Supramarginal Gyrus, anterior division	5,92	-54	-24	46
L Precentral Gyrus	5,30	-36	-22	68
L Parietal Operculum Cortex	4,41	-50	-24	16
L Central Opercular Cortex				
L Heschl's Gyrus				
L Planum Temporale				
FA vs. TA				
R Postcentral Gyrus	5,80	42	-14	56
R Precentral Gyrus				
R Superior Parietal Lobule	3,69	36	-42	68
L Inferior Frontal Gyrus, pars opercularis	4,71	-46	20	24
L Middle Frontal Gyrus				

L Inferior Frontal Gyrus, pars triangularis				
L Frontal Orbital Cortex	3,42	-46	24	-10
L Frontal Operculum Cortex				
L Frontal Pole	3,26	-52	36	-2
TN vs. FN				
L Postcentral Gyrus	4,59	-38	-28	56
L Precentral Gyrus				
FN vs. TN				
R Postcentral Gyrus	4,75	40	-20	50
R Precentral Gyrus				
TN vs. TA				
L Inferior Frontal Gyrus, pars opercularis	6,44	-46	20	24
L Middle Frontal Gyrus				
L Inferior Frontal Gyrus, pars triangularis				
L Precentral Gyrus	5,17	-50	18	16
L Frontal Orbital Cortex	5,11	-44	24	-12
L Frontal Operculum Cortex				
L Frontal Pole	4,84	-52	36	-2
TA vs. TN				
R Cingulate Gyrus, posterior division	4,19	6	-28	40
R Precuneus Cortex				
R Cingulate Gyrus, anterior division				
L Cingulate Gyrus, posterior division	3,88	-2	-28	36
L Precuneus Cortex				
L Central Opercular Cortex	4,11	-58	-8	10
L Postcentral Gyrus				
L Planum Polare				
L Planum Temporale				
L Postcentral Gyrus	3,87	-64	-16	36
L Supramarginal Gyrus, anterior division				
L Superior Temporal Gyrus, anterior posterior division	3,56	-60	-10	4
L Central Opercular Cortex				
L Superior Temporal Gyrus, anterior division				
L Superior Temporal Gyrus, posterior division				
Heschl's Gyrus				

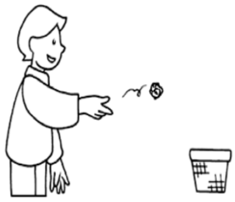
R Supramarginal Gyrus, posterior division	3,73	60	-38	40
R Supramarginal Gyrus, anterior division				
R Parietal Operculum Cortex				
R Angular Gyrus				
R Planum Temporale	3,63	62	-40	34
R Superior Temporal Gyrus, posterior division	3,46	66	-34	38
TA vs. FN				
L Postcentral Gyrus	5,57	-44	-28	60
L Precentral Gyrus				
L Superior Parietal Lobule	4,39	-32	-42	66
L Supramarginal Gyrus, anterior division				
L/R Precuneus Cortex	3,90	0	-44	44
L/R Cingulate Gyrus, posterior division				
L Cingulate Gyrus, posterior division	3,54	-6	-24	40
L Precuneus Cortex				
L Cingulate Gyrus, anterior division				
R Cingulate Grryus, posterior division	3,18	6	-44	20
R Precuneus Cortex				
FN vs. TA				
L Inferior Frontal Gyrus, pars opercularis	4,83	-46	20	24
L Middle Frontal Gyrus				
L Inferior Frontal Gyrus, pars triangularis				
L Precentral Gyrus	4,19	-54	16	16
L Frontal Orbital Cortex	4,18	-46	24	-10
L Frontal Operculum Cortex				
L Frontal Pole	4,10	-54	42	2
L Frontal Orbital Cortex				
R Precentral Gyrus	5,54	40	-18	50
R Postcentral Gyrus				
R Superior Parietal Lobule	2,86	36	-42	68

Appendix 4

Experimental Material of the Negation Test administered to patients with brain damage

1. Practice material

Sentence	Picture
Il bambino scrive	
Il ragazzo non nuota	
Il ladro cammina	
Il bambino non piange	

La donna non lava i piatti	
Il ragazzo sta seduto	
Il bambino non si lava i denti	
Il bambino si pettina	
Il ragazzo nuota	

L'aereo non vola	
Il ragazzo scivola	

2. Items

Block 1

Verb ID	Condition	Sentence	Picture
1	TA	L'uomo scivola	1.1
2	FrA	La ragazza piange	2.2
13	TrN	Il cuoco non cucina	13.2
11	TuN	Il ragazzo non fuma	11.3
3	FN	La bambina non ride	3.1
4	TA	La donna telefona	4.1
7	TrN	Il pilota non gareggia	7.2
15	FuA	L'artista dipinge	15.3
8	FrA	L'atleta salta	8.2
19	TA	La maestra parla	19.1
17	FrA	La ballerina danza	17.2
10	TA	Il bambino mangia	10.1
1	TrN	L'uomo non scivola	1.2
18	FuA	Il principe cavalca	18.3
12	FuA	Il vigile legge	12.3

20	TuN	Il pompiere non dorme	20.3
16	TA	Il signore beve	16.1
9	FN	Il medico non scrive	9.1
19	TrN	La maestra non parla	19.2
13	TA	Il cuoco cucina	13.1
15	FN	L'artista non dipinge	15.1
14	FrA	La signora spazza	14.2
3	FuA	La bambina ride	3.3
10	TrN	Il bambino non mangia	10.2
6	FuA	Il marinaio rema	6.3
4	TrN	La donna non telefona	4.2
9	FuA	Il medico scrive	9.3
5	TuN	Il contadino non semina	5.3
16	TrN	Il signore non beve	16.2
7	TA	Il pilota gareggia	7.1
11	FrA	Il ragazzo fuma	11.2
17	TuN	La ballerina non danza	17.3
8	TuN	L'atleta non salta	8.3
20	FrA	Il pompiere dorme	20.2
14	TuN	La signora non spazza	14.3
12	FN	Il vigile non legge	12.1
6	FN	Il marinaio non rema	6.1
5	FrA	Il contadino semina	5.2
2	TuN	La ragazza non piange	2.3
18	FN	Il principe non cavalca	18.1

Block 2

Verb ID	Condition	Sentence	Picture
11	FuA	Il ragazzo fuma	11.3
3	TA	La bambina ride	3.1
5	FuA	Il contadino semina	5.3
20	FN	Il pompiere non dorme	20.1
16	TuN	Il signore non beve	16.3
2	FuA	La ragazza piange	2.3
9	TrN	Il medico non scrive	9.2
4	FrA	La donna telefona	4.2
10	TuN	Il bambino non mangia	10.3
18	TA	Il principe cavalca	18.1
14	FN	La signora non spazza	14.1
5	FN	Il contadino non semina	5.1
8	FuA	L’atleta salta	8.3
15	TA	L’artista dipinge	15.1
17	FN	La ballerina non danza	17.1
12	TrN	Il vigile non legge	12.2
14	FuA	La signora spazza	14.3
1	TuN	L’uomo non scivola	1.3
13	TuN	Il cuoco non cucina	13.3
20	FuA	Il pompiere dorme	20.3
6	TrN	Il marinaio non rema	6.2
8	FN	L'atleta non salta	8.1
19	FrA	La maestra parla	19.2
18	TrN	Il principe non cavalca	18.2
16	FrA	Il signore beve	16.2
12	TA	Il vigile legge	12.1
7	TuN	Il pilota non gareggia	7.3

13	FrA	Il cuoco cucina	13.2
3	TrN	La bambina non ride	3.2
10	FrA	Il bambino mangia	10.2
11	FN	Il ragazzo non fuma	11.1
17	FuA	La ballerina danza	17.3
15	TrN	L'artista non dipinge	15.2
9	TA	Il medico scrive	9.1
1	FrA	L'uomo scivola	1.2
2	FN	La ragazza non piange	2.1
4	TuN	La donna non telefona	4.3
6	TA	Il marinaio rema	6.1
7	FrA	Il pilota gareggia	7.2
19	TuN	La maestra non parla	19.3

Block 3

Verb ID	Condition	Sentence	Picture
8	TA	L'atleta salta	8.1
13	FN	Il cuoco non cucina	13.1
7	FuA	Il pilota gareggia	7.3
18	FrA	Il principe cavalca	18.2
12	TuN	Il vigile non legge	12.3
1	FuA	L'uomo scivola	1.3
6	TuN	Il marinaio non rema	6.3
11	TA	Il ragazzo fuma	11.1
3	TuN	La bambina non ride	3.3
15	FrA	L'artista dipinge	15.2
14	TrN	La signora non spazza	14.2
13	FuA	Il cuoco cucina	13.3
20	TrN	Il pompiere non dorme	20.2

16	FuA	Il signore beve	16.3
2	TrN	La ragazza non piange	2.2
6	FrA	Il marinaio rema	6.2
8	TrN	L'atleta non salta	8.2
10	FuA	Il bambino mangia	10.3
19	FN	La maestra non parla	19.1
17	TA	La ballerina danza	17.1
9	TuN	Il medico non scrive	9.3
5	TrN	Il contadino non semina	5.2
3	FrA	La bambina ride	3.2
2	TA	La ragazza piange	2.1
11	TrN	Il ragazzo non fuma	11.2
12	FrA	Il vigile legge	12.2
4	FN	La donna non telefona	4.1
20	TA	Il pompiere dorme	20.1
17	TrN	La ballerina non danza	17.2
9	FrA	Il medico scrive	9.2
14	TA	La signora spazza	14.1
1	FN	L’uomo non scivola	1.1
19	FuA	La maestra parla	19.3
18	TuN	Il principe non cavalca	18.3
10	FN	Il bambino non mangia	10.1
5	TA	Il contadino semina	5.1
7	FN	Il pilota non gareggia	7.1
15	TuN	L'artista non dipinge	15.3
4	FuA	La donna telefona	4.3
16	FN	Il signore non beve	16.1