On Idioms: Cornerstones for a Neurological Model of Language Processing*

Dieter G. Hillert

University of California, San Diego

The examination of the cognitive and neural correlates of idiom comprehension is an excellent test ground for a neurological model of language processing. Idioms are hybrid linguistic elements: They carry similar to metaphors figurative meanings, but employ also alternative parsing strategies. Here new evidence will be discussed that predicts comprehension of figurative meanings by means of temporal and spatial parameters. Accordingly, an account of the human language system is suggested that divides between a left-sided Core Language System (CLS) and a bilateral Pragmatic Language Network (PLN). Online comprehension of literal and idiomatic phrases seems to take place exclusively in the core language system. Moreover, the computational costs associated with idiom processing seem to be compatible with those costs related to syntactic ambiguity resolution or to syntactic movements. In contrast, creative figurative meanings such as metaphors may be primarily a domain of the bilateral pragmatic language network. Several conclusions will be drawn about the cognitive and neural correlates of language processing.

Keywords: Broca's area, figurative language, idioms, language disorders, language system, neuroimaging, pragmatics, semantics, sentence processing, syntax

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“Es gibt keine induktive Methode, welche zu den Grundbegriffen der Physik führen könnte.” There is no inductive method, which would lead to the fundamental concepts of physics.

-Albert Einstein [Physik und Realität, 1936]

1. Introduction

In modifying the above mentioned quote on physics by Albert Einstein, the fundamental methodological problem of linking linguistic and neuronal events can be emphasized: “There is no inductive method, which would lead to the fundamental concepts of linguistics, a statement that could have been introduced by proponents of Cartesian linguistics (e.g., Chomsky, 1966; 1968). However, Albert Einstein (1936) himself writes that “linking the basic terms of everyday thinking with the complexity of sensory experiences is only intuitively apprehensible and inaccessible to scientific (logical) assessment.”¹ In the attempt to describe the relationship between brain and linguistic behavior, neurolinguistic research is faced with the full complexity of this fundamental methodological problem (e.g., Sereno, 1991; Marshall & Fink, 2003; Chomsky, 2000; Poeppel & Embick, 2004; Schall, 2004). However, during the last two decades the gap between basic concepts in linguistics and empirical science became closer to allow a more fruitful exchange between theory and data. The reason is that both fine-grained analyses of linguistic structures and the development of advanced neuroimaging techniques are important cornerstones in the attempt to model the human language system. Considerable progress has been achieved in developing neuroimaging tools, which substantially increases our ability to measure non-invasively the spatial and temporal parameters of cognitive events. At the same it is also essential to capture these cognitive events formally and coherently to explore the cognitive mechanism underlying subtle linguistic computations.

Herein we focus primarily on the neural basis of parsing idiomatic units, a topic more controversially discussed since the late seventies (see for reviews Fernando & Flavell, 1978; Cermák, 1988; Gibbs & Nayak, 1989; Jackendoff, 1995; 1997; 2002). Idioms are an excellent test ground for the examination of lexical access and selection because in contrast to metaphoric and unambiguous literal language they typically involve for comprehension alternative parsing strategies. To examine the neural underpinning of how idiomatic meanings are accessed and selected during sentence comprehension, new functional magnetic resonance imaging (fMRI) data on idiom processing will be discussed within the framework of a neurological model of language comprehension.

However, let us first introduce the proposed cornerstones of the underlying theoretical framework, before turning to new empirical findings: While lexical computations involve access to semantic and/or conceptual representations in long-term memory (content), syntactic computations generate parsing structures in working memory (form). The difference between semantic and conceptual information is not only theoretically motivated, but also empirically grounded (cf. Katz & Fodor, 1963; Katz, 1972; 1973; 1980). Semantic computations can be regarded as the interface between syntactic algorithms and non-linguistic conceptualizations. While semantic representations include properties that are relevant for the syntactic analysis of a sentence such as the thematic roles of a verb or the lexical semantic entries associated with an idiomatic expression, concepts can be associated with meanings that are dissociated from linguistic constrains.

The neural correlates of semantic, syntactic or conceptual computations seem to be dissociated. During online or real-time sentence comprehension semantic or syntactic computations seem to take place primarily in the classical language regions, which include Wernicke’s and Broca’s area. In contrast, conceptual computations, however, seem to take place throughout the cortex and can be accessed from different access points intrinsically or extrinsically to the left-sided classical fronto-temporal language network. The neurological language model discussed here considers in addition to levels of linguistic and conceptual representations qualitatively different types of computations associated with these levels of representations. For instance, syntactic default structures such as the canonical word order may be stored and accessed in different cortical regions than those syntactic computations that require
complex operations to generate a meaningful interpretation. The analysis of language-related lesion studies and the results of functional neuroimaging experiments point to the following four premises:

(i) **Lexical dataset:** Semantic and syntactic representations are a subset of information stored in the mental lexicon and are typically accessed in the left superior and middle temporal gyrus.

(ii) **Syntactic algorithms:** Syntactic categories and phrases are shifted to parse alternative structures and these algorithms seem to take place consistently in the left inferior frontal gyrus.

(iii) **Conceptual inferences:** Meaning constructions vary in their degree of computational complexity and are accessed through episodic access points (traces) predominantly in the temporal-hippocampal region and in the prefrontal cortex.

(iv) **Linguistic modularity:** Fast-acting linguistic operations are organized in a modular fashion, but their neural correlates are shared by different cognitive domains.

Premises (i-iv) are derived from the data discussed and represent the framework of the proposed neurological model of language processing. In general, the model divides between the Core Language System (CLS) and the Pragmatic Language Network (PLN). This distinction is different from the idea presented by Hauser, Chomsky and Fitch (2002). They state that only the narrow language faculty is equipped with the uniquely human property of recursion. However, Everett (2005) for example reported that the language *Pirahã*, spoken by a tribe of about two hundred Amazonian natives (Hi’aiti’ihi), does not make use of recursion. Again, Gentner, Fenn, Margoliash and Nusbaum (2006) experiments indicate that songbirds (European starlings) may be able to learn these recursive patterns, although as Marcus (2006) argues they may not be able to generalize recursive patterns to new sounds. Finally, recursion is a cognitive algorithm, which can be observed in other cognitive domains such as music as well. Thus, at present it is unclear whether recursion in sentence processing is domain-specific and a unique and essential property of the human language system. More important for sentence processing seems to be people’s ability to hold incoming speech in a linguistic buffer for re-
analysis and re-interpretation. Re-computations seem to be essential for comprehension of complex sentence structures, including the resolution of syntactic ambiguities as it is the case for idiomatic expression. Thus, to mention only two basic properties, the creative usage of lexical concepts as well as the cognitive ability to (re)compute relatively complex syntactic structures appear to be unique features of the human language system.

Here it is suggested that the CLS operates during a narrow time window of a few hundreds milliseconds. The PLN processes linguistic information beyond this narrow time window and computes relatively complex concepts and propositions. It processes lexical and morpho-syntactic information in an automatic and modular fashion. This two-level approach seems to be compatible to some extent with Townsend and Bever’s (2001) Late Assignment of Syntax Theory (LAST). In the first step, the language system computes a low-level segmentation of words into phrases (default parse), before grammar generates in a second step a more detailed structure. Townsend and Bever refer to online processing evidence they found for \textit{wh}- and NP-fillers. Since \textit{wh}-sentences provide explicit cues, \textit{wh}-gaps are filled immediately; in contrast, an assignment of antecedents to NP-gaps occurs relatively late during sentence comprehension, because no explicit cues are provided. In discussing how people compute literal and non-literal meanings, the distinction between the CLS and PLN is methodologically extremely useful. Here we focus on the cognitive and neural process underlying comprehension of idiomatic expressions. Much like metaphors, they refer to figurative meanings. However, only idiomatic expressions require alternative syntactic strategies as it is required for the resolution of syntactic ambiguities.

\textbf{Linguistic analysis}

\textit{Parsing alternative structures}

Idioms are a subset of a broad range of different types of fixed expressions such as (e.g., collocations, titles and names, or verb particle constructions (Jackendoff, 1997; 2002; Hillert & Ackermann, 2002). They are idiosyncratic as they are violating often morpho-syntactic rules. An idiom may be stored as a single unit in the mental lexicon, because its figurative meaning cannot be derived from the individual word meanings it is composed of. Spoken comprehension of an ambiguous sentence such as \textit{Mary breaks the ice} involves
several parsing steps. Initially, the parser segments and merges incoming speech and generates a hierarchical syntactic structure between the lexical elements of the sentence. Regarding a literal reading of example (1), the verb assigns the Θ-role Agent (Ag) to the subject NP and reserves an argument slot for the Θ-role Theme (Th). The subject noun phrase (NP) and the following verb phrase (VP) need to be merged to generate a sentence structure.

In turn, the Θ-role Theme will be activated and the parser’s output will be mapped onto a semantic representation. For different possible reasons such as the bias of a pragmatic context and/or the high familiarity of an idiomatic expression the parser computes at the idiom recognition point a non-compositional, alternative reading. If this occurs at a very early access stage, the parser needs only to suppress the thematic slots already activated to assign the verb an intransitive function (2). In general, different parsing strategies can apply, depending on onset cue, contextual bias and/or frequency. Which factors or combination of factors determine access to a figurative reading, is still controversially discussed.

Idioms vary in their degree of morpho-syntactic flexibility (e.g., Katz &
Postal 1964; Fraser, 1970; Newmeyer 1974). Whether certain syntactic operations can apply to a particular idiomatic expression seems to depend in many cases on pragmatic functions (Newmeyer, 1972). For example, a figurative reading of the passive in (3a) sounds odd, because the focus the bucket is not corresponding to any discourse entity.

(3) a. [The bucket was kicked]i [by Sam]j; *[Died]i [by Sam]j
b. [The beans]i [were spilled]j [by Mary]k : [The information]i [was revealed]j [by Mary]k

However, the passive phrase (3b) preserves a figurative interpretation, but in case of (3a) all lexical elements of the VP refer as a whole to a single concept. Again, the intransitive verb seem can modify very often an idiomatic expression. Example (4) indicates that an NP-movement is involved.

(4) The proposal does not hold water: [The proposal]i seems [ _i not to hold water]

In this example, however, a literal interpretation is less plausible, but the parser still needs to revise its initial (de)compositional analysis. While morphosyntactic rules apply at the surface structure of a sentence, how is it possible to license units larger than X^0 (terminal nodes), if syntactic movements can apply? ²
Two main proposals are discussed. In Chomsky’s (1981: note 94) version verbal idioms are treated as lexical verbs with internal structure (5a). In Jackendoff’s approach (1997) the complete idiomatic expression is indexed to the lexical conceptual level. As already discussed in (3), the subject and the direct object in kick the bucket are not stipulated on the semantic level (5b).³

(5) a. \[ V \ [VP \ [V \ kick] \ [NP \ the \ bucket]] \]
   b. \[ VP \ [V \ kick] \ [NP \ the \ bucket] \] \[ Event \ DIE ([ ] [ ])]

It is obvious that semantic information plays an important role in describing the syntactic flexibility of idioms (Wasow, Sag, & Nunberg, 1983). However, there is often no direct correlation between the lexical semantic and syntactic level, because many non-compositional idioms are to some extent syntactically flexible. As discussed below, a formal syntactic approach seems to be most suitable for analyzing the linguistic heterogeneity of idiomatic expressions and for predicting variance of computational complexity.

The role of syntactic features

Herewith an idiom account is proposed that considers individual syntactic flexibility in addition to preserving the figurative meaning on a syntactic level (6). This approach is to some extent comparable with van Gestel’s (1995) “en bloc insertion” account.⁴

Syntactic features pose constrains on the syntactic flexibility for idiomatic

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² In generative grammar, the surface structure (s-structure) of a sentence is derived from its deep structure (d-structure) via syntactic movements, traditionally called “transformations” (Chomsky, 1981). In X-bar (X’) theory \[X^0\] is the head or terminal node of the phrase, which is also called zero projection (e.g., Chomsky, 1986; Di Sciullo & Williams, 1987). Its value ranges over at least the lexical categories N (noun), A (adjective), V (verb), and P (proposition).

³ Marantz (1997; Halle & Marantz, 1994) postulate an additional semantic level of structural meanings to account for the observations that kick the bucket cannot mean die, because the verb phrase subcategorizes a direct object.

compounds (6a) or phrases (6b-c). They are introduced as negative features (inhibitors) at the head-level of the idiomatic structure that is co-indexed with the relevant semantic concepts. For instance, the figurative interpretation of a compound such as *duck soup* does not allow genitive [-Gen]. Again, topicalization and passive voice is not allowed for *kick the bucket* [-Top, -Pass], but for *spill the beans*. Topicalization or passive voice will not be suppressed, because no negative features constrain the relevant syntactic shifts (e.g., *The beans, the opposition spilled, …*). At this point it is worthwhile to mention that metaphoric expressions typically do not require alternative parsing strategies for comprehension, but lexical elements will be interpreted in an alternative conceptual space. For instance, in the non-conventional (novel) metaphoric expression *The botanical garden is the green lung of the city* the concept *park* receives new semantic features from the concept *lung* (+breath) which allows a comparison between the function of a “lung” and a “park”. The extension of the core meaning of a lexical concept A (grey circles) by the semantic properties of the core meaning of the lexical concept B (black circles) is illustrated in (7). Thus, metaphoric interpretations may occur post-syntactically on a pragmatic level (e.g., Lakoff & Johnson, 1980; Gibbs, 1994; Fauconnier, 1985; Fauconnier & Turner, 1998; Turner, 1996).

Conventional metaphors (e.g., *Love is a journey*; Lakoff, 1993) or image
metaphors (e.g., My wife’s waist is an hourglass; Lakoff & Turner, 1989) may involve the same type of conceptual mapping procedures as novel metaphors. Because of medium-to-high frequency of occurrence, conventional metaphors may require lower computational costs than novel metaphors. Comprehension of common idiomatic expression may, however, engage lexical-syntactic computations of the CLS; but constructing the meaning of metaphoric meanings may require lexical-conceptual operations, which vary in their complexity according to their degree of “conventionality”.

In turn, processing idiomatic structures requires access to alternative parsing structures and may therefore involve higher computational costs or a higher cognitive demand than a default literal parse. An increase of computational costs in complex sentence processing is typically associated with higher cortical activity in the prefrontal cortex, including Broca’s area. It is however also conceivable that parsing of idiomatic expressions occurs primarily in the left and/or right temporo-parietal region because of their particular lexical status. In contrast, metaphoric interpretation in general may involve a broader bilateral cortical network than idioms because their meanings are constructed on the conceptual level. The examination of how the human brain parses figurative meanings is an excellent test ground for modeling the neural basis of language processing.

**Mental Computations**
Conflicting processing accounts

In addition to providing a linguistic framework accompanied by a structural analysis it is important to specify the underlying mental computations for developing a cognitive model of language not immune to empirical results. Although behavioral studies contribute only indirectly to the neurological substrate of mental computations, some interesting processing differences were found for comprehension of literal, figurative, and anomalous sentences. Here we do not try to solve the dispute between different processing accounts, but discuss those cognitive and linguistic aspects that are relevant for a neurological model of language processing. As for idiom comprehension, overwhelming evidence speaks for a literal-independent and/or parallel access account: During sentence comprehension idiomatic meanings are accessed independently of literal meanings (e.g., Bobrow & Bell, 1973; Gibbs, 1980; Swinney & Cutler, 1979; Swinney, 1981; Ortony, Schallert, Reynolds, & Antos, 1978; Hillert & Swinney, 2000; Peterson, Burgess, Dell, & Eberhard, 2001; Peterson & Burgess, 1993; Estill & Kemper, 1982, McGlone, Glucksberg, & Cacciari, 1994). The configuration hypothesis is a literal-dependent or a serial access model of idiom comprehension and has been regarded as being incompatible with a parallel access account (e.g., Cacciari & Tabossi, 1988; Cacciari & Glucksberg, 1991; Tabossi & Zardon, 1993, 1995; Titone & Connine, 1994). It implies that idiomatic meanings are accessed at a recognition point, called idiom key. At this point a specific word combination predicts an idiomatic interpretation of the phrase. However, the experimental evidence presented in Cacciari and Tabossi (1988) is far from being conclusive as discussed in Hillert and Swinney (2000). For instance, in one experiment probes were presented at the offset of a sentence (Italian: *Il ragazzo pensava che suo fratello fosse nato con la camicia*; translation: *The boy believed that his brother was born with a silver spoon in his mouth*). An end-of-sentence effect (wrap-up factor) typically reflects the discourse meaning, which differs from local lexical semantic priming effects. Independent of this wrap-up factor, a significant trend for literal priming was found in addition to idiomatic priming, but perhaps discounted for the sake of the configuration account. In other words, literal and figurative meanings seemed to be always activated during idiom comprehension, but at which moment in time contextually irrelevant meanings will be inhibited seem to
depend largely on the familiarity and length of a single idiomatic expression. Independent of contextual bias the figurative meaning of *dog’s ear* may be accessed not earlier than at its offset (8a). By contrast, the figurative meaning of idiom *It’s raining cats and dogs* may be already accessed at the first word of the object NP, because people are quite familiar with this only-figuratively interpretable expression (8b).

It is important to emphasize at this point that the use of offline paradigms such as word-by-word reading or word-picture matching tasks may reveal completely different results than those found in an online task. The results of offline tasks typically involve cognitive inferences well beyond the time window, in which automatic linguistic computations are created. It is apparent that idiomatic expressions reflect a heterogeneous category and item- and subject-specific factors may play a crucial role in generating a particular figurative parse. Accordingly, the graded salience hypothesis tries to unify these different accounts. Depending on the degree of saliency, figurative and literal meanings are accessed in serial, parallel or direct (e.g., Cronk, Lima, & Schweigert, 1993; Chiarello, Burgess, Richards, & Pollock, 1990; Giora, 1997; Giora & Fein, 1999; Van Lancker-Sidtis, 2004). Here we suggest however an online sentence processing account that considers the processing mode in addition to item- and subject-specific factors.

**Online processing mode**

A computational account of idioms is proposed that considers the mode of processing as an important component for differentiating between distinct levels of computations. The mode of processing puts specific demands on cognitive resources. By using an experimental paradigm, that does not
constrain the task condition to a specific time window, cognitive resources may have been recruited not related to the hypothesis itself but to meta-cognitive abilities. As emphasized before, the examination of linguistic inferences generated by an offline task may produce results incompatible with those data found for automatic linguistic processing (e.g., Schneider & Shiffrin, 1977; Swinney, 1979; Fodor, 1983; Marslen-Wilson & Tyler, 1980; Levelt, 1989; Hillert, Barrington, & Gupta, 1994). Automatic linguistic computations do not draw on general resources. They operate rapid and mandatory governed by language-specific rules and constraint by specific working memory capacity (see Waters & Caplan, 2001; 2004). Error reports of a language processing task or increased BOLD (blood oxygen-level dependent) signals in an fMRI task may not be related to linguistic processes per se, but to post-perceptual inferences typically launched several hundreds milliseconds after automatic linguistic computations are completed. The process mode is an important aspect in empirical research on language to allow cross-fertilization between those studies that apparently produced contrary results (e.g., Swinney & Cutler, 1979; Estill & Kemper, 1982; Schweigert & Moates, 1988; Tompkins, 1990; Tompkins, Boada, & McGarry, 1992; Hillert, 2004). For instance, in Tompkin et al’s (1992) word-monitoring study target words appeared in biasing (literal or figurative) or neutral sentence contexts (e.g., target word: rat; biasing context: My lawyer was studying my contracts. When he smelled a rat, he warned me). Despite a relatively small token number, this online study indicates that patients with unilateral lesions (left- or right-sided) showed as healthy controls faster reaction times for the figuratively or literally biasing sentences compared to the unbiased sentences. However, in an idiom definition task both patients’ groups performed worse than the healthy control group.

During online sentence comprehension strings of words are sequentially processed and after accessing a new lexical entry, automatic bottom-up processes are continuously exposed to more general conscious processes. In other words, while it seems to be fairly safe to measure local online effects, information referring back to words presented previously in the sentence is necessarily enriched by pragmatic knowledge accessed in a controlled and conscious manner. Let us assume the listener hears It’s time to let the cat … and recognizes after the word cat that an alternative figurative interpretation of the sentence may be possible. During incoming speech, the CLS performs an
automatic default parse that generates a syntactic-semantic structure for a plausible literal interpretation. These compositional bottom-up processes are not halted or interrupted by the onset of the figurative parsing, but continue simultaneously until further downstream the contextually relevant interpretation will be selected. In contrast to literal-dependent models, the proposed model predicts that the CLS performs in any circumstances an automatic (de)compositional default parsing operation even when an alternative figurative reading has been activated during the parsing process. The alternative reading will be activated at the lexical onset of the idiomatic expression. Here we use the term *idiom onset* with respect to the sequence of words required to make contact with the figurative representation. In case of regular words, the onset starts with the first syllabus and activates multiple lexical entries until the selection of the relevant lexical entry occurs at the uniqueness point (Marslen-Wilson & Tyler, 1980). As previously mentioned, the length of the idiom onset depends on its specific properties and also on the listener’s familiarity with a particular expression. Overall, it is assumed that idiomatic meanings are accessed such as lexical concepts by the CLS system. Access to them occurs highly automatic, but examining these processes requires considering the incremental steps involved in literal and figurative computations of fixed expressions.

**Neural Correlates**

*The role of Broca’s area*

As any kind of cognitive function, the experimental investigation of linguistic processing is largely dependent on task-specific conditions to test a particular cognitive function. A function x can be spared or impaired in a single patient or patient group, depending on the type of task condition used. Thus, evidence requires to fractionate function x into x1 and x2 taking account of processing modes in addition to structural aspects. In spite of the problematic concept of (double) dissociations (Shallice, 1988; Van Orden, Pennington, & Stone, 2001), it reveals only limited information about the computations shared between neural and cognitive processes and about the structure and function of neural subsystems. However, since the beginning of modern cognitive neuropsychology at the end of the 19th century, findings of group and single-case lesion studies largely contributed to the question of the neural correlates of
language processing. However, lesion data are difficult to interpret to characterize specific linguistic properties of the unaltered and spared cognitive architecture. A large portion of linguistically relevant lesion data stems from aphasia research. Aphasia is typically caused by hemorrhage, ischemia, or trauma resulting in cortical lesions of the language centers (Broca’s and Wernicke’s areas) and neighboring (sub)cortical regions. In addition, brain tumors and progressive neurological disease (e.g., Alzheimer’s or Parkinson diseased) can also cause aphasic symptoms. People’s language functions are primarily left-sided (95% of right-handers; 61.4% of left-handers) given that only about 10% of the world population is left-handed (Taylor & Taylor, 1990).

The birth of modern cognitive neuropsychology is associated Paul Broca’s (1861) discovery that lesions in the left opercular (*pars opercularis* maps to Brodmann’s area (BA) 44; Korbinian Brodmann 1909) and triangular sections (*pars triangularis* maps to BA 45) of the inferior frontal gyrus (IFG), which occupies about one-third of the frontal lobe, causes language production problems. BAs 44/45 are situated inferior of the premotor cortex (BA9) and in the depth of the lateral sulcus it borders on the insula. Again, the neural circuits involving Broca’s area include the prefrontal cortex and subcortical structures. For instance, subcortical damage that leaves Broca’s area intact can lead to Broca-like speech production deficits (e.g., Alexander, Naeser, & Palumbo, 1987; Mega & Alexander 1994). Carl Wernicke (1874) reported that lesions to the posterior region of the left superior temporal gryus (BA 22) and surrounding areas cause severe language comprehension problems. Often the lesions causing Wernicke’s aphasia extend to the angular (BA 39) and supramarginal gyrus (BA40) and to corresponding subcortical damage (Damasio, 1991). Analogously to Broca’s area, lesions in Wernicke’s area can be completely recovered (Lieberman, 2000). In particular, subcortical structures seem to play an important role in language processing, because it never has been demonstrated that a purely cortical lesion produces an aphasic syndrome (D’Espositio & Alexander, 1995). Another weakness of drawing conclusions from cortical stroke-lesions is that the impaired cognitive computations reflect the neural areas served by different cerebral arteries. For instance, the classical literature did not assign a function to the temporal pole, because this area is typically not involved in stroke damage. Paragrammatic disorders found in Wernicke’s aphasia appear not to be related to syntactic
deficits but to lexical access and/or selection problems (Butterworth & Howard, 1989).

Broca’s aphasic patients have in particular difficulties to comprehend sentences if their meanings cannot be concluded from a canonical parsing heuristic and if the surface structure of the sentence is the product of so-called syntactic movements. They leave behind syntactic gaps that need to be filled to comprehend the sentence. The canonical word-order of English is considered to be SVO (subject-verb-object). The concept of syntactic movements, developed by Chomsky (1965; 1986), goes back to the idea that the surface structure of a complex sentence is derived from this sentence’s deep-structure, the canonical structure. Such derivations involve a syntactic relationship between the moved lexical element and an empty position (gap) in the sentence. For example, in the question *Who did the monkey bite *___*, the direct object of the verb *bite* to be interpreted as *who* has been moved to the beginning of the sentence. Thus, sentence structures such as wh-structure, object-relative (*The boy that the monkey bit *___* was laughing*), object-cleft (*It is the boy that the monkey bit *___* ) are specifically difficult to comprehend for patients with Broca’s aphasia because the canonical word order (*The monkey bit the boy*) needs to be reconstructed (e.g., Kaan & Swaab, 2002; Grodzinsky, 2000; Hickok & Avrutin, 1996; Goodglass, 1993; Caplan, 1992; Caplan & Futter, 1986). The mental operation of reconstruction requires more computational costs on the syntactic level than analyzing sentences with a default parsing heuristic. Typically, the default parsing heuristic is used in case of sentences whose word order is canonical. A particular language can have more than one canonical structure. Bach (1962; 1971), for example, revised its original view that *German* is a SOV language (as *Korean* and *Japanese*) and argues for a SVO analysis (as *English*). Linguistic theories prefer to define a primary canonical structure to a particular language, even in cases of languages with (relatively) free word order (e.g., *Walpiri, Hungarian, Bantu* languages). Here we refer with the term canonical structure to those (literal) sentence

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5 Syntactic movements are also involved when the logical form of a sentence is derived from the surface structure of the sentence. As to my knowledge this derivation has never been seriously considered as possible source for aphasic comprehension deficits.
structures that are most frequently used by native speakers and which are at the same time theoretically motivated to be the base structure used to derive syntactically more complex structures.

However, several empirical findings argue strongly against the hypothesis that Broca’s area is exclusively in charge of linguistic parsing. For instance, Caplan, Baker and Dehaut (1985) examined comprehension of twelve different sentence types in 150 (French- and English-speaking) aphasic patients. They varied along a single dimension of comprehension severity with no unique correlation between severity and lesion site. Thus, a syntactic comprehension deficit seems not to correlate with a particular lesion site (see also Tramo, Baynes, & Volpe, 1988; Caplan, Hildebrandt, & Makris, 1996; Dronkers, Redfern, & Knight, 2000). These large-scale lesion studies reveal that (a) left-hemisphere lesions have greater impact on syntactic processing than right-hemisphere lesions, (b) syntactically complexity seems to correlate with the degree of aphasic processing deficits, and (c) Broca’s area is specifically involved in syntactic processing, but supports similar types of computations across different cognitive domains. These conclusions seem to be compatible with the cognitive demand hypothesis (Thompson-Schill, D’Esposito, Aguirre, & Farah, 1997; Friederici, 2002; Kaan & Swaab, 2002). Linguistic hypotheses such as trace deletion or tree pruning describe more formalized computational differences between different sentence types.

However, several findings and observations seem not be compatible with the syntactic deficit hypothesis. Damage to Broca’s area correlates not only with syntactic but also with semantic deficits, and Broca’s area is involved in processes across different cognitive domains (e.g., Poldrack, Wagner, Prull, Desmond, Glover, & Gabrieli, 1999; Bushell, 1996; Dronkers, Wilkins, Van Valin, Redfern, & Jaeger, 2004). Thus, there seems to be no question that Broca’s area plays a particular role in parsing specific sentence structures. However, it remains an open question whether cortical activities (or lack of those) in Broca’s area are related to an increase in computational complexity per se, and/or whether specific syntactic parsing operations are mainly or exclusively supported by specific neural structure of Broca’s region or its subregions such as BA 44 and/or BA 45.

Disorders of figurative processes

As discussed before, processing of figurative meanings requires alternative
parsing strategies. The question is whether these alternative computations are supported by Broca’s area as part of the CLS. Typically, lesion studies on figurative meanings compared the performance right- with left-hemispheric damaged patients. Earlier studies seem to indicate that the right cortex is dominant for processing figurative, connotative or pragmatic meanings (e.g., Brownell, Simpson, Bihrlie, Potter, & Gardner, 1990; Joanette, Goulet, & Hannequin, 1990; Molloy, Brownell, & Gardner, 1990; Foldi, 1987; Van Lancker & Kempler, 1987; Brownell, Potter, Michelow, & Gardner, 1984; Winner & Gardner, 1977). For instance, Winner and Gardner’s (1977) study, which has been frequently cited as evidence for a right-hemispheric account, examined comprehension of metaphoric sentences expressing a psychological state (e.g., A heavy heart can really make a difference) or a cross-sensory meaning (e.g., It was such colorful music). Patients with different lesion sites were asked to match one of four pictures to a spoken sentence. One picture matched the figurative reading (e.g., in case of heavy heart: a crying person), one the literal reading (a person carrying a large red heart and staggering under its weight), one depicted a salient attribute (a 500 lb weight) and one illustrated the NP (a red heart). While in general aphasic patients choose significantly more often figurative pictures (58%), patients with right-sided lesions picked significantly more literal pictures (40%). However, a breakdown of the results found for the different subgroups is more enlightening. Aphasis patients with posterior lesions selected much less the figurative reading (46%) than aphasic patients with anterior lesions (67%); again patients with Alzheimer’s disease (unspecified diagnosis) picked metaphoric expressions about equally often as posterior aphasic patients (45%) and healthy controls chose most often the figurative interpretation (73%). Overall, the error score indicate that the performance difference between posterior aphasic patients and right-damaged patients (46 vs. 40%) is only marginal. Thus, the data indicate that both the left posterior region (Wernicke’s area and vicinity) as well as the right-hemisphere seemed to be involved in metaphoric processing. However, a verbal follow-up task that required participants to explain the metaphoric sentences revealed a different pattern than the sentence-picture matching task. As predicted, aphasic patients relied on repeating the words in the sentence; however, in 85% of their responses right-damaged patients provided a figurative interpretation (e.g., in case of heavy heart: “He’s got many troubles”). This finding appears to speak
against the right-hemisphere account as such that right-damaged patients may not have difficulties to process metaphoric meanings per se, but with visuo-spatial task conditions. This interpretation is consistent with Caramazza, Gordon, Zurif and DeLuca’s (1976) finding that patients with right-sided lesions seem to have difficulties with verbal tasks requiring visuo-spatial computations (e.g., *If John is taller than Bill, who is shorter?*). Again, in van Lancker and Kempler’s (1987) study, right-hemispheric damaged patients performed worse than aphasic patients when asked to select pictured representations of sentences containing idioms and speech formulas. A detailed comparison between these different studies is, however, restricted due to heterogeneous factors such as patients’ lesion sites, task conditions and/or stimulus material. Also, it has been reported that right-hemispheric damaged patients performed poor when asked to discriminate (literal) lexical-semantic information (Gainotti, Caltagirone, Miceli, & Masullo, 1981).

However, that the right brain is not necessarily the dominant cortex for processing non-literal meanings has been also confirmed by several lesion studies (e.g., Bush & Drummond, 1985; Zaidel, Kasher, Soroker & Baroti, 2002; Gagnon, Goulet, Giroux, & Joanette, 2003; Papagno, Tabossi, Colombo, & Zampetti, 2004; Papagno, Curti, Rizzo, Crippa, & Colombo, 2006; Papagno & Caporali, 2007). For instance, Papagno et al.’s (2006) study used a sentence-picture matching task to examine comprehension of unambiguous idiomatic phrases in aphasic patients and in patients with right-sided lesions. The results show that idiom comprehension was significantly more impaired for both groups than literal sentence comprehension. However, aphasic patients performed significantly worse than right-sided patients. Furthermore, the analysis of patients’ lesion sites revealed that only patients with right frontal lesion were impaired in idiom comprehension, but not patients with lesions outside of the frontal lobe. In contrast, the lesion site of right-sided patients did not affect their literal sentence comprehension. Similar, no difference was found for frontal as well as for non-frontal aphasic patients regarding idiomatic and literal sentence comprehension. The data reported by Papagno et al. speak against laterality of idiom processing. Both patient groups seem to have difficulties with the task conditions for different reasons. Right-sided frontal patients might have had difficulties with visual-spatial short-term buffering and aphasic patient’s disorder may be related to lexical-syntactic deficits. In both
scenarios a different cause affects idiom processing, but does reflect a disorder of idiom processing per se.

In Papagno and Caporali’s experiment, aphasic patients’ performed significantly worse on idiom oral definition and on idiom sentence-to-picture matching than on idiom sentence-to-word matching. However, the study only compared the performance between aphasic patients and a healthy control group, but did not examine patients with right-sided lesions. Again, a single left-handed patient with lesions to the right medial occipito-temporal lobe and the splenium of the corpus callosum performed significantly worse in reading kanji-words than in reading kanji-idioms (Suzuki, Suzuki, Iizuka, Endo, Yamadori, & Mori, 2004). Although the possibility of an atypical linguistic lateralization cannot be excluded, this dissociation supports the PLN account of idiom processing. Again, comprehension of figurative language (idioms and metaphors) seems to be also impaired in a case of Down syndrome (verbal WAIS-IQ of 80) despite of spared core linguistic abilities (Papagno & Vallar, 2001). Because the subject suffered from visuo-spatial deficits, it was concluded that her difficulty to interpret figurative meanings was related to right-hemisphere processes. This conclusion does not consider, however, that figurative processes might involve an increase in cognitive demand when compared with unambiguous linguistic core processes. Thus, the patient’s deficit may simply reflect the inability to cope with an information overload due to reduced short-term memory capacities. This interpretation may particularly apply to patients with Alzheimer’s disease who suffer from conceptual processing deficits across different cognitive domains (e.g., Kempler, Van Lancker, & Read, 1988; Papagno, 2001; Papagno, Lucchelli, Muggia, & Rizzo, 2003).

As previously discussed, subjects’ performance is also largely dependent on the type of task condition (mode of processing) used to examine comprehension of figurative meanings. In Tompkins et al.’s (1992) word-monitoring paradigm right-hemispheric patients’ ability to recognize familiar idiomatic expressions was spared but not in an offline idiom definition task. Hillert (2004) reported, moreover, spared online idiom comprehension in a single right-hemispheric damaged patient and in two aphasic patients by using a cross-modal lexical decision paradigm. That idiom comprehension is not an exclusive domain of the right cortex, is also supported by the performance of
children with agenesis of the corpus callosum (Huber-Okrainec, Blaser & Dennis, 2005; but see Paul, Van Lancker-Sidtis, Schieffer, Dietrich, & Brown, 2004).

Taking into account that offline measures imply the contribution of multiple cognitive operations such as problem solving (inferences) or search through conceptual space (mining), it is surprising that only a few neuropsychological studies on parsing figurative or literal sentence structures used online measures to constrain the examination of linguistic processes to a narrow time window. The distinction between word-and sentence-level processing is a very important parameter that may contribute to contrasting performance found in studies on idiom processing. Here we assume that comprehension of idiomatic expressions embedded in a sentence context will primarily involve left-sided cortical activity of the CLS. Thus, it is to assume that parsing of alternative sentence structures but not default structures engages primarily Broca’s area.

**Neural mapping of figurative processes**

Most fMRI or PET studies reveal that non-canonical sentence structures increase left-sided cortical activity in BAs 44/45/47/6/9 (Broca’s area and vicinity) in addition to bilateral activities in the superior and middle temporal gyri (BAs 21/22) and in the left angular/supramarginal gyri (BAs 39/40) (e.g., Ben-Shachar, Palti & Grodzinsky, 2004; Ben-Shachar, Hendler, Kahn, Ben-Bashat & Grodzinsky, 2003; Humphries, Willard, Buchsbaum, & Hickok, 2001; Caplan, Alpert, Waters & Olivieri, 2000; Friederici, Wang, Herrmann, Maess, & Oertel, 2000; Hickok & Poeppel, 2000; Caplan, Alpert & Waters, 1998; Dapretto & Bookheimer, 1999; Just, Carpenter, Keller, Eddy & Thulborn, 1996; Stromswold, Caplan, Alpert & Rauch, 1996; Damasio & Damasio, 1992). However, Mason, Just, Keller and Carpenter (2003) reported that independent of preference strategies ambiguous sentences produce higher cortical activity in the left IFG in contrast to unambiguous sentences. This result indicates that not only syntactic movements can produce an increase of cortical activity in Broca’s area, but also sentence structures that involve more than one parse. We assume therefore that the neural substrate of Broca’s area is not specifically responsible for processing syntactic movements, but for parsing alternative structures.

Bottini, Corcoran, Sterzi, Paulesu, Schenone, Scarpa, Frackowiak and Frith
(1994) conducted the first PET study on metaphoric processing to examine in six healthy speakers plausibility judgments of metaphoric and literal phrases. They reported relatively greater activations in different regions of the right-hemisphere, particularly in the IFG, the pre-motor cortex and the posterior temporal lobe. Bottini and colleagues concluded that in contrast to processing literal meaning, judging metaphors would require reference to long-term episodic memories. Moreover, they also assumed that frontal lobe activations reflect the search for long-term memories or the generation of visual imagery to facilitate decision making. The PET study conducted by Nichelli, Grafman, Pietrini, Clark, Lee and Miletich (1995) partly confirmed Bollini et al.’s findings. Nine healthy speakers read Aesop’s fables while judged for instance the metaphoric or literal meaning of these fables. In addition to left-hemispheric activations, figurative judgments (the moral of a story) produced a relative increase in activity compared to literal details (semantic or syntactic judgments). However, the right-sided activation might not be necessarily due to figurative inferences, but to the process of drawing inferences per se or the usage of pragmatic context in judging the passage. Again, Ahrens, Liu, Lee, Gong, Fang and Hsu (2005) fMRI study examined conventional and anomalous metaphors in Mandarin Chinese sentences (translated: The framework of this theory is very loose vs. Their financial capital has a lot of rhythm). The contrast “conventional metaphors > literal sentences” evoked an increased right-hemispheric activation in the inferior temporal gyrus and the contrast “anomalous metaphor > literal sentences” revealed an increased bilateral activity in the temporo-frontal network. The comparison between anomalous and conventional metaphors generated bilateral activity in the middle frontal and precentral gyrus, and right-sided activity in the superior frontal gyrus. Other fMRI studies on metaphoric processing seems to support the account that novel or anomalous metaphors are primarily processed in the right temporo-frontal network (Kircher, Brammer, Tous Andreu, Williams & McGuire, 2001; Mashal, Faust & Hendler, 2005; Mashal, Faust, Hendler & Jung-Beeman, 2005). However, some MRI studies do not support the right-hemispheric account of figurative processing. For instance, Lee and Dapretto (2006) used a triplet priming paradigm, in which the final word specifies a literal or a metaphoric interpretation (e.g., hot — cold — chilly/unfriendly). No evidence was found for a selective role of the right cortex in processing
figurative meanings. Thus, Lee and Dapretto conclude that increased complexity involved in figurative processing may account for right-sided cortical activity (cf. Stringaris, Medford, Giampietro, Brammer & David, 2007; Rapp, Leube, Erb, Grodd & Kircher, 2004). However, the results of the two more recent fMRI studies point to a bilateral involvement of idiom processing. Zempleni, Haverkort, Renken, and Stowe’s (2007) used in their fMRI study a uni-modal visual phrase-by-phrase judgment tasks: single Dutch phrases, which constitute a complete sentence, were presented one at a time, and at the offset of the last phrase a target word was displayed related or unrelated to the sentence meaning. The data support a bilateral account of figurative processing since the left and right IFG and the left middle temporal gyrus were involved in ambiguous and unambiguous idiom processing. However, it was also noted that the right middle temporal gyrus seemed to have only supported ambiguous idiom processing. In Lauro, Tettamanti, Cappa, and Papagno’s (2008) fMRI study a phrase-picture matching task was employed to examine the neural correlates of ambiguous and unambiguous idioms. A verbal phrase was visually presented in the upper part of a screen and after 2 sec a picture appeared below the sentence. Participants were asked to judge whether the picture matches the meaning of the expression or not. Figurative processing, which engaged greater activation in terms of magnitude and spatial extent than literal processing, activated bilaterally the temporal gyrus and the IFG, but also the left superior medial frontal gyrus (BA 9) and the right temporal pole. By contrast, the literal sentence meanings engaged the left inferior parietal lobe and the right supramarginal gyrus.

Again, Oliveri, Romero and Papagno (2004; see also Papagno, Oliveri & Romero, 2002; Rizzo, Sandrini, & Papagno, 2006) used repetitive transcranial magnetic stimulation (rTMS) to disrupt bilateral activity in the frontal and temporal regions while subjects performed a sentence-picture matching task. The sentences were literal (He is drawing) or included an opaque idiom (He is in shape). In case of idiomatic sentences, pictures illustrated either an idiomatic (a man showing off his muscles) or a literal reading (a mouse embedded in a geometric wedge of cheese) and in case of literal sentences the pictures showed the literal reading (a boy is drawing) or a literally related picture (a boy approaches a canvas). While right temporal rTMS facilitated performance on idiomatic and literal sentences, left temporal rTMS disrupted participant’s
performance. The right rTMS facilitation may be caused by disinhibition of homologous left-sided regions. The main result seems to support the proposed distinction between a CLS and PLN, because the left temporal lobe activity was critical for idiom processing.

In addition to spatial mapping it is important to consider the moment in time at which a specific cognitive event peaks. Event-related potential (ERP) studies are in contrast to fMRI more suitable for specifying the temporal parameters, although they have a limited spatial resolution. The electroencephalogram (EEG) of multiple stimuli of a specific task condition is time-locked and averaged. The results of averaging show typical ERP components relative to the onset of specific stimuli or relative to other components. The amplitude of the N400 component seems to reflect the degree of difficulty to integrate semantic information: The larger the N400 amplitude the more difficult is semantic integration (Kutas, Lindamood, & Hillyard, 1984). It may the nature of the ERP paradigm that most studies on figurative language focused on metaphoric meanings rather than idiomatic structures. An exemption is Zhou, Zhou and Chen’s (2004) study on idiom comprehension. They asked subjects to decide whether the last characters of Chinese four-character idioms are correct or not. Significant differences in different brain regions for three different time windows are reported: (1) an early right-sided negativity (120-50 ms) in the frontal and temporo-parietal regions, (2) negativity (320-80 ms; the N400 effect) in the left frontal and anterior temporal regions and (3) positivity (480-540 ms; P600 effect) in the left temporo-parietal and occipital regions. These ERP results indicate that the semantic and syntactic analysis is a domain of the CLS.

Metaphors elicit larger N400s than literal phrases but smaller N400s than semantically implausible sentences, and responses to metaphoric readings took significantly longer than to literal readings (e.g., Glucksberg, Gildea, & Bookin, 1982; Pynte, Besson, Robichon, & Poli, 1996; Coulson & Van Petten, 2002; Bonnau, Gil & Ingrand, 2002; Tartter, Gomes, Dubrovsky, Molholm, & Stewart, 2002; Kazmerski, Blasko, & Dessalegn, 2003). An ERP study by Sotillo, Carretie, Hinojosa, Tapia, Mercado, Lopez-Martin and Albert (2005) seems to support the PLN account of metaphor processing. Participants were asked to read sentences (e.g., Green lung of the city) followed by a related (park) or unrelated target word (semaphore). While a larger N400-amplitude
was found for metaphorically related words than for the unrelated words, the inverse solution (spatial source localization algorithm) revealed activity between both conditions in the right middle and superior temporal region.

Distinct cortical areas for explicit and ambiguous idioms

A more recent fMRI study, which was conducted with young healthy adults, supports the view that familiar explicit (unambiguous) idiomatic and familiar ambiguous idiomatic sentences are processed in different cortical subregions of the left prefrontal cortex (Hillert & Buračas, 2009). In using a speed sentence decision (SSD) paradigm, participants decided as quickly as possible whether spoken sentences were plausible or not. All experimental sentences had a SVO word order, and were (a) explicit literal (e.g., *He met her in the new mall*), (b) included an explicit (e.g., *He felt like a million bucks*) or an (c) ambiguous idiomatic phrase (e.g., He skated on very thin ice) or were (d) implausible (e.g., *She drank the nice stone*). To control degrees of figurativeness, we collected ratings about the sentences’ figurativeness according to a seven-point scale. Regression analyses between BOLD signals and ratings for figurativeness revealed two significant cluster activities (*p* < .01): The first cluster consists of local maxima in the left IFG alone or in the left IFG and in the left middle frontal gyrus; the second cluster revealed local maxima in the superior frontal gyrus alone or in superior frontal and in the medial part of the superior frontal gyrus. Comparisons between contrasts confirmed the findings of the analysis for figurativeness: Broca’s area and vicinity was specifically involved in processing the figurative meaning of explicit idiomatic sentences (*z*-score > 2.3; *p* = 0.01). In contrast, the left superior frontal gyrus (including the medial

![Fig. 1. Axial view of left-sided cluster activation for (a) figurativeness (graded), (b) explicit idiomatic > literal, and (c) ambiguous idiomatic > literal (see text for details).](image-url)
part) seems to be involved in computing standing ambiguities of idiomatic expressions (Figure 1). Literal sentences, however, generated exclusively cortical activity in the left temporo-parietal region compared to the explicit idiomatic sentence.

Broca’s area has been typically associated with a specialization for parsing complex sentence structures that require reconstructing the canonical sentence structure in using syntactic movements such as *merge* and *move* (Chomsky, 1995; 1981). Our results indicate that the activity of Broca’s region is not only related to syntactic movements, since we examined canonical SVO structures. However, processing figurative expressions may require alternate parsing reflected in an increase of computational costs. This interpretation is also supported by our findings that implausible sentences correlate with an increase of prefrontal lobe activity compared to meaningful sentences (see also Ni, Constable, Menci, Pugh, Fulbright, Shaywitz, Shaywitz, Gore, & Shankweiler, 2000). One open question is why standing ambiguities of idiomatic phrases are processed differently from explicit idiomatic phrases?

Given our current knowledge about the neural correlates of sentence processing, we assume that Broca’s area plays an important role in parsing and rehearsal of meaningful sentences (e.g., Demonet, Thierry, & Cardebat, 2005; Mason, Just, Keller, & Carpenter, 2003; Small & Burton, 2002; Bookheimer, 2002, Caplan, 2001; Sakai, Hashimoto, & Homae, 2001). By contrast, the cortical activity found for ambiguous idiomatic sentences in the left superior frontal gyrus (including medial parts) may reflect search processes through knowledge space (e.g., Schacter, 1987; Squire, 1987; Tulving, 1994a, 1994b; Shallice, Fletcher, Frith, Grasby, Frackowiak, & Dolan, 1994 Buckner, Petersen, Ojemann, Miezin, Squire, & Raichle, 1995). It is therefore concluded that Broca’s region seems to operate like a linguistic buffer to rehearse information during online sentence processing. This buffer is specifically involved in alternative parsing to generate unambiguous sentence structures. However, alternative parsing strategies can be also found in non-linguistic domains such as music (e.g., Maess, Koelsch, Gunter, & Friederici, 2001). Therefore, that in our study explicit idiomatic phrases show significantly stronger BOLD signal activity in Broca’s area as compared to explicit literal sentences may be related to the computational cost involved in generating alternative parsing solutions.
Conclusion

Idioms are hybrid expressions sharing figurative meanings with metaphors and parsing operations with non-figurative, (de)compositional language. Accordingly, the present approach on idiom comprehension is an attempt to further our understanding of the cognitive and neurological foundations of language processing. Multiple factors determine how our brain processes a particular idiomatic expression. In general, our language system is highly dynamic that operates according to linguistic-pragmatic cues, subject-specific knowledge, and item- and task-specific characteristics. Psycholinguistic and neuroimaging evidence clearly indicate the involvement of specific cortical regions, particularly under the condition of spoken sentence comprehension. In considering the premises outlined in the introduction, a framework for a neurological model of language processing is proposed that takes account of specific processing stages. Because of the right ear advantage, the CLS, which comprises Broca’s area (linguistic buffer) and Wernicke’s area (including the auditory system), operates typically left-sided. Again, computations of the PLN are bilateral. They consist of decisional inferences within the prefrontal cortex and of search processes (mining), which take place throughout the bilateral conceptual network.

It is suggested that canonical sentences structures or lexical representation are accessed in an bottom-up fashion within the superior and middle temporal cortex. These default processes do not necessarily employ Broca’s region, since they may not require rehearsal operations. Again, the left temporal pole seems to be involved in processing uniquely connotative meanings such as proper names (e.g., Grabowski, Damasio, Tranel, Ponto, Hichwa, & Damasio, 2001; Damasio, Tranel, Grabowski, Adolphs, & Damasio, 2004). Similar to the function of the hippocampus (inside the temporal lobe), the inferior temporal gyrus provides episodic access points (traces) to conceptual information stored throughout the bilateral cortex (Mishkin, Suzuki, Gadian, & Vargha-Khadem, 1997; Aggleton & Brown, 1999). Sentence comprehension seems to involve Broca’s area only if the computational costs increase as a result of rehearsal and parsing. The neuroimaging data discussed support the view that ambiguity resolution may engage the bilateral cortex to search for relevant conceptual cues. Again, the prefrontal cortex, that may play a
particular role in drawing inferences, is regarded to be multimodal in nature that synthesizes external and internal information (e.g., Miller, 1999; Miller & Cohen, 2001). The principal assumptions about the cortical regions and types of computations involved in sentence comprehension are therefore summarized as follows:

The computational costs associated with the CLS are related to lexical and syntactic complexity. Wernicke’s region and its vicinity provide access to lexical entries and computes default sentence structures. Broca’s area (BAs 43/44), however, will be engaged, if sentence comprehension involves parsing of alternative structures, resolving lexical ambiguities and other rehearsal operations. However, it is controversially discussed whether BA 44 is specialized for syntactic processing while BAs 43 and 47 engage exclusively semantic processing. Linguistic computations may operate modular at the cognitive level, but not necessarily at the neural level. For instance, Broca’s area is involved in a range of non-linguistic computations, which makes it difficult to be believe that there a specific neural structure supporting specific linguistic computations (J.A. Fodor, 1968). By contrast, the PLN will be recruited, if conceptual representations are accessed or inferences are drawn to resolve ambiguities or to generate more complex meaning structures. The PLN may engage a variety of different cortical regions throughout the cortex. As such it can be regarded as a non-modular network on the cognitive and neural level as it operates after the initial default computations of the CLS. These general assumptions provide the framework for those computations that are involved in figurative and literal processing. Idiom comprehension may engage Broca’s area and vicinity because they require alternative parsing operations. In turn, alternative cognitive operations go hand in hand with higher computational costs. Accordingly, Hillert and Buračas (2009) found evidence that explicit idiomatic sentences are processed in Broca’s area while unresolved ambiguous idiomatic sentences employ the left superior and medial frontal region.

The computational costs involved in idiom comprehension may be compatible with those costs involved in processing garden-path sentences or syntactic movements during sentence comprehension. However, comprehension of default sentence structures, which are explicit, canonical and non-figurative, evokes typically left-sided computations in the superior and
middle temporal cortex. Syntactic-semantic representations are accessed in Wernicke’s area, which is located in immediate proximity to the primary auditory cortex and surrounding areas. The computational costs involved in comprehension of default sentence structures are minimal and significantly lower compared to figurative or non-canonical sentence structures. However, the construction of figurative meanings during conventional or novel metaphor comprehension involves conceptual inferences that are reflected in bilateral cortical activation patterns.

The conclusions drawn from the present literature on idiomatic phrases and other figurative expressions may be regarded as being still preliminary. Future studies should consider multiple factors such as subject-specific familiarity, degrees of figurativeness, syntactic flexibility, modes of processing to examine the spatial and temporal parameters associated with figurative sentence comprehension. The prediction of computational costs may be best captured by formal models. At the same time, it may be important to consider also the dynamics of language processing across a life-cycle. For instance, a recent study indicates that with age (ca. 25-67 yrs.) lateralization of verb generation seems to become more evenly distributed (Szafarski, Holland, Schmithorst, & Byars, 2006). That said, it might be possible that the computational costs for certain linguistic structures increase with age and more cortical areas are engaged to compensate for decreasing process capacities. In line with the conclusions presented here, modular computations of the CLS may be much less sensitive to age-related processing costs than those figurative processes that engage the bilateral PLN. From a phylogenetical viewpoint, the CLS may be a by-product of the conceptual system (J.A. Fodor, 1975: *the language of thought*) and may have been matured under cognitive pressure to compute linguistic elements in larger units (see Chomsky, 1975; Pinker & Bloom, 1990). It is therefore plausible to assume that humans are equipped with a genetic disposition for specific computational algorithms, a view that is certainly not supported by connectionist modelers. A genetic disposition seems to exist for certain types of cognitive computations, which are shared by different cognitive domains. Thus, the concept of a universal grammar appears

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6 Having said this, it should be emphasized that the value of modeling cognitive
to be a by-product of the *language of thought*, and it is the computational mode that seems to determine the extent to which a cortical area operates in a modular fashion.

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