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VERBAL SHORT-TERM MEMORY AND LANGUAGE PROCESSING: WHAT REPETITION CAN TELL US

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1. INTRODUCTION

Working memory is a component of human memory that involves the temporary storage and manipulation of information during ongoing cognitive activity, as for example language processing.

According to the very influential Baddeley and Hitch (1974)'s model, and to its subsequent development (Baddeley, 1986, 2000), working memory is divided into four different components: the central executive regulates the flow of information within working memory, retrieves information from long-term memory, and coordinates the activity of the phonological loop, which is specialized in short-term processing and maintenance of verbal information, and of the visuospatial sketchpad, its visuospatial equivalent. A fourth component has more recently been added, the episodic buffer, which is assumed to form an interface between the working memory components and long-term memory.

The phonological loop has been claimed to be involved in language processing, as highlighted by researches on language acquisition in healthy children and in children with specific language impairment (see Gathercole, 2006 for review), as well as on children and adults learning a second language (e.g. Papagno & Vallar, 1992, 1995; Masoura & Gathercole, 1999). Studies on neurologically impaired patients confirmed the relationship between memory and linguistic systems (e.g. N. Martin & Saffran, 1990, 1992; R. C. Martin, Shelton, & Yaffee, 1994), and provided elements to better understand the functions and structure of short-term memory.

Many researches have focused on the components of short-term memory: based on the performance of various neurologically impaired patients, some authors claimed that in tasks assessing short-term memory, only the phonological information of words is exploited, and not their semantics (see Papagno, Vernice, & Cecchetto, 2013), while other authors hypothesized the existence of a semantic buffer, involved in the processing of semantic information during short-term memory tasks (see R. C. Martin, 2005).

This dissertation focuses on two main aspects regarding short-term memory: on the one hand, through a series of behavioral studies on healthy subjects, it is aimed at disentangling the debate on the importance of semantic information during processes involving short-term memory; on the other hand, it suggests the exploitation of differences in short-term memory load during rehabilitation treatments of neurologically impaired patients.

Studies 1 and 2 investigated healthy subjects' performance on serial recall tasks manipulating the familiarity with phonology and semantics of the words used. Results replicated the performance of a patient affected by semantic dementia described by Papagno et al. (2013), and confirmed that short-term memory performance is enhanced by familiarity with the phonological forms of the words, and not by the knowledge of their meanings.

Studies 3 and 4 focused on sentence repetition, another task that taps on short-term memory resources. These experiments were aimed at testing the efficacy of a specific sentence repetition treatment protocol for people with aphasia. Using sentences with similar superficial appearance, but with different complexity of the syntactic structure, it is possible to manipulate the memory load required for repetition, and to obtain better performance when using the easier structure to prime the more complex one. This finding could give interesting hints for the development of new treatment approaches at sentence level, accounting for both linguistic theory and memory system.

Through Study 5, the efficacy of a non-invasive brain stimulation technique, namely a-tDCS, in improving short-term memory performance was tested: the modulation of cortical excitability of the left inferior parietal lobule, considered to be the neural correlate of a subcomponent of the phonological loop, improves the maintenance of words in their correct order during serial recall. This could be particularly interesting, since tDCS may be used in cognitive rehabilitation of patients with short-term memory impairments.

2. CHAPTER I

VERBAL SHORT-TERM MEMORY

One of the topics of interest in cognitive psychology over the last 40 years has been the functional structure of human memory. In particular, much research has been devoted to a specific component of memory, namely working memory (WM).

This system has a limited capacity, and is in charge of storing and manipulating information during ongoing cognitive activity. For example, linguistic information has to be temporarily stored during the processing of language comprehension, because a sentence becomes available word by word over time, and comprehension can only take place if the whole sentence has been processed through the correct analysis of all its components. Therefore, language processing depends to a great extent on working memory.

A very influential model of working memory, the one we will refer to in this dissertation, has been the Baddeley and Hitch (1974)'s one. According to this model, WM includes three components: the *phonological loop* (capable of holding speech-based information) and the *visuospatial sketchpad* (its visuo-spatial equivalent) are slave sub-systems, whose activity is coordinated by an attentional control system, the *central executive*, which processes information during cognitive tasks.

The extensive investigation on the phonological loop highlighted some limits of the original model. For example, it could not explain why during sentence recall the number of words that are repeated is usually higher than words recalled in a list of unrelated items (Baddeley, Vallar, & Wilson, 1987).

The *episodic buffer*, a fourth component of the WM model, was introduced in order to account for this and other types of phenomena (see Baddeley, 2000; Baddeley & Wilson, 2002), that otherwise could not be explained. It serves as an interface between different systems that function with different sets of codes, and uses a multi-dimensional code to provide simultaneous access to different components of working memory, and to long-term memory. Regarding the given example on sentence recall, thanks to the episodic buffer information can be retrieved from long-term memory, and used to cluster words into "chunks", with capacity being then set by the number of chunks rather than the number of words.

The most extensively investigated component of working memory is the phonological loop, which is involved in short-term processing and maintenance of verbal information. The phonological loop can be further fractionated in two subcomponents (Baddeley, 1986): the *phonological short-term store*, that is the input storage where the memory trace is maintained for about 2 seconds, and an *articulatory rehearsal process*, which prevents the decay of the memory trace by subvocally refreshing it, and allows transferring visually presented material to the phonological short-term store by recoding it (Baddeley, 1990).

Various different effects depend on the structure of the phonological loop, as highlighted by behavioral studies on healthy subjects. Thanks to these studies, it has been demonstrated that information in the short term is retained in a speech-based form.

One of the effects is the *phonological similarity effect* (e.g. Conrad, 1964; Conrad & Hull, 1964). The immediate recall of phonologically similar items is worse than the recall of dissimilar ones. For example, it is easier to correctly recall the sequence "man, fish, boat" than "cat, rat, mat". This happens because the phonological representation of a string in the phonological store tends to decay, and in this degradation process similar items tend to be mixed up, since the probability of losing a phonological feature that discriminates one item from the others is greater when the number of distinctive features is smaller: the less the distinctive features between words are, the more probably confusion will occur during recall. Orthographic and semantic similarities do not lead to disruption of accuracy, proving that orthographic and semantic levels of representation do not play a central role in the immediate memory performance. Indeed, the phonological similarity effect suggests that in the phonological store the verbal information is held in a phonologically-coded format.

Another effect depending on the structure of the phonological loop is the *word-length effect* (e.g. Baddeley, Thomson, & Buchanan, 1975; Cowan, Day, Saults, Keller, Johnson, & Flores, 1992). The ability of maintaining and repeating strings of words that take a short time to be articulated (e.g. cat, day, pen) is better than with words that take a much longer time to be articulated (university, opportunity, vegetable). The recalling performance decreases with words that require longer articulation, since they also require longer times for rehearsal, and this maximizes the possibility for the memory trace to fade before it is rehearsed.

Articulatory suppression has been used as a validation of the interpretation of the word-length effect in terms of limited rate at which the memory trace can be refreshed. By preventing rehearsal through the continuous uttering of an irrelevant speech sound, as "ta ta ta", the word-length effect is abolished, proving its dependency on the rehearsal process: there is no significant difference between the performance in the recall of short or long words, if the presentation of stimuli occurs during articulatory suppression. This happens not only for auditorily presented stimuli, but also when items are presented visually, because visual stimuli have to be recoded into a phonological format and then subvocally rehearsed in order to access the phonological store. Articulatory suppression also abolishes the phonological similarity effect when stimuli are presented visually, since the similarity acts at the level of storing phonological material, which access the store through rehearsal. On the other hand, this does not happen with auditory presentation (Levy, 1971; Baddeley, Lewis, & Vallar, 1984): verbal material has direct access to the phonological short-term store, and does not need to be rehearsed, so it is not affected by articulatory suppression (i.e. the recall of phonologically similar items is worse than the recall of phonologically dissimilar ones, even when the subject has to articulate an irrelevant speech sound during the presentation of stimuli).

Therefore, the pattern of effects of articulatory suppression, word length, and phonological similarity confirm the distinction between two components in the phonological loop: an articulatory process, the rehearsal, and a non-articulatory phonological code, corresponding to the phonological short-term store.

The distinction between the two subcomponents of the phonological loop, and between their neuroanatomical correlates, has been investigated through neuropsychological studies (e.g. Vallar & Cappa, 1987). A representative example comes from the comparison of two left brain-damaged patients, LA and TO (Vallar, Di Betta, & Silveri, 1997). LA, with a lesion to the temporo-parietal cortex, had damage to the phonological short-term store, as proved by low verbal span and the absence of phonological similarity effect. His ability to rehearse, however, was unimpaired, as demonstrated by normal performance on phonological judgments, which are known to involve the rehearsal process (Burani, Vallar, & Bottini, 1991). This pattern was compared to TO's one, whose lesion to the premotor cortex caused a damage to the rehearsal process, as demonstrated by low performance on phonological judgments and no effect of articulatory suppression, together with an intact phonological similarity effect. The described dissociation was considered as evidence of the presence of two components in the phonological loop.

Research with neuroimaging techniques (PET and fMRI) also tried to establish the neuroanatomical correlates of the two subcomponents of the phonological loop (e.g. Paulesu, Frith, & Frackowiak, 1993; Awh, Smith, & Jonides, 1995; Henson, Burgess, & Frith, 2000). The comparison of brain network activations during various tasks involving different subcomponents allowed hypothesizing their neural correlates. However, data from neuroimaging studies are inconsistent, probably because of the use of different techniques, methods, and tasks.

The comparison of results from neuropsychological and neuroimaging studies suggested that the neuroanatomical correlates of the phonological short-term store are located in the inferior parietal cortex, while the articulatory rehearsal in the inferior frontal cortex (see Vallar & Papagno, 2002 for a meta-analysis).

A research with transcranial magnetic stimulation technique (TMS, a non-invasive brain stimulation technique that increases or decreases neuronal activity by modulation of the magnetic field) (Romero Lauro, Walsh, & Papagno, 2006) confirmed that the inferior parietal lobule (Brodmann's Area 40) and the premotor region (BA 44) are the neural correlates for the phonological loop.

2.1 PHONOLOGICAL LOOP AND LANGUAGE PROCESSING

2.1.1 LANGUAGE ACQUISITION AND L2 LEARNING

Since Baddeley and Hitch (1974)'s seminal work, many studies have been conducted to analyze the role of the phonological loop. One suggestion has been that the phonological loop is involved in language acquisition in children and L2 learning in adults.

In children's acquisition of native language, the phonological loop seems to play a central role, because it mediates the long-term storage of phonological information involved in vocabulary development. This mediation was demonstrated by studies on healthy children, whose phonological memory skills (tapped by nonword repetition) are highly related to natural vocabulary acquisition (Gathercole & Baddeley, 1989; Gathercole, Frankish, Pickering, & Peaker, 1999), and to the performance on tasks requiring explicit name learning (Gathercole & Baddeley, 1990a).

The association between phonological memory and vocabulary acquisition was assessed by Gathercole and Baddeley (1989) in a longitudinal study, in which 4 or 5 year-old children (T1) were tested within 2 months of entering primary school, and then one year later (T2). Vocabulary knowledge was assessed by means of the Short Form of the British Picture Vocabulary Scale (Dunn & Dunn, 1982), a version of the Peabody Picture Vocabulary Test. Children were asked to point to the picture (out of four) corresponding to a word read aloud. Items were ordered by increasing difficulty, and the test stopped when the child made four errors over six successive items. This way, a measure of vocabulary development was obtained. Children were then asked to repeat 40 English word-like nonwords. Correlations between the two measures (vocabulary and nonword repetition) were found at both ages (T1 and T2), indicating a stable association between vocabulary knowledge and repetition performance. Moreover, repetition performance (that is to say: phonological memory) at age 4 was found to be a significant predictor of vocabulary skills one year later.

Participants to this research were then divided in two groups, according to their high or low phonological memory skills (but matched nonverbal intelligence), and took part in another study, designed to simulate natural vocabulary acquisition (Gathercole & Baddeley, 1990a). Children were asked to learn names of four toys, and the low-memory group took longer to learn the new names. The measure found to be most predictive of speed of learning was the phonological memory score.

These results, illustrating that phonological memory skills are highly associated with vocabulary acquisition, were confirmed by several researches on children with specific language impairment (SLI) (e.g. Gathercole & Baddeley, 1990b; Dollaghan & Campbell, 1998; Ellis Weismer, Tomblin, Zhang, Buckwalter, Chynoweth, & Jones, 2000; Archibald & Gathercole, 2006), whose low performance on tasks requiring the repetition of single nonwords and serial recall of lists of real words highlighted dramatic impairments of phonological memory, which have been considered a possible cause of language development impairments.

In their study, Archibald and Gathercole (2006) tested a sample of 20 SLI children, measuring different cognitive abilities, namely verbal short-term memory, visuo-spatial short-term memory, working memory and phonological awareness. The most marked impairments were found on working memory and verbal short-term memory. The former was assessed through the Working Memory Test Battery for Children (Pickering & Gathercole, 2001), that, among other measures, provides an assessment of the working memory capacity: children were engaged in processing activity (e.g. understanding a sentence, or counting dots), and simultaneously had to maintain some aspects of that processing for subsequent recall. Verbal short-term memory was assessed through immediate recall of digits, words and nonwords, a word list matching test (in which the child is presented with two lists made by the same words, and has to say whether the words were in the same order), and nonword repetition. Performance on this last task was particularly impaired, appearing to be a measure of phonological loop capacity more sensitive to the SLI deficit than serial recall. The authors argued that difficulties in repeating nonwords do not only highlight impairments of the phonological loop, but can also be influenced by pre-existing lexical knowledge (see Gathercole, Willis, Emslie, & Baddeley, 1992).

The role of short-term phonological storage in long-term phonological learning was investigated also in children learning a foreign language.

In her longitudinal study, Service (1992; see also Service & Kohonen, 1995) measured the ability to repeat English-sounding nonwords in a group of 9-year-old Finnish children, before they started English language classes. The accuracy of phonological processing tapped by nonword repetition highly correlated with proficiency in English, measured 2.5 years after the first testing by means of production, listening and reading comprehension in the foreign language.

This research demonstrated how accuracy in repeating nonwords is predictive of foreign-language learning in school-aged children, maintaining that an accurate initial representation in verbal short-term memory may be determinant for the learning of new vocabulary.

A superior phonological memory function is associated with greater facility in acquiring foreign vocabulary also in adults (Papagno & Vallar, 1992, 1995). In their 1995 study, Papagno and Vallar compared measures obtained by groups of polyglots (i.e. students able to fluently speak at least three languages, including their native one) and non-polyglots (students able to speak only one foreign language at a basic level) in different tasks. General intelligence, native language vocabulary knowledge, visuo-spatial span and visuo-spatial learning did not differ between the two groups, whereas polyglots showed a significantly better performance on tasks assessing phonological short-term memory, namely digit span and nonword repetition. Moreover, the two groups showed comparable abilities in learning associations of pairs of words, while polyglots had a better performance when the task required learning the association of pairs of word-nonword. The study on polyglots suggested a role of the phonological loop in L2 learning in adults: subjects with greater capacities of phonological memory learn foreign vocabulary more efficiently.

However, the relationship between short-term memory and long-term knowledge is reciprocal. Gathercole et al. (1992) demonstrated that the richer the existing vocabulary is in a child, the more it determines both phonological memory performance and further vocabulary development. In a longitudinal study, children were tested at 4, 5, 6 and 8 years of age on their vocabulary knowledge (Short Form of the British Picture Vocabulary Scale, Dunn & Dunn, 1982) and nonword repetition. Beyond age 5, the already discussed causality in the relationship between phonological memory and vocabulary knowledge appears to shift direction, the extent of the lexicon becoming predictive of phonological memory capacity. The authors explain these results claiming that the extent of children's vocabulary (and so, the familiarity with a wider range of phonological forms) allows the use of analogies with existing vocabulary items to maintain the unfamiliar sequences of phonemes, leading to both a better nonword repetition and an easier learning of new words.

Masoura and Gathercole (1999) replicated these data on foreign language learning: they showed that when a child can already rely on good lexical knowledge in its native language (the research involved 9-11 year-old children), nonword repetition is predictive of knowledge of foreign but not native vocabulary, since the lexical knowledge of the latter may reduce the dependency on phonological short-term memory.

These data suggest that people use existing language knowledge to mediate their attempts in learning, but when this knowledge is not available (i.e. when unfamiliar forms are presented), they are forced to rely only on verbal short-term memory to provide the necessary temporary storage of the phonological material, while more stable representation are being constructed (Baddeley, Papagno, & Vallar, 1988; Papagno, Valentine, & Baddeley, 1991; Papagno & Vallar, 1992).

2.1.2 NEUROPSYCHOLOGICAL PATIENTS

The idea that the phonological loop plays a role in language processing has been investigated also by studies on neurologically impaired patients. Baddeley and Hitch (1974)'s model could accommodate the explanation of performance of patients as KT, described by Shallice and Warrington (1970), and PV, reported by Basso, Spinnler, Vallar, & Zanobio (1982), who presented marked impairments in span tasks, but were otherwise intellectually unimpaired. The low performances in short-term memory tasks were explained as impairments of the phonological storage, whereas the preservation of other components of the memory system allowed good abilities in coping with everyday life. Further investigations (Baddeley et al., 1988) carried out on PV, together with the description of a patient presenting a similar pattern (Trojano & Grossi, 1995), confirmed what in the same years was hypothesized for children with delayed language development: short-term memory is an essential mechanism for long-term learning of novel words, when no pre-existing semantic representation is available. Indeed, PV showed good abilities when asked to learn pairs of unrelated words, whereas her performance in the word-nonword pair learning highlighted a dramatic impairment when stimuli were auditorily (but also visually) presented.

Many other studies have been conducted on patients with neurological disorders, in order to have a deeper understanding of the links between the phonological loop and language processing.

Researches on aphasic patients highlighted an association between low performance on tasks measuring phonological loop functioning and impairment in the processing of linguistic representations (e.g. N. Martin & Saffran, 1990, 1992; R. C. Martin et al., 1994), suggesting that short-term memory and linguistic systems are related and share some underlying processes.

In particular, N. Martin and colleagues (N. Martin & Saffran, 1997; N. Martin & Ayala, 2004) analyzed the performance of large samples of aphasic patients on a variety of tasks assessing both verbal short-term memory and language processing abilities (naming, comprehension, phonological processing). Strong correlations were found between the level at which the linguistic impairment appeared (i.e. lexical-semantic or phonological) and the type of difficulties encountered during span tasks. For example, those patients who showed problems at the phonological level (in tasks as phoneme discrimination and auditory rhyme judgments), during span tasks had more difficulties in retrieving items from final positions of the input string than patients with lexical-semantic impairments, who presented greater problems in retrieving initial items of the list. This pattern is in line with the serial position effect, according to which recall accuracy varies as a function of item position in a list: the retrieval of items in the final positions would rely on the phonological short-term store (recency effect), whereas the recall of initial items would rely on the retrieval of information from long-term memory (primacy effect). When damage to the phonological short-term store occurs, there is no output from this store and the final items of the list are not produced. This explains why patients showing a deficit in phonological processing in N. Martin and colleagues' descriptions, also showed marked difficulties in retrieving the last items during list recall.

The analyses of the patterns of impairment showed by some aphasic patients led R. C. Martin's group to hypothesize, beside phonological short-term memory, a semantic short-term memory, whose damage would lead to difficulties in dealing with the semantic processing of items during span tasks (e.g. R. C. Martin et al., 1994; R. C. Martin & Romani, 1994; Hanten & Martin, 2000; R. C. Martin & He, 2004; R. C. Martin, 2005). R. C. Martin et al. (1994) described a patient (AB) without difficulties in single-word comprehension and naming tasks, as well as in tasks measuring the retention of phonological information, but who was extremely impaired in short-term memory tasks that required the retention of word semantics (e.g. category probe task, where the subject has to decide whether a probe item belongs to the same category as one of the words previously presented from a list of increasing length).

Hoffman and colleagues (Hoffman, Jefferies, Ehsan, Hopper, & Lambon Ralph, 2009; Hoffman, Jefferies, & Lambon Ralph, 2011) challenged the "semantic buffer" account, claiming that in the so-called "semantic short-term memory" patients, the damage would be to a system in charge of a general semantic processing, rather than to a specialized semantic buffer. The authors argue that the semantic deficit emerging during short-term memory tasks could be the result of the mildest form of a spectrum of impairments involving the processing of semantic features, a spectrum at the other end of which would stand the “semantic aphasics”: Wernicke’s, transcortical sensory, and global (see Chapter 3 for a more extensive description of the two positions).

2.1.3 SENTENCE RECALL

So far, the role of short-term memory has been discussed through a brief review of studies that tested (non)word list repetition and the recall of word-nonword pairs.

But what does it happen when the item to recall is not a single word, but a whole sentence? Is this type of repetition mainly supported by access to temporary phonological representations of the sentence held in short-term memory, or to the products of syntactic and semantic analysis of the sentence structure?

According to Potter and Lombardi (see Lombardi & Potter, 1992; Potter & Lombardi, 1990, 1998), sentence recall involves the integration of phonologically and lexically activated items with semantic information and structural aspects of the sentence. While list recall is supported by phonological short-term memory, sentence repetition is underpinned by a dynamic memory system with access to lexical semantic information (Baddeley’s episodic buffer).

Potter and Lombardi (1990) claimed that in a sentence recall task, it is not the short-term representation of the surface sequence that allows verbatim recall; instead, more levels of representations are activated with respect to those activated in a word list recall, namely phonological, syntactic, and semantic levels. The authors maintained that the immediate memory for a sentence is conceptually based and reconstructive, and that during the process of regeneration of the to-be-recalled sentence, the activated lexical entries fit the activated syntactic and conceptual information. If more than one conceptually suitable lexical item is activated (e.g. a synonym used as distractor), it is possible that the sentence is incorrectly repeated. If the intruding item is the verb, and requires a different syntactic structure, the whole recalled sentence would present a structure different from the original (Lombardi and Potter, 1992). The authors claimed that the syntax of the sentence is not directly represented in memory, but regenerated using the normal mechanisms of sentence production, with the verb determining the structure. Moreover, when the selected verb allows more than one structure, a structure that has been recently activated is likely to be reused, giving rise to the so-called *syntactic (structural) priming*.

However, children (Willis & Gathercole, 2001) as well as brain-damaged patients (McCarthy & Warrington, 1987a, 1987b) seem to rely on phonological short-term memory to a greater extent than adults during language processing necessary for sentence repetition. McCarthy and Warrington (1987a) suggested that when the analysis of language is delayed in transcoding incoming language into the necessary central cognitive representations (because of a lesion in language-impaired patients, or because of poorer proficiency in the case of young children), language processing requires the support of phonological memory for an off-line analysis. This is demonstrated, for example, in Willis and Gathercole (2001)'s study: 4 and 5-year-old children are more accurate in repeating sentences containing short rather than longer words.

Baddeley & Wilson (2002) described the performance of a sample of densely amnesic patients in a prose recall task. Since the results highlighted preserved abilities in the immediate recall, and grossly impaired capacities in the delayed recall, the authors claimed that the good performance in immediate recall was due to a good quality representation of the phonological input in the episodic buffer (that clusters the prose into chunks) and to the capacity to maintain the representation thanks to the executive processes controlled by the central executive. In delayed recall, the impaired long-term memory does not have the capacity to retain the representation, and this explains the poor performance.

Therefore, it is possible to maintain that in sentence recall not only the phonological loop is sustained by the episodic buffer to a greater extent than in word list recall, but also that the access to levels of processing other than the phonological one (i.e. syntactic and semantic) is fundamental to retain the correct representation of the sentence.

A lively ongoing debate tried to clarify the role of the phonological loop during sentence processing at the syntactic level. As already mentioned above, comprehending a sentence implies that its elements (in a phonological format) remain available over time, to let the lexical entries be integrated in the correct structure, because structure and lexical entries do not always become available at the same time during the presentation of a sentence. For example, some structures require the displacement of elements, and in these cases the structure and the lexical entries have to remain available to allow the correct comprehension of the sentence. A clear (and complex) example comes from object relatives clauses in center embedded position (e.g. Chomsky & Miller, 1963; Gibson, 1998).

In the sentence "*The lion that the horse touched passed the pig*", the object (*the lion*) of the relative clause (*that the horse touched*) is the subject of the main clause (*the lion* *passed the pig*). This complex structure contains a structural link between two discontinuous positions: the argument position of the object of the verb *touched* is empty, and the processing of the sentence requires the retrieval of the element *the lion* to fill the empty argument position of the object of the relative clause. Moreover, in this example, complexity is increased by the interruption of the processing of the main clause by the embedding of the relative clause within the main sentence.

This was an example to show how sentence processing can be very demanding from the point of view of memory resources, since some sentences require the maintenance and control of different elements (words, structures) at different levels (phonological, syntactic) over time.

The memory resources used for sentence computation could rely on working memory components (the central executive and the phonological loop), or may be a specialized subset.

This latter position is supported by the Separate Sentence Interpretation Resource theory (see Caplan & Waters, 1999 for a detailed presentation of the theory), which suggests that a separate memory subsystem is responsible for the syntactic and semantic operations performed online during sentence interpretation. According to this theory, the central executive and the phonological loop would play a role only at a post-interpretative stage of sentence comprehension. This theory is mainly supported by negative results, which show that an impairment of the phonological loop does not necessarily affect language comprehension (Howard & Butterworth, 1989; Waters & Caplan, 1996). Nonetheless, behavioral (e.g Fedorenko, Gibson, & Rohde, 2006) and neuropsychological (e.g. Caramazza, Basili, Koller, & Berndt, 1981; Friedrich, Glenn, & Martin, 1984; Papagno, Cecchetto, Reati, & Bello, 2007) studies suggested an involvement of the phonological loop when syntactically complex sentences are used to assess language comprehension (see also Cecchetto & Papagno, 2011).

A repetitive transcranial magnetic stimulation (rTMS) study (Romero Lauro, Reis, Cohen, Cecchetto, & Papagno, 2010) investigated and confirmed the role of the phonological loop during the processing of various sentence structures. TMS is a non-invasive brain stimulation technique that can be used to interfere with information processing in a specific cortical area, thus demonstrating the role of the stimulated area for the performance of a given task.

More specifically, the aforementioned TMS study aimed at defining the distinct involvement of the two subcomponents (phonological short-term store and articulatory rehearsal) in the comprehension of syntactically complex and long sentences, by means of disrupting the activity of the supposed neural correlates of the phonological short-term store (BA 40) and of the articulatory rehearsal (BA 44). Participants completed a sentence-to-picture matching task: they heard a sentence while seeing a picture on the screen, and had to decide whether the picture matched the sentence. Sentences had different degrees of length and complexity: *short* sentences were active ("*The dog is chasing the cat*"), passive ("*The boy is kissed by the woman*"), dative ("*The boy is giving the cake to the girl*"), with no coordination or subordination; *long* sentences had noun phrase coordination ("*The girl is welcoming the man and the woman*") or sentential coordination ("*The boy is drinking milk and the girl is eating an apple*"), without long distance dependencies; sentences with long distance dependencies were of two types, namely subject/object relative clauses in right peripheral position (subject: "*The man is watching the dog that is chasing the cat*", object: "*The man is watching the cat that the dog is chasing*"), and subject/object center embedded relative clauses (subject: "*The* *dog that is chasing the cat is watching the girl*", object: "*The man whom the woman is watching is eating pasta*"). The analysis of accuracy and reaction times during the sentence-to-picture matching task highlighted the involvement of both components of the phonological loop in the processing of syntactically complex structures, while processing of long but syntactically simple sentences proved to rely only on the phonological short-term store. A second experiment (a sentence verification task with long sentences in which word order was crucial for a correct judgment, and that did not require a picture matching operation) found that the disruption of the phonological short-term store affected the performance on sentences in which the processing of word order was crucial. Therefore, this experiment ruled out the possibility that the involvement of the phonological loop occurred only at a post-interpretative stage, i.e. when subjects had to match a sentence to the corresponding picture, as suggested by Caplan and coworkers.

A very interesting point concerns the neural correlates of the articulatory rehearsal component of the phonological loop. It is well known how damage to the left inferior frontal gyrus (BA 44, Broca's area) can disrupt syntactic processing (e.g. Caramazza & Zurif, 1976; Schwartz, Saffran, & Marin, 1980; Berndt & Caramazza, 1980): typically, agrammatism is a consequence of a lesion to Broca's area. During language processing, left BA 44 is activated when a reconstruction of sequential input is necessary due to element displacements and long dependencies (e.g. Friederici, 2006). The left inferior frontal gyrus is also involved in verbal short-term memory tasks, such as digit span, that do not require syntactic processing (see Romero Lauro et al., 2006).

Therefore, the activation of Broca's area during syntactic processing is consistent with the possibility that it might reflect the involvement of the phonological loop: the computation required during sentence processing could be governed by language specific rules, together with the aid of auxiliary resources, including verbal short-term memory.

2.1.4 NON-INVASIVE BRAIN STIMULATION

As already briefly mentioned, neuropsychological studies on patients with brain damage (e.g. Baddeley & Wilson, 1985; Vallar & Cappa, 1987; Cubelli & Nichelli, 1992; Vallar et al., 1997; Silveri, Cappa, & Salvigni, 2003; Papagno et al., 2007), neuroimaging studies (e.g. Paulesu et al., 1993; Awh et al., 1995; Henson et al., 2000) and rTMS studies (Romero Lauro et al., 2006, 2010) support the hypothesis that the inferior parietal lobule (BA 40) and Broca's area (BA 44) are the neural correlates of the phonological short-term store and the articulatory rehearsal, respectively.

As already reported, non-invasive techniques of stimulations (as TMS) can be used to modulate the cortical activity by increasing or decreasing cortical excitability of the targeted areas. One more recent technique is transcranial direct current stimulation (tDCS), which allows modulating cortical excitability and verifying the effects of this modulation on cognitive performance by delivering a constant flow of current to the areas of interest through electrodes. tDCS is delivered through a battery powered device that delivers constant current. Two saline-soaked sponge electrodes of various dimensions are applied: one over the targeted area, and the other, the reference electrode, is placed on another location on the opposite side of the body (usually on the contralateral shoulder or supraorbital region).

The modulation of spontaneous cortical activity depends on the polarity of the current flow released by tDCS (Liebetanz, Nitsche, Tergau, & Paulus, 2002): anodal tDCS (a-tDCS) requires the application of the anode (i.e. the positively charged electrode) on the area of interest, and is supposed to increase excitability, whereas cathodal tDCS (i.e. the stimulation of the targeted area with negatively charged electrode) usually decreases it (but effects of cathodal tDCS are more controversial, see Monti, Cogiamanian, Marceglia, Ferrucci, Mameli, Mrakic-Sposta, et al., 2008).

Investigations with tDCS usually require three sessions (which order is randomized across participants):

In the *experimental* session, the area of interest is stimulated. In the *control* session, a control area (supposed not to be involved in the experimental task) is stimulated. This allows verifying that possible changes in performance are specific for the stimulation of the area of interest, and not due to a general effect of tDCS. During *sham* session, current is delivered only for a few seconds: this gives participants the initial itching sensation at the beginning of the stimulation (therefore, not allowing them to be aware of the effectiveness of the stimulation), but prevents any modulation of cortical excitability, so that a baseline measure of participants' performance on the experimental task is obtained.

To our knowledge, there is no study that investigates the possible changes in performance on verbal short-term memory by modulating cortical activity by means of tDCS. This should be of particular interest, since tDCS has been successfully used in cognitive rehabilitation (see Holland & Crinion, 2012 for review).

3. CHAPTER II

IMMEDIATE SERIAL RECALL

3.1 RATIONALE

3.1.1 THE SEMANTIC BUFFER HYPOTHESIS

As already mentioned, in 1994 R. C. Martin and colleagues introduced a new short-term memory component, semantic short-term memory (R. C. Martin et al., 1994), which would work in concert with the phonological short-term memory in keeping active the representation of a word for processing. The authors considered this buffer necessary to explain the performance of a brain-damaged patient (AB), comparing it with the performance of another patient (EA) (see also R. C. Martin, 1987). Both patients showed an impaired span, but while EA seemed to have a low retention of phonological information, AB appeared to have a deficit in the retention of semantic information. EA had an impairment to the phonological short-term storage: she did not show the phonological similarity effect or the recency effect, performed better with visual than auditory presentation, and repetition of words was better compared to nonwords. On the other hand, AB presented a phonological similarity effect with visual presentation, and his performance was overall better when items were auditorily rather than visually presented. Moreover, the comparison of AB and EA's performances in the recall of letters and words highlighted an advantage in the recall of letters for AB, and of words for EA. AB's performance was explained through a poor retention of the semantic information conveyed by words, a type of information that has not to be retained for letters. The comparison between the two patients on the serial recall of auditorily presented words, however, failed to reach significance, therefore highlighting a comparable impairment in the ability to handle acoustic input (either it is considered from a phonological or a semantic point of view).

These results, replicated in studies on other patients (R. C. Martin & Romani, 1994; R. C. Martin, Lesch, & Bartha, 1999; R. C. Martin & Freedman, 2001; R. C. Martin & He, 2004), led the research group to introduce the semantic short-term memory as a component of the working memory system. Damage to this component would cause a specific deficit when dealing with semantic information during short-term memory tasks, leaving more general semantics abilities (e.g. naming, single word comprehension) almost intact.

Before moving to the studies that rejected the existence of this component, some information about the neuroanatomical aspect of the semantic short-term memory is required.

According to R. C. Martin group, the analysis of lesions causing a semantic short-term memory deficit would localize the semantic buffer in the left inferior frontal region, with possible extension to the adjacent parietal regions (R. C. Martin, 2005). Not surprisingly, this area includes Broca's area, which (as mentioned in the previous chapter) is considered to be the neuroanatomical correlate of the articulatory rehearsal. Therefore, at least part of the deficits described for the so-called "semantic short-term memory patients" could be ascribed to the impairment of the rehearsal process.

A strong challenge to the semantic buffer hypothesis came from Lambon Ralph's group (see Hoffman et al., 2009, 2011), who claimed that "semantic short-term memory patients occupy the mildest end of spectrum of semantic control disorders", ascribing the deficit described by R. C. Martin and colleagues to a damage of the cognitive control processes that regulate activation in the semantic system, then ruling out the need for a specific semantic short-term memory.

The authors claimed that the appropriate retrieval of semantic knowledge from long-term memory is a complex process that requires a number of regulatory processes (semantic control). Tasks assessing the ability in dealing with semantic information require different degrees of semantic control, and semantic short-term memory tasks require a high degree of this cognitive control, because by definition they need activation of representation to be maintained without any external support (for example, in semantic short-term memory tasks, the semantic information cannot be refreshed by refixating on the presented picture or word). On this basis, the authors hypothesize that patients with mild semantic control deficits might show impairment on semantic short-term memory task, while less demanding semantic tasks would appear unaffected.

In a first study (Hoffman et al., 2009), the performance of two semantic short-term memory patients on differently demanding tasks was compared to that of a group of 11 aphasic patients with semantic impairments (verbal comprehension deficits, failure in both picture and word test of semantic association; a detailed description of the patients is in Jefferies & Lambon Ralph, 2006). This comparison led the authors to claim that the two sets of patients shared a common semantic impairment, manifested at different levels of severity.

To further verify this hypothesis, three semantic short-term memory patients were tested (Hoffman et al., 2011). Patients' semantic processing was assessed by means of picture naming, word-picture matching and semantic associations, and the performance suggested that semantic processing was intact. On the other hand, short-term memory (unimpaired with regards to the phonological aspects) resulted damaged for semantically mediated information: patients showed a reduced lexicality effect (according to which the recall of words should be better than the recall of nonwords, see Hulme, Maughan, & Brown, 1991) and a low performance on the semantic category task.

The experimental tasks directly manipulated the level of semantic control required (on which the aphasic patients with semantic impairments systematically failed), and the authors predicted that the manipulations would affect semantic processing, regardless of the strength of a short-term memory component in the tasks themselves.

Tasks required processing polysemous words and resolving ambiguity between potential word meanings by selecting the contextually appropriate meaning; they also measured the sensitivity to cues that bias semantic processing towards the correct response, the abilities in resisting interference from strong but irrelevant semantic associations, and the capacity of detecting associations between distantly related concepts. All the tests were presented in a visual (less demanding from a short-term memory point of view) and an auditory (more demanding) modality. If the patients' deficits were the result of a reduction in the capacity of a semantic short-term buffer, they should be affected only by modality, and not by the degree of semantic control required, since high and low control conditions required the retention of the same amount of semantic information (in terms of number of words). On the other hand, if the control hypothesis was right, patients should be more impaired on trials with a high semantic control requirement.

The prediction that manipulations of semantic control would influence semantic processing in semantic short-term memory patients was confirmed: the degree of semantic control influenced the performance, even when the visual presentation of stimuli decreased the short-term memory load of the tasks. Thanks to these results, the authors claimed that what R. C. Martin and colleagues interpreted as an impairment to a specific short-term memory component, was instead the result of high semantic control demands, to the point that patients who can handle semantic control to some extent, are unable to deal with such demanding tasks. Hoffman and colleagues conclude that semantic short-term memory deficits should be seen not as a distinct disorder, but as occupying the least impaired end of a continuum of semantic control disorders, claiming that in such view there is no need to postulate the existence of a semantic short-term memory component in the working memory structure.

3.1.2 DOES SHORT-TERM MEMORY NEED SEMANTICS? EVIDENCES FROM SEMANTIC DEMENTIA

Short-term memory performance is definitely affected by long-term knowledge. One example is the mentioned lexicality effect, namely a better performance in recalling real words as compared to nonwords (Hulme et al., 1991). This suggests that recalling real words benefits from the activation of pre-existing long-term representations. However, this facilitation produced by long-term representations could be of two types: short-term memory performance could be enhanced by familiarity with the phonological form of the word, or, alternatively, by semantic information. Although these two types of information work together, they can be differently available: on the one hand, a person can access all semantic information about a word, whose phonological form nevertheless cannot be entirely retrieved. This is the typical “tip-of-the-tongue” phenomenon. Less frequently, on the other hand, one knows a word but cannot remember its meaning: this happens for example with foreign speakers who can recognize a given word as already heard but cannot remember its meaning anymore.

The role of long-term knowledge on short-term memory performance is made explicit in Hulme and colleagues' (Hulme, Roodenrys, Schweickert, Brown, Martin, & Stuart, 1997) *redintegration hypothesis*. According to this hypothesis, phonological representations are stored in long-term memory. When phonological representations decay during a span task, they undergo a process of reconstruction that reactivates long-term representations, which of course are not available for nonwords. This can explain why subjects produce better performances in recalling words relative to nonwords; it also explains word frequency effects, namely the fact that high frequency words have an easier access to representations that facilitates redintegration.

While the role of phonological representations in span is uncontroversial, there are contrasting opinions about the role of semantic representations. On the one hand, Walker and Hulme (1999) suggest that redintegration could happen also through the access to semantic representations of words, since they found that concreteness (a semantic variable) affects performance.

In the same vein, the interpretation suggested by Saint-Aubin and Poirier (2000) attributes a role to semantic representations. They hypothesize that the presentation of a sequence of words creates a phonological representation of items, subject to decay.

During the recall process, phonological representations are retrieved in the correct order. The deteriorated phonological representation of a specific item can help to access the correct long-term representation of the item itself. High frequency and semantic similarities lead to a better recall of items, because these variables increase the accessibility to the long-term representation, which incorporates lexical-semantic information (Saint-Aubin & Poirier, 1999, 2000).

Studying people affected by semantic dementia can investigate the role of semantic representations in span tasks, because these patients have intact phonology, while semantic representations are largely deteriorated.

Semantic dementia is a neurodegenerative condition characterized by the progressive degradation of semantic knowledge, caused by structural and functional alterations of anterior and inferior regions of bilateral temporal lobes (Snowden, Goulding, & Neary, 1989; Hodges, Patterson, Oxbury, & Funnell, 1992). Patients affected by semantic dementia can fluently speak, but comprehension and production of words progressively deteriorates to severe anomia, with preserved syntactic structure and phonology. At the first stages of their disease, subjects are able to correctly read and repeat regular words, as well as irregular high frequency ones, whose meaning has already been lost (Knott & Patterson, 1997); they are also able to learn new phonological sequences, thanks to their intact phonological short-term memory (Jefferies, Bott, Ehsan, & Lambon Ralph, 2011).

If semantic information were relevant in immediate serial recall, semantic dementia patients should show a pathological performance with items whose meaning has been lost. On the other hand, if only phonological representations were crucial, these patients' span would be intact for phonologically known words, independently of the availability of the meaning.

Although several studies found that semantic dementia patients show an effect of semantic variables (e.g. Patterson, Graham, & Hodges, 1994; Knott & Patterson, 1997; Knott, Patterson, & Hodges, 2000; Jefferies, Lambon Ralph, & Baddeley, 2004; Jefferies, Jones, Bateman, & Lambon Ralph, 2005; Majerus, Norris, & Patterson, 2007), Papagno et al. (2013) found some methodological weaknesses and claimed that only familiarity with phonological representations facilitates immediate serial recall, not word meaning knowledge.

In Patterson et al. (1994)'s study on three patients affected by semantic dementia, the authors attribute a critical role for short-term memory to semantic representations, claiming that it is thanks to the knowledge of the meaning that words are correctly retrieved during serial recall. Patients were tested on the immediate serial recall of words that had previously been divided in sets of semantically known and unknown words, but the actual phonological knowledge of the items was not assessed (for example, by means of lexical decision, where words and nonwords are presented, and subjects have to decide whether an item is a real word or not), leaving the possibility of familiarity with the phonological form – even in absence of access to the semantic representation – open. Moreover, the two sets of words were not matched for frequency of use. Therefore, the results of this study cannot rule out the possibility that performances on the serial recall task were affected by variables connected with the familiarity with the phonological form of words.

Similar criticisms can be moved to Knott and Patterson (1997) and Majerus et al. (2007)'s works, who did not control for the patients' ability to recognize the phonological form of words, despite the loss of their meaning: all these studies compared performances obtained by semantic dementia patients on serial recall tasks involving “known” and “unknown” words, without checking to what extent the knowledge of the so-defined “unknown” ones was actually lost. Therefore, results showing a better performance on “known” words do not disentangle the question whether it is the semantic knowledge or the familiarity with the phonological form that helps the redintegration process.

On this open question, Papagno et al. (2013) based their study: they controlled for the level of impairment of phonological representations of words in a patient affected by semantic dementia, in order to verify whether redintegration is based on the familiarity with the phonological form or on semantic knowledge of words.

Papagno and colleagues interpret word frequency effects, leading to a better performance in short-term memory tasks, as due to the frequency of the phonological form of the word. Based on this hypothesis, they investigated word and nonword span in the patient, controlling for her knowledge of the phonological representation of items. On the basis of this patient’s performance in tasks such as lexical decision, word comprehension, picture naming, and naming by description, stimuli were divided in four groups: known words; words whose phonological form was familiar to the patient, but with semantic information unknown to her; words unknown from both the phonological and the semantic point of view (then, considered as nonwords by the patient); nonwords.

Consistently with the hypothesis that only the phonological form of the word is crucial in short-term memory tasks, they found that the patient had a comparable performance for known words and words whose phonological form (but not semantics) was known, while unknown words elicited a performance similar to nonwords. The authors argued, therefore, that verbal short-term memory is preserved when phonological representations are available, despite the severe deterioration of semantic memory.

The following experiments are aimed at further investigating and testing the reliability of the results obtained by Papagno and colleagues. If they are correct, a comparable performance is expected in healthy subjects: the immediate recall of items should not be affected by the knowledge of their meaning, but only by the familiarity with the phonological form of the word.

The experimental design of Study 1, in which Italian uncommon words were used, revealed the inadequacy of using this set of words, because it was not possible to control for each subject's familiarity with phonological form and semantics of items, being words in participants' native language. Therefore, in Study 2 words in an unknown language were used, and participants were trained to get acquainted with phonology and meaning of items.

3.2 STUDY 1 – ITALIAN WORDS

3.2.1 METHODS

Screening procedure

Fifty-one words (31 tri-syllabic, 15 four-syllabic, 3 bi-syllabic, and 2 five-syllabic) judged as uncommon were selected; the selection was made by two researchers with a linguistic background, using an Italian dictionary (http://www.treccani.it/vocabolario/). A questionnaire was given to 214 undergraduate students (32 males, 182 females, age ranging between 19 and 47, mean age 22.3), asking them to answer two yes/no questions for each of the above-mentioned words:

1. Have you ever heard this word?

2. Do you have an idea (even vague) of its meaning?

Then 8 tri-syllabic words (list A) with the highest number of answers "yes" to question #1 and "no" to question #2 (mean: 39, 18%) were selected, and 8 tri-syllabic words (list B) with the highest number of answer "no" to both questions (mean: 194.5, 91%).

So, two lists were built, supposed to be:

List A: tri-syllabic words whose phonological form is familiar, but with unknown semantic information;

List B: tri-syllabic words unknown from both the phonological and the semantic point of view.

Eight tri-syllabic words (list C), whose meaning is certainly known (e.g. "pronoun", "miller", "baking pan"), were selected, matched with the 16 constituting lists A and B for concreteness and frequency (according to CoLFIS, Bertinetto et al., 2005).

List D included 8 tri-syllabic pseudowords, balanced for syllabic complexity, length, and Ncount (defined as the number of real words obtained changing one letter at a time of the pseudoword) (Benetello, Finocchiaro, Capasso, Magon, Miceli, in prep.).

Participants

Eighty-six (63 females, 23 males) healthy subjects were tested.

Their age ranged between 19 and 41 (mean: 23, sd=4), and years of education varied between 14 and 18 (mean: 15.8, sd=1.3). All subjects were right-handed, Italian native speakers, and did not present neurological or psychiatric diseases.

Experimental tasks

The 32 words (whose rate of articulation varied between 1000 and 1560 ms) were recorded on digital support and presented to the experimental subjects through headphones at 1000 ms interval.

For each list (presented in a pseudo-randomized order) subjects heard three sequences of N (ranging from 2 to 8) words. In a sequence, a word was presented only once, in random position. Subjects had to repeat back the sequence immediately after presentation. If 2 out of 3 sequences were correctly repeated, the sequence of the next length was presented (N+1), otherwise the task switched to the next list of words. This task ended after the presentation of all the four lists.

The span task was followed by two questionnaires:

In the first one, for each of the 16 words (lists A&B) subjects were asked to report whether they had heard it before (in order to assess whether the phonological form was familiar); in the second one, they were presented with five definitions (four false and one real) and asked to select the correct one for each of the 16 words (to assess the knowledge of the meaning).

On the basis of the participants' answers, 59 subjects out of 86 were selected and divided in two experimental groups:

Group 1: 15 subjects (6 males, 12 females, mean age 21.6) who reported to be familiar with the phonological form of the word, but could not identify its correct definition, for at least 5/8 words of list A or B (hence List Z);

Group 2: 44 subjects (10 males, 34 females, mean age 23.7) who reported that they were not familiar with the phonological form, and could not identify the correct definition either, of at least 5 out of 8 words of list A or B (hence List Y).

The remaining 27 subjects were not included in the analyses either because they did not reach the minimum span of 2 in one of the lists, or because they did not reach the cut-off of 5 out of 8 answers consistent with the expected ones.

Data analysis

Word span corresponds to the maximum length at which the subject is able to produce at least two correct sequences out of three.

"List Z" is the list on which Group 1 reached the cut-off of 5/8 *recognized* words (i.e. words whose phonological form, but not the meaning, is familiar).

"List Y" is the list on which Group 2 reached the cut-off of 5/8 *unknown* words (i.e. words whose both phonological form and meaning are unknown).

For each group, the performance on List Z (for Group 1) and List Y (for Group 2) was compared to the performance on List C (*known* words) and List D (*nonwords*).

A random effect analysis of variance (ANOVA) was run, with “word span” as dependent variable, “subject” as random factor, and “list” as fixed factor.

3.2.2 RESULTS

For Group 1 the mean span was 2.87 (sd = 0.83) on List Z, 3.93 (sd = 0.7) on List C, and 2.13 (sd = 0.35) on List D.

The mean number of *unknown words* (i.e. unknown from both a phonological and a semantic point of view) was 1.13.

The mean number of *known* (from both a phonological and a semantic point of view) words was 1.13.

The random effect ANOVA revealed a main effect of list [$F(2,28) = 63.459$; $p < .001$]. Post-hoc tests (Bonferroni) indicated that the performance on all the three lists differed (all $p < .001$) (see Figure 1).

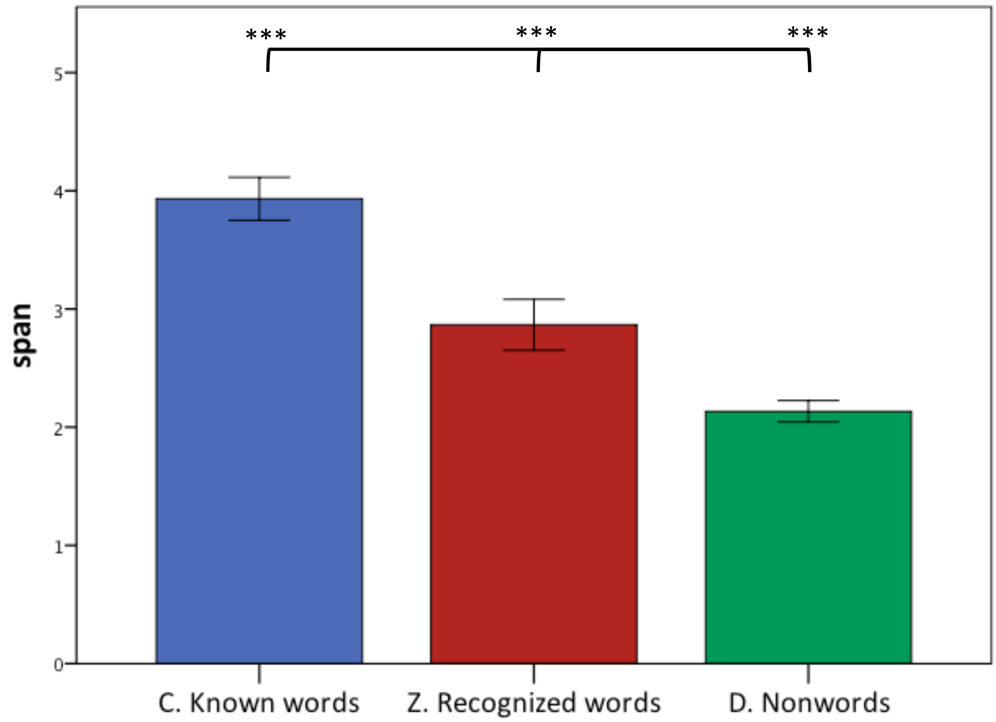

Figure 1. Performance of Group 1 on lists C, Z, and D.

For Group 2 the mean span on List Y was 3.18 (sd = 0.97), on List C was 4.77 (sd = 0.89), and on list D was 2.56 (sd = 0.63).

The mean number of *recognized words* (i.e. words whose phonological form was familiar) was 0.82.

The mean number of *known* (from both a phonological and a semantic point of view) words was 0.34.

The random effect ANOVA revealed a main effect of list [F(2,86) = 192.795; $p < .001$]. Post-hoc tests (Bonferroni) indicated that the performance on all the three lists differed (all $p < .001$) (see Figure 2).

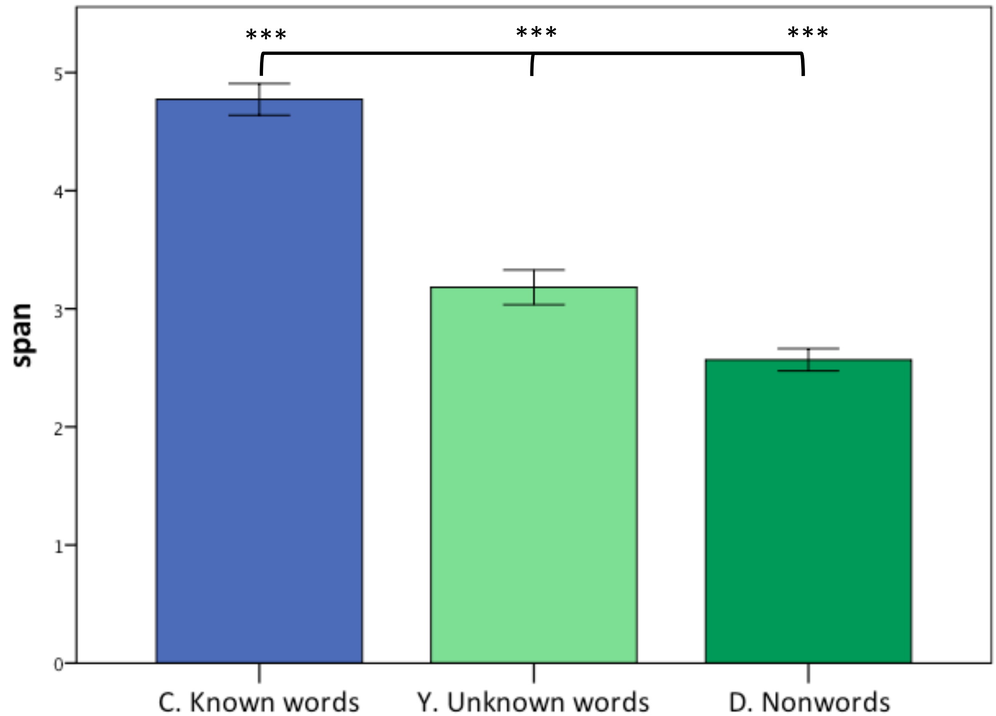

Figure 2. Performance of Group 2 on lists C, Y, and D.

The performance of the three subjects (Subgroup 2A) was analyzed, who were not familiar with the phonological form, and could not identify the correct definition either, of any of the words of list Y (therefore, showing a performance very similar to the SD patient described by Papagno et al., 2013).

The random effect ANOVA revealed a main effect of list [F(2.4) = 12.000; $p < .05$]. Post-hoc tests (Bonferroni) showed a significant difference between lists C and Y, and between C and D (all $p = .04$), whereas the performance on Y and D did not differ ($p = 1$) (see Figure 3).

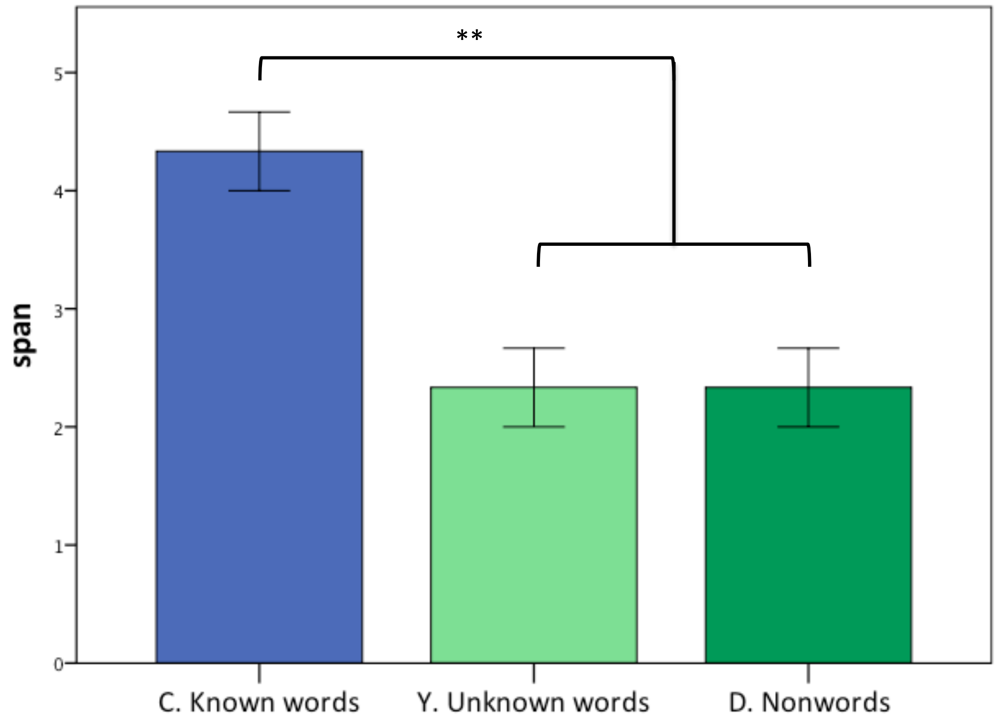

Figure 3. Performance of Subgroup 2A on lists C, Y, and D.

It was not possible to run the same analysis on Group 1, since all subjects but one knew (i.e. were able to find the correct definition of phonologically familiar words) at least one word of list Z, therefore making it impossible to rule out the influence of access to semantics.

This single subject had a span performance of 3 on list Z, 4 on list C (*known words*) and 2 on list D (*nonwords*).

3.2.3 DISCUSSION

In a span task, the performance on *recognized words* (phonology without semantics) is significantly better than the performance on *nonwords*. These data, in line with previous findings (e.g. Hulme et al., 1991) demonstrate that in a verbal short-term memory task familiarity with the phonological form is enough to facilitate the retrieval of words, and replicate the performance of the semantic dementia patient (Papagno et al., 2013), who showed a better performance when tested with words whose meaning was lost, but whose phonological form was still familiar, than when tested with unknown (from both a semantic and a phonological point of view) words and with nonwords.

The comparison between the performance on *unknown words* (unfamiliar from both phonological an semantic point of view) and on *nonwords* is significant, as well. These data, in contrast to the patient's results, suggest that participants did not process *unknown words* as pseudowords. This difference can be easily explained if we consider the experimental design: the criterion to be met in order to include a subject in the experimental sample was reaching the cut-off of 5 out of 8 words unfamiliar from both phonological an semantic point of views. This means that in the list of *unknown words* there could have been up to 3 words that did not meet the criterion of being unknown. Indeed, an *a posteriori* analysis on Group 2 performance showed that 10% of the words (mean: 0.82) were recognized from a phonological point of view; moreover, 15 of those words (mean: 0.34) were also matched with the correct definition, therefore showing an access to both the phonology and the semantics of the words. This, indicating a non-complete loss of semantic or phonological information, could have interfered with the span performance of participants, not allowing us to consider list Y as a clear *unknown words* list.

Similarly, with regards to Group 1, 14% of the words (mean: 1.14) were not recognized from a phonological point of view, making the performance worse than expected if all the words would have been recognized.

Therefore, it is possible (at least momentarily) to rule out the idea that the difference obtained between the performance on *known words* and on *recognized words* suggests a facilitating role of semantics in recalling the correct word, ascribing the difference itself to a fault of the experimental design.

To better understand the relevance of phonological as compared to semantic information in tasks assessing short-term memory capacity, another study, described in Study 2, was conducted.

3.3 STUDY 2 – "CROATIAN" WORDS

3.3.1 METHODS

Materials

As showed above, the preliminary study with very uncommon Italian words, unknown to the majority of people, indicated that such stimuli could not be the basis of fully reliable experiment. Therefore, it was decided to use a language unknown to participants, and to train them on the meanings and phonological forms of the new words.

Sixty disyllabic words were selected from Croatian and modified in order to respect Italian phonotactic rules (structure of the words was CVCV, CCVCV, or CVCCV).

Ten words constituted List 1 (*phonology plus semantics*), ten words constituted List 2 (*phonology without semantics*), and ten words constituted List 3 (*unknown words*). The remaining words were untrained and used in the training phase as foils during lexical decision and word-picture matching tasks (see below).

Each word of lists 1 and 2 was matched with a meaning (concrete, that could be visually represented and with the same frequency of use (CoLFIS, Bertinetto et al., 2005)). The meaning was selected among those of the words used by Papagno et al. (2013). The selected meaning not necessarily corresponded to the actual meaning of the Croatian word. Indeed, the aim was to match as far as possible the condition of the semantic dementia patient; therefore, we assigned to the Croatian words the same meaning of the Italian words selected for the patient.

The 60 words (whose rate of articulation varied between 618 and 937 ms) were recorded on digital support by a male voice.

All the different sections of the experiment were administered by means of the software *E-Prime 1.1*.

Participants

Thirty (11 males) healthy subjects were tested. Their age ranged between 19 and 46 (mean: 27.62, sd = 5.96), and years of education varied between 13 and 18 (mean: 17.17, sd = 1.84). All subjects were Italian native speakers, and did not suffer from neurological or psychiatric diseases. None of them was familiar with Croatian or any other Slavic language.

Procedure

Subjects were tested individually in two different sessions lasting approximately 1 hour each.

On Day One, subjects were trained and tested on either List 1 or List 2; on Day Two they were trained and tested on the other list. List 3 (*unknown words*) was always tested immediately after List 2. In order to avoid interference between items belonging to Lists 1 and 2, testing sessions were at least 3 days apart.

The order of presentation of List 1 and List 2 was counterbalanced across participants.

During the sessions, participants sat in front of a computer at about 0.5 m from the screen. Written instructions were given before each experimental phase, and the examiner was available to provide additional instruction if necessary.

Training Phases for Lists 1 and 2

Familiarization with word lists was performed in both a written and an auditory modality: participants heard words through headphones, while singularly reading them on the screen. The written word was showed on the screen for 2000 ms. The inter-stimuli interval (i.e. white screen and silence) was 1000 ms.

Words were presented in a random order, and each list was repeated four times.

During *familiarization* with words belonging to List 1 each time a word appeared on the screen, on the top of it, a black-and-white drawing representing the meaning of the word was presented, along with the written word (for example when the word "*puno*" appeared, the drawing of a shoe was showed over the word).

During *familiarization* with words belonging to List 2, in order to convey the idea of "real words", namely words that are associated with a meaning (albeit unknown), at the first presentation (out of four), a black-and-white drawing depicting the (presumed) meaning of the word appeared, with the same modalities as for List 1. Subjects were explicitly told that they did not have to learn the meaning. Again, the aim was reproducing a situation as much similar as possible to the patient's one, who had knew in her life these very same words whose meaning was however unknown to her at the moment of testing.

After *familiarization*, participants completed three different tasks in order to assess their learning of the new words:

- *Word retrieval*: participants were visually presented with a drawing (List 1) or with the first letter (or first two letters, in the case of two words beginning with the same sound) of a word (List 2), and had to orally produce the whole word. The examiner recorded the correct responses by pressing the mouse. Participants did not get any feedback about the correctness of their responses. Unless the participant was able to correctly retrieve all the items twice consecutively, he/she underwent the *familiarization* phase again, being presented with the same list of words (with the same modality explained above). At the end of this further session of *familiarization*, a *word retrieval task* was administered again. If the subject was able to correctly retrieve all words, he/she was asked to repeat it again without any additional presentation of the list. Indeed, this procedure went on until all the words were correctly retrieved twice.

- *Lexical decision*: participants were visually and auditorily presented with a word, and had to judge, by pressing a key on the keyboard, whether the word belonged to the list they had just learned or had not been presented before. During this task, 20 items were presented in random order: 10 were the actual words belonging to the list, and 10 were untrained items. Unless responses were 100% correct, participants had to repeat the *familiarization* phase, and then the *lexical decision* again, until performance was 100% correct.

- *Word-picture matching* (only for List 1): participants were visually and auditorily presented with a word while seeing a drawing, and had to press a key in order to answer whether the word-picture matching was correct. During the task, each drawing was presented in random order three times: once correctly matched with the word, once matched with another word belonging to List 1, and once matched with an untrained item. Unless responses were 100% correct, participants had to repeat the *familiarization* phase, and then the *word-picture matching* again, until performance was 100% correct.

The order of presentation of *lexical decision* and *word-picture matching* tasks was counterbalanced across participants.

Experimental task – Immediate serial recall

The words of each list were used to prepare 10 six-item sequences for serial recall. Six-item lists were used, since this was the length of the lists used with the semantic dementia patient (Papagno et al., 2013). In particular, 6-item sequences prevent a ceiling effect.

Serial recall tasks were administered immediately after the training phase.

A word was presented only once in a sequence. Items were auditorily presented through headphones, with a 1000 ms interval between each other. The task was to repeat the items in the same order immediately after presentation.

Participants were told to produce non-verbal gestures (e.g. a tap on the desk) if they could not recall an item at a given serial position.

Data analysis for the immediate serial recall tasks

Each error was scored as either item or order error. An item error was defined as a phonological error (substitution, intrusion or omission of one phoneme), a wrong word (i.e. not originally presented in that list), an intrusion (when the participant produced a word, not presented in that particular sequence), a repetition (when the participant produced an item twice), or an omission. A word of the list recalled at the wrong serial position was considered as an order error. Errors were computed using the methodology suggested by Saint-Aubin and Poirier (1999, “Method 1”) to compensate for the fact that, if more items are recalled, the probability of an order error increases. Namely, the error scoring was obtained dividing the total number of order errors by the total number of items recalled.

The dependent variable was the number of errors each subject made on each list (computed first as the overall sum of item plus order errors on each six-item sequence, and then as the separate sum of item errors and order errors).

A random effect analysis of variance (ANOVA) was run, with “number of errors” as dependent variable, “subject” as random factor, and “list” as fixed factor. A series of planned separated ANOVAs was also run, in order to control for possible confounding factors as age, gender, years of education, and order of presentation of tasks.

Because phonological errors are easily justifiable when dealing with first-time heard words, two different analyses were run to compare the performances on List 3 (*unknown words*): in the first analysis, phonemic substitutions, intrusions or omissions were considered as errors in all the three lists; in the second analysis phonemic substitutions in List 3 were excluded by the count of errors.

3.3.2 RESULTS

Familiarization

The number of times participants required to reach the familiarization criteria highly differed between the two lists: for List 1 (*phonology plus semantics*), the mean number of repetition was 5.63 (sd = 4.43), while for List 2 (*phonology without semantics*) it was 9.77 (sd = 5.08). The difference was significant [$t(29) = 5.082$, $p < .001$] (see Figure 4).

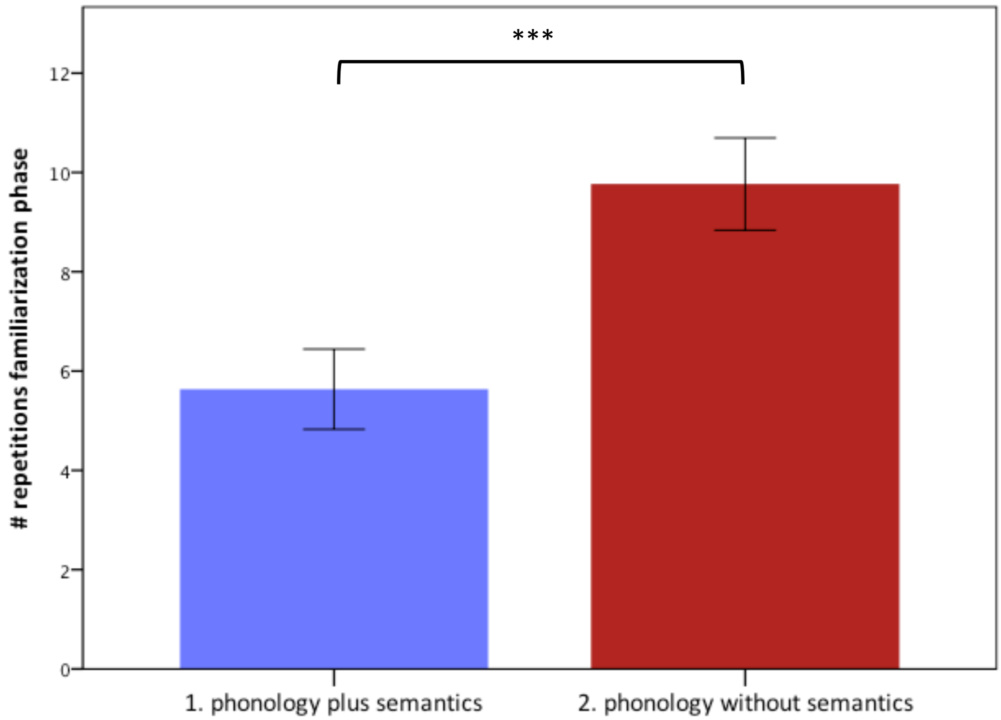

Figure 4. Number of repetitions in the familiarization phase.

Immediate serial recall

The mean number of overall (item plus order) errors following Saint-Aubin and Poirier (1999)'s Method 1 on List 1 was 22.3 (sd = 8.5), on List 2 was 23.3 (sd = 7.39), and on List 3 was 39.48 (sd = 7.85) when considering phonological errors, while it was 30.07 (sd = 6.86) when excluding them (see Figure 5).

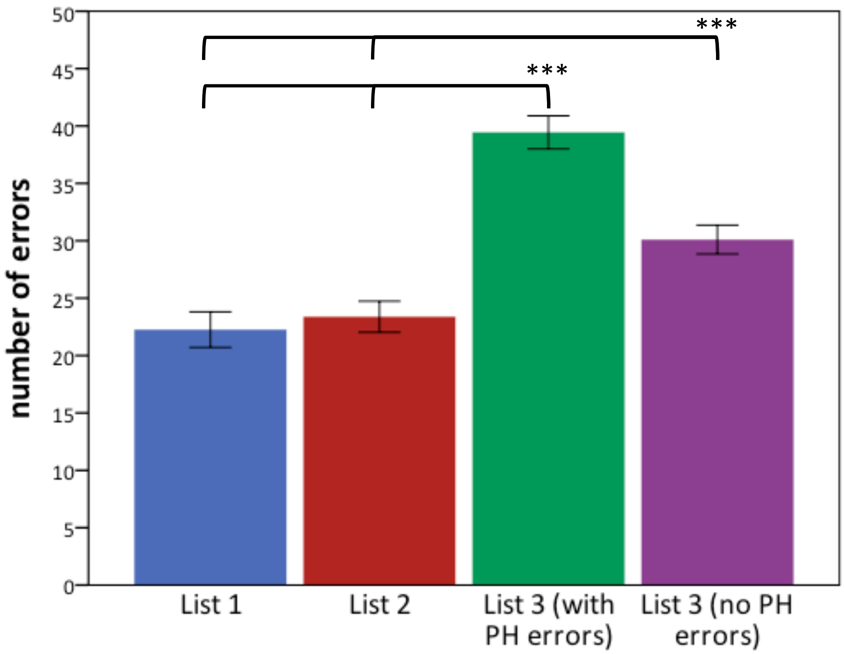

Figure 5. Overall errors (item+order).

In the first analysis (considering phonological errors also for List 3), there was a main effect of list [$F(2,58) = 95.207$; $p < .001$]. Post-hoc tests (Bonferroni) indicated that the performance on Lists 1 and 2 did not differ ($p = 1$), whereas performance on List 3 significantly differed from both List 1 and List 2 (all $p < .001$).

When separately analyzing item and order errors, the analysis showed that differences between the two trained lists and the *unknown words* list were due to item errors.

The mean number of order errors (following Saint-Aubin and Poirier's method) on List 1 was 2.03 (sd = 1.37), on List 2 was 2.41 (sd = 1.13), and on List 3 was 2.21 (sd = 0.98).

The mean number of item errors on List 1 was 20.27 (sd = 7.91), on List 2 was 20.90 (sd = 6.87), and on List 3 was 37.27 (sd = 7.77).

The random effect ANOVA with “number of order errors” as dependent variable did not reveal a main effect of list [$F(2,58) = 1.022$; $p > .05$) (see Figure 6), whereas the random effect ANOVA with “number of item errors” as dependent variable showed a main effect of list [$F(2,58) = 103.420$; $p < .001$) (see Figure 7).

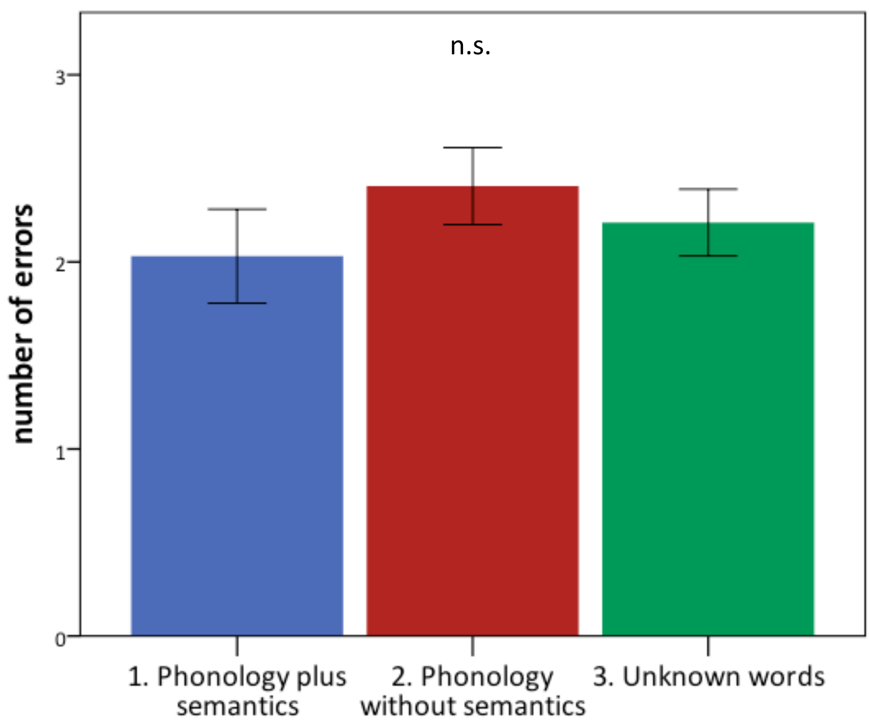

Figure 6. Order errors.

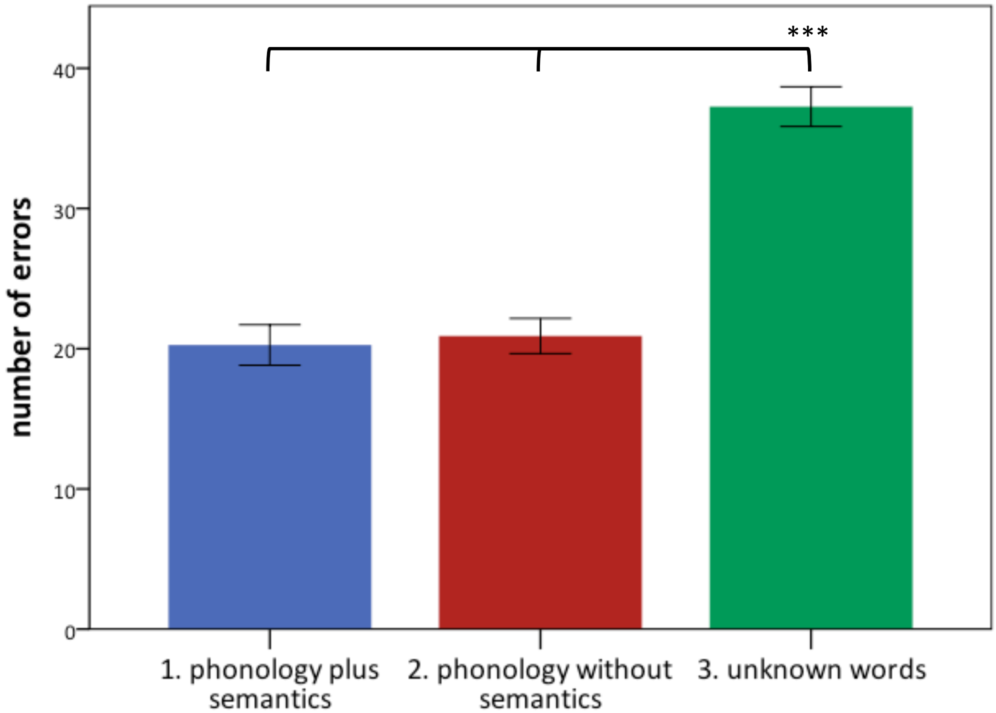

Figure 7. Item errors.

Post-hoc tests (Bonferroni) indicated that the performance with regards to item errors on Lists 1 and 2 did not differ (p = 1), whereas performance on List 3 significantly differed from both List 1 and List 2 (all p < .001) (See Figure 8 and Table 1 for a detailed description of item errors).

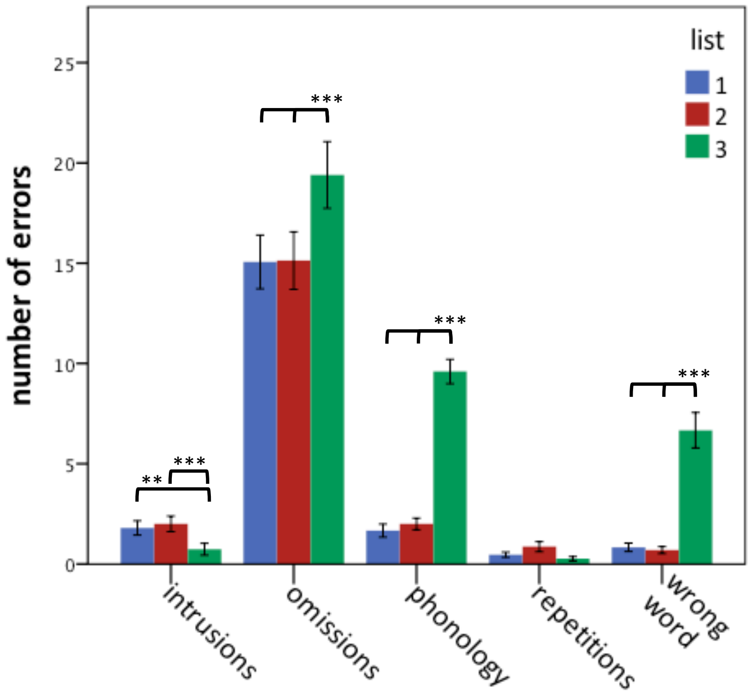

Figure 8. Types of item errors.

	Omissions	Phonology	Wrong Words	Intrusions	Repetitions
1. Phonology plus semantics list	15.07 (7.33)	1.67 (1.81)	0.83 (1.15)	1.80 (1.97)	0.47 (0.68)
2. Phonology without semantics list	15.13 (7.86)	2.00 (1.60)	0.70 (0.95)	2.00 (2.12)	0.87 (1.38)
3. Unknown word list	19.40 (9.11)	9.60 (3.32)	6.67 (4.83)	0.73 (1.62)	0.27 (0.58)

Table 1. Error rates for the different types of item errors (standard deviations in brackets).

Further analyses revealed that omissions, phonological and wrong word errors were significantly higher on List 3 than on both List 1 and List 2 (all $p < .001$), while intrusion errors were significantly lower on List 3 than on List 1 ($p = .008$) and List 2 ($p = .001$). List 1 and List 2 did not differ in any type of error (all $p = 1$).

The random effect ANOVA run on a different set of data for List 3, namely excluding phonological errors, revealed a main effect of list [$F(2,58) = 21.249$; $p < .001$].
Post-hoc tests (Bonferroni) indicated that the performance on List 3 significantly differed from both List 1 and List 2 ($p < .001$).

ANOVAs run to control for possible confounding factors as age, gender, years of education, and order of presentation of tasks did not show any significant effect (all $p > .05$).

Given the significantly different number of repetition in the *familiarization* phase for List 1 and List 2, an additional ANOVA was run, including in the model "number of repetitions" as a covariate. The performance on List 1 and List 2 remained comparable: $F(1,56.52) = 1.392$, $p = .2$. Therefore, the possibility that the comparable performance on these two lists was due to a higher number of repetitions during the training phase for List 2 (phonology without semantics) can be ruled out.

3.3.3 DISCUSSION

In this study the hypothesis that in verbal short-term memory what is relevant is the phonological form of a word, and not the meaning, was tested. To this aim, 30 Italian native speakers were submitted to an immediate serial recall task using modified Croatian words for which subjects had previously learned both the meaning and the phonological form or the latter only. The performance with *phonology without semantics* words was significantly better than the performance on *unknown words* and comparable to that with *phonology plus semantics*. These data confirm that familiarity with the phonological form is sufficient for immediate serial recall, replicating in healthy subjects the pattern obtained with a patient affected by semantic dementia (Papagno et al., 2013).

One could argue that a worse performance on *unknown words* than with the other two types of items depend on the fact that those items were by definition untrained, leading to a higher error rate because of a higher number of phonological substitutions. This possibility is made unlikely by the fact that the difference between performances on trained items (Lists 1 and 2) and *unknown words* remained significant even when data from the latter were cleared from phonological errors.

A detailed analysis of error types highlighted a significantly higher number of omissions during serial recall of *unknown words*. On the other hand, as predictable, intrusions of words not presented in a given sequence are higher when dealing with trained words (i.e. Lists 1&2).

A remarkable difference concerns the time it took to participants to learn the words belonging to Lists 1 and 2. The number of repetitions necessary to correctly retrieve all the words during the word retrieval task was considerably lower when words were associated with a meaning (List 1), than when they were not (List 2). That the processing of semantic features helps the acquisition of new words is not surprising and is known at least since Craik and Lockhart (1972)'s theory of levels of processing. In fact, acquiring a new word in a context that suggests its possible meaning is an experience that occurs frequently in first language acquisition and the beneficial effects of the presence of semantic features is replicated in students of a foreign language (Hulstijn, Hollander, & Greidanus, 1996). The possibility of learning new words by semantically associating items with already known words is also reported in Papagno et al. (1991)'s Experiments 3 and 4, where it is showed that, during articulatory suppression in a word-nonword pairs learning, subjects circumvented the disruption of phonological coding by means of existing semantic associations.

The presence of semantic features helps maintaining the phonological representation in long-term memory, although learning new words benefits from a good phonological short-term memory (Baddeley, Gathercole, & Papagno, 1998).

In line with the retrieval-based hypothesis (Saint-Aubin & Poirier, 2000), differences between trained and untrained items did not depend on order errors, which were produced at a comparable rate on the three lists. Indeed, the significant difference derived from the item error rate.

Under Saint-Aubin and Poirier's account, if verbal short-term memory were enhanced by semantic information, we would expect a lower item error rate for immediate serial recall of *phonology plus semantics* words than of *phonology without semantics* words, because their semantic representation should help item recall, but not order recall. Conversely, the comparable number of item errors on the two trained lists confirms the idea that it is the presence of a phonological representation of the items, rather than the access to the conceptual information, that produces a better performance.

The lack of significance in the comparison between List 1 and List 2 in this study, together with the performance of the patient described by Papagno et al. (2013), who showed a comparable performance between words whose semantic and phonological information were available, and words whose semantics was lost but phonology retained, strengthen the hypothesis that what supports redintegration is the availability of the phonological representation of a word, and not of its semantics. We are aware that the words employed in this study were learned immediately before testing, so their semantic and phonological representations were "new" for participants. In a normal situation, phonological and semantic representations of words are well consolidated, which was not the case in the present study. Nevertheless, it was verified that participants mastered these words at the moment of testing by requiring that responses were 100% correct in all tasks probing knowledge of phonological form and of meaning.

Although using an artificial language to assess influences of semantics and/or phonology makes a task less naturalistic than it is desirable, this allows precise control over the amount of exposure to items and avoids the need to control variables such as frequency and familiarity relying on lexical databases, which can be an imprecise proxy for an individual's experience with the language.

Similar methods were used in studies investigating reading and orthographic learning abilities in children (e.g. McKague, Pratt, & Johnston, 2001; Duff & Hulme, 2012; Wang, Nickels, Nation, & Castles, 2013) and adults (e.g. McKay, Davis, Savage, & Castles, 2008). Results of these studies do not show a unique pattern with regards to the contribution of semantics and phonological training with novel words, but it is important to underline that most of them focused on differences between regular and irregular orthographies in a non-transparent language as English (and English-based nonwords). Noticeably, when analyzing performances on regular orthographies (as the Italian and the modified Croatian used here), the role of semantic pre-exposure does not seem to facilitate learning to read nonwords.

Although these data confirm that when a word is associated with its meaning, it is easier to learn it, they also indicate that the significant difference in the number of repetition required to learn the different types of words does not explain the comparability of performances between the *phonology plus semantics* and the *phonology without semantics* lists. Therefore, it is possible to maintain that redintegration exploits the phonological form of a word, and not its semantic information.

3.4 CONCLUSIONS

These two studies, and in particular Study 2, confirmed on a sample of healthy subjects what had already been described for a patient with semantic dementia (Papagno et al., 2013), namely that the long-term memory information exploited during a verbal short-term memory task is the familiarity with the phonological form of a word, and not its meaning.

4. CHAPTER III

REHABILITATION THROUGH COMPLEXITY MANIPULATION

4.1 STRUCTURAL PRIMING

The importance of the phonological storage for sentence processing was demonstrated by studies on patients who have reduced memory spans and perform poorly on comprehension and repetition of sentences that require a complete analysis of syntactic structure (e.g. Saffran & Marin, 1975; Caramazza, Berndt, Basili, & Koller, 1981; Caramazza, Basili, Koller, & Berndt, 1981).

As already pointed out in the first chapter, some aspects of language disorders link linguistic and short-term memory systems, highlighting the role of verbal short-term memory in sentence comprehension and repetition (see N. Martin & Saffran, 1990; R. C. Martin et al., 1994; Knott et al., 2000; Papagno et al., 2007 for studies on brain-damaged patients; see Romero Lauro et al., 2010; Cecchetto & Papagno, 2011 for studies on healthy subjects).

The reduced processing capacity observed in agrammatic aphasia (e.g. Kolk & Heeschen, 1992) can at least partly explain the effects of syntactic/argument structure complexity described in the literature. Aphasic patients' performance has been showed to be related to the differences between syntactic/argument structures, as for example transitives and unaccusatives (e.g. Bastiaanse & van Zonneveld, 2005), unergatives and unaccusatives (e.g. Lee & Thompson, 2004), and number of arguments required by a verb (e.g. Thompson, Lange, Schneider, & Shapiro, 1997; Collina, Marangolo, & Tabossi, 2001). These studies showed a correlation between the syntactic/argument complexity (i.e. movements required to derive the superficial structure of a sentence from its deep structure; number of arguments) and sentence processing (production and comprehension) abilities of people with agrammatic aphasia.

Structural (syntactic) priming (Bock, 1986; see Pickering & Ferreira, 2008 for review) is an experimental paradigm used to study sentence processing in non-brain damaged individuals. Repetition of a sentence structure (e.g. passive) in one or more prime trials leads to a tendency to use the same structure in a picture description task. The structural priming paradigm has been adapted for treatment to improve sentence processing in aphasia, based on the premise that it can increase accessibility of a syntactic structure, making it temporarily easier to retrieve. One advantage of the structural priming paradigm is that it can be used in cases of severe agrammatic aphasia, in which production is limited to single words or two-word phrases.

Structural priming refers specifically to an increase in the ease of producing a sentence following production of a sentence with different words but with identical syntactic structure. In a typical priming paradigm, a spoken sentence, e.g. "*The librarian gave the girl a book*" is repeated in the priming trial. This is followed by presentation of a picture (e.g. a baseball pitcher throwing a ball to a catcher) to be described with a spoken sentence. A "primed" outcome in this example would be the use of a double object dative to describe the picture, *“The pitcher threw the catcher the ball”*, rather than a prepositional phrase dative, *“The pitcher threw the ball to the catcher”*, or some other structure, e.g. *“The two people are playing catch”*. The priming effect has been attributed to persistence of an activated structural representation independent of the sentence’s lexical and semantic content. It is this persistence that makes the structure more accessible for a period of time (e.g. Kolk & Heeschen, 1992). This phenomenon has been studied extensively in unimpaired adult speakers (see Ferreira & Bock, 2006 for review), adults who stutter (Tsiamtsiouris & Cairns, 2009) and children (Thothathiri & Snedeker, 2008). It has also been demonstrated in studies of sentence comprehension (e.g., Thothathiri & Snedeker, 2008; Tooley & Traxler, 2010; Tooley & Bock, 2011) and dialogue (Branigan, Pickering, & Cleland, 2000).

Saffran and Martin (1997) explored the use of structural priming to promote short-term facilitation of sentence production in agrammatic aphasia, but there have been only a few studies applying this method to treatment of agrammatism (Fink, Schwartz & Myers, 1998; Kohen, Kalinyak-Fliszar & N. Martin, 2007; Kohen, Milsark, Gruberg, Kalinyak-Fliszar & N. Martin, 2008). The logic in using structural priming to treat sentence processing disorders in aphasia is that it counteracts the detrimental effects of the reduced processing capacity by temporarily raising the activation levels of structures, making them at least temporarily more accessible. Some studies investigated the possible maintenance of facilitation effects in producing a structure over time: Bock and Griffin (2000) demonstrated on healthy subjects that the effect is resistant to time and interference from producing other structures, while Saffran and N. Martin (1997) reported that the effect was present a week after a one-session facilitation study with agrammatic patients. A research on a treatment protocol incorporating structural priming

(Kohen, Kalinyak-Fliszar & N. Martin, 2007) indicated that it can lead to lasting improvements in sentence production: following a full-scale treatment (10 sessions), improvements appeared to last as long as five months.

It is important to determine the level of linguistic representation at which structural priming effects occur. This has been studied extensively in typical speakers. Bock and Loebell (1990) demonstrated that primes which had similar syntactic frames (prepositional datives: "*The widow gave a car to the church*" and prepositional locatives: "*The widow drove a car to the church*"), but different thematic structure (in prepositional datives the prepositional object is a beneficiary, whereas in prepositional locatives the prepositional object is a locative) were equally effective in priming prepositional datives compared to a control prime condition (double-object dative primes, "*The widow sold the church a car*"). The authors also showed that cross-structural priming of picture descriptions was not effective: they compared effectiveness of prepositional datives ("*Susan brought a book to Stella*"), infinitives ("*Susan brought a book to study*"), and double-object datives ("*Susan brought Stella the book*"), as primes for prepositional dative descriptions of pictures. The prepositional datives facilitated prepositional dative descriptions. Although superficially similar to the prepositional dative forms, the infinitives were no more effective in facilitating prepositional dative descriptions than the double-object dative primes. These data point to the syntactic structure representation as the representation that carries most (or all) of the priming influence.

In the following experimental treatment studies, the effectiveness of structural priming to improve sentence processing through a sentence repetition task in three aphasic patients with different degrees of language impairment was explored. A sentence repetition task was used because the required sentence structures were hardly elicitable through a picture description, which is the more commonly used task in the structural priming paradigm. Moreover, two out of three patients (the English ones) presented serious impairments in spontaneous speech production, making the spontaneous use of the targeted structures unlikely. Sentence repetition has been showed to be a successful paradigm for rehabilitation (e.g. Kohn, Smith, & Arsenault, 1990; Francis, Clark, & Humphreys, 2003).

Another hypothesis to investigate was that structural priming facilitating effects vary depending on the complexity of the syntactic structure of the prime and target sentences. Numerous studies have analyzed the influence of complexity of structures on effectiveness of treatments, and found that when prime and target sentences share common underlying structures, stronger effects (i.e. generalization to the untrained structure) are given by training the more complex rather than the less complex structure (e.g. Thompson, Shapiro, & Roberts, 1993; Thompson, Shapiro, Ballard, Jacobs, Schneider, & Tait, 1997; Thompson, Ballard, & Shapiro, 1998; Thompson, 2001; Thompson, Shapiro, Kiran, & Sobecks, 2003). For example, Thompson et al. (2003) used sentences requiring *wh*- movement, and showed that the strongest treatment effects occurred when training object relative clauses ("*The man saw the artist who the thief chased*") to improve performance on simpler structures, as object clefts ("*It was the artist who the thief chased*") and *wh*- questions ("*Who has the thief chased?*").

However, since in the following treatment studies a cross-structural priming paradigm was used in which prime and probe sentences were similar only superficially but differed in underlying syntactic structure, it is not anticipated that the easier sentence type would necessarily facilitate the more complex one (or, for what matters, the other way around). In fact, one cannot be sure that superficial similarity in presence of structural diversity has a beneficial rather than a detrimental effect.

In the treatment of English-speaking patients, sentences with verb-particle transitives (VPart: "*The man is blowing up the balloon*") and with prepositional transitives (VPrep: "*The man is blowing on the tea*") were used. The contrast between these two sentence types could be particularly interesting, since they allow constructing contrasting pairs of stimuli that are nearly identical in lexical content and length, avoiding potential confounding factors as word frequency and sentence length. A recent study (Kohen, Milsark, & N. Martin, 2011) has investigated the ability in repeating sentences with these two constructions in patients with aphasia. Based on the hypothesis that the complexity of verb syntactic (or argument) structure is a key factor in agrammatism, the authors predicted a better performance in the repetition of verb-particle transitives than with prepositional transitives, since verb-particle constructions have fewer semantic elements and less complex syntactic structure. Prepositional transitives have a prepositional phrase embedded within the verb phrase, while verb-particle structures are simple Subject-Verb-Object sentences. Moreover, in prepositional transitives the preposition has to be processed as an independent semantic element, providing independent contribution of semantic information, while in verb-particle sentences the particle is part of the predicate, without an independent semantic force, therefore requiring the processing of fewer semantic elements than prepositional transitives.

These differences suggested that verb-particle sentences would be easier to repeat than prepositional transitive sentences, and evidence from Kohen et al. (2011)'s study supported this hypothesis.

Regarding the treatment for the Italian patient, the contrast concerned the performance on reflexive and unaccusative sentences. More precisely, transitive verbs matched for length and frequency to unaccusatives that require the particle "si" (see below for explanation) were selected. Therefore, pairs of sentences as "*La maestra si accorge di un imbroglio*" ("The teacher realized a fraud", where the unaccusative verb "accorgersi" mandatorily requires the particle "si") and "*La maestra si taglia con le forbici*" ("The teacher cuts herself with scissors", where the transitive verb "tagliare" requires the pronoun "si" in the reflexive construction) were obtained.

It was assumed that unaccusative sentences were easier to process than reflexives, based on the following considerations.

In unaccusative sentences, the theme moves from the postverbal position where it is generated (see Burzio, 1986) to the preverbal subject position, where the nominative case is assigned; in reflexive sentences, the theme is realized by the clitic pronoun, "si", which co-refers with the subject. As clitic pronouns do, the reflexive "si" has to move from its argumental position to a dedicated position in the clause, where it forms a cluster with the verb. Crucially, in unaccusative sentences the particle "si" morphologically is a part of the verb, while in reflexives it is an independent pronoun, which co-refers with the subject. So, unaccusative structures are mono-argumental while reflexive structures are bi-argumental (albeit the two arguments have the same denotation). Arguably, this makes reflexive sentences more demanding from a syntactic point of view.

In a preliminary study, 36 healthy Italian-native speakers were asked to read 16 prime sentences (8 unaccusatives and 8 reflexives), and, immediately after, to complete a written sentence beginning with "subject + si", which, therefore, could be completed with either an unaccusative or a reflexive construction (see Pickering & Branigan, 1998; Branigan, Pickering, & Cleland, 1999). Unaccusative completions were significantly more frequent than reflexive ones, independently of the structure present in the prime sentence. It is possible to tentatively conclude that to some extent unaccusative sentences are more commonly (and, likely, more easily) produced than reflexive sentences.

In the sentence repetition treatment of patients with aphasia, the prediction was that the less complex structures (verb-particle sentences in English, unaccusative sentences in Italian) would be repeated better than the more complex ones (prepositional transitives and reflexives, in English and Italian respectively), because they require fewer processing demands; therefore, since verb-particle and unaccusative sentences will be repeated better, when using them as primes in the cross-structural treatments, they will result in better (i.e. more effective) priming than the more complex structures.

During the treatments, participants heard sentences and had to immediately repeat them. Each of the two treatment blocks focused on a particular structure, which was trained (i.e. the patient had the possibility to self-correct the response, and got feedback by the examiner). During a treatment session, after three trained (prime) sentences, a probe was read to the patient, who had to repeat it without any feedback, and without the possibility of self-correction. Probes could either belong to the untrained structure (cross-structural treatment) or to the same structure as the trained sentences (same-structure treatment). Each treatment session consisted of 36 trained sentences and 12 probe sentences. The measure used for analyses was the performance obtained during probe sessions: before each treatment session, the repetition of probe sentences was tested, together with their other-structure matched sentences (Sets 1 or 2, 12 pairs of sentences, see below).

In order to be sure that any possible change in performance was not due to the mere repetition, but to the effects of treatment, before starting a treatment block, performance of patients on the sentences tested during probe sessions (Sets 1 or 2) had to be stable. To assess this, baseline probes were administered (mere repetition of sentences belonging to the set that will be treated) until performance did not increase on each structure more than 10% in two consecutive sessions. Once a stable baseline level was obtained, treatment block started.

Any possible generalization of the effects of treatment to untreated sentences was assessed by testing the performance on Set 3 (12 pairs of sentences) before the beginning and at the end of the whole treatment protocol, and between the two treatment blocks.

4.2 STUDY 3 - ENGLISH PATIENTS

4.2.1 METHODS

Material (see Appendix 1)

Stimuli consisted of 72 paired sentences equally divided into verb-particle (VPart) and prepositional transitive (VPrep) constructions. Paired sentences were balanced for length, and lexical content was controlled for frequency (Francis & Kucera, 1982). Sentences were constructed so that identical subjects and verbs were followed by either a prepositional phrase (VPrep construction) or a particle and direct object noun (VPart construction). Sentence pairs consisted then of a verb-particle construction ("*The man is blowing up the balloon*") and the matched prepositional transitive sentence ("*The man is blowing on the coffee*").

Out of the 72 pairs, 36 were selected as experimental stimuli (sentences used during probe sessions), and 36 were used as primes during treatment sessions.

Participants

KC was a 52-year-old man with 14 years of education. Eight years prior to enrolment in this study, he sustained a massive left-hemisphere stroke, resulting in a large chronic left middle cerebral artery territory infarction. The lesion resulted in aphasia with an Aphasia Quotient of 67.8 (based on the Western Aphasia Battery-Revised, WAB-R: Kertesz, 2006) and classification between Wernicke and conduction aphasia. His speech was fraught with semantic paraphasias and characterized by frequent perseverations and inappropriate use of both lexical and functional words, resulting in fluent but paragrammatical short sentences. Performance on two sentence processing tests of the Philadelphia Comprehension Battery (*PCB*, Saffran, Schwarz, Linebarger, N. Martin & Bochetto, 1987) indicated that his ability to make grammaticality judgments was moderately to severely impaired (.60, n = 60) and his comprehension of sentences with reversible semantic roles was severely impaired (.55, n = 60). Word repetition span was 2.2 (subtest of the *Temple Assessment of Language and Short-term memory in Aphasia, TALSA*, N. Martin, Kohen & Kalinyak-Fliszar, 2010). He was able to correctly repeat .19 sentences with various structures (actives, passives, prepositional datives, double object datives, compound noun phrases, subject relatives, object relatives, prepositional transitives, verb-particle transitives; n = 54).

DC was a 49-year-old man who sustained a left middle cerebral artery infarct 2 years before his participation in this study, resulting in a left fronto-temporo-parietal craniectomy.

His speech was typically agrammatic: telegraphic, mainly consisting of short sequences of nouns, no functional words apart from some stereotypical sentences, and a few verbs. DC's language profile was consistent with Broca's-Transcortical Motor aphasia; his aphasia quotient on the WAB-R (Kertesz, 2006) was 57.7. Performance on two sentence processing tests of the PCB (Saffran et al., 1987) indicated mild to moderate difficulty in making grammatically judgments (.70 correct, n = 60) and marked impairment in comprehension of sentences with reversible semantic roles (.62 correct, n = 61). Word repetition span was 2.8 (subtest of the TALSA, N. Martin et al., 2010). He correctly repeated .20 (n = 54) sentences with various constructions (see above).

Design

A single-subject multiple-baseline multiple-probe design (Horner & Baer, 1978) was used (see Table 2). In the first two sessions, subjects were asked to repeat all 36 experimental sentence pairs (Full Test), presented in a randomized order by live voice. Each sentence was presented only once, and the examiner did not provide any feedback.

According to the performance obtained in the two pre-test Full Tests, sentence pairs were equally (in terms of number of correct sentences repeated) divided into 3 sets (12 pairs each): Sets 1 and 2 were used for treatment, while Set 3 remained unexposed during the treatment.

The number of baseline probes depended on the participants' performances: from a minimum of 3, they continued until a stable performance (< 10% increase in two consecutive sessions on each structure) was reached. Baseline probes were administered for all items belonging to Sets 1 and 2 before each treatment block (see below), in order to establish a stable baseline level of performance.

There were two treatment blocks, consisting of a maximum of 12 sessions each. Treatment was either cross-priming (VParts primed, VPreps probed; VPreps primed, VParts probed) or same-structure priming (VPreps primed, VPreps probed). Before each treatment session, probes, identical to those administered in baseline, were given, representing the response to the previous session's treatment. Treatment continued until $\geq$ .83 (10 out of 12, behavioral criterion) correct was achieved for two consecutive probe sessions or until 12 treatment sessions were completed. Also the Shewhart chart trend-line was used as a measure of treatment effects. The Shewhart procedure (Shewhart, 1931; Robey, Schultz, Crawford, & Sinner, 1999) provides an additional measure to assist in interpretation of single-subject research design data (e.g. Renvall, Laine, and N. Martin, 2007; Faroqi-Shah, 2008; Tuomiranta, Kohen, Kalinyak-Fliszar, Laine & N. Martin, 2010). It is especially useful in determining significance of improvements when behavioral criteria are not met. To establish a Shewhart chart trend-line, the mean and standard deviation of baseline probe performance are calculated. A horizontal trend-line (i.e. Shewhart chart trend-line) representing two standard deviations above the mean is drawn across the baseline phase and extended through the treatment and maintenance phases. A significant change from baseline through treatment and maintenance is indicated if two successive probes are outside the bounds of this trend-line.

Treatment Protocol

During treatment, a sentence was read aloud by the clinician, followed by repetition by the participant. Feedback about accuracy was always provided for the primes.

After three prime sentences, one of the 12 probe sentences was administered for immediate repetition. No feedback was provided for probe sentences.

Each treatment session consisted of 36 prime sentences, and 12 probes. During Treatment 1, sentences from Set 1 were probed, while during Treatment 2, Set 2 was used. Every fourth session, sentences from both sets were probed, in order to obtain a continuous baseline for Set 2 during Treatment 1, and a maintenance measure for Set 1 during Treatment 2.

After the end of each treatment block, the Full Test (sets 1, 2 and 3) was probed, in order to see any possible generalization of the treatment to unexposed sentences. After the end of Treatment 2, follow-up probes on all the 3 sets were administered (1, 2, 4, 8 weeks after the last treatment session), to determine if there were any lasting effects of the treatment.

Treatment Phases	Items Probed
1. Pre-test administered two times over two sessions.	Full test, 36 paired sentences
2. Baseline 1-3 (or until stable performance on Set 1 probed structure sentences)	Sets 1&2 (12 pairs each)
3. Treatment Set 1 (12 sessions, or until .83 correct is achieved on the probed structure for 2 consecutive probe sessions)	Set 1 (Set 2 is also probed every fourth session, in order to obtain continuous baseline)
4. Between-treatment probe	Full test, 36 paired sentences
5. Baseline 4&5 (or until stable performance is reached on Set 2 probed structure sentences)	Sets 1&2 (12 pairs each)
6. Treatment Set 2 (12 sessions, or until .83 correct is achieved on the probed structure for 2 consecutive probe sessions)	Set 2 (Set 1 is also probed every fourth session, in order to obtain maintenance measure)
7. Follow-up Testing: 1, 2, 4, 8 weeks after the last treatment session	Full test, 36 paired sentences

Table 2. Protocol for treatment.

Data analysis

The dependent variable was the number of correctly repeated verb-particle and prepositional transitive sentences during probe sessions. McNemar's Test was used, to account for changes in the performance on each single trial (i.e. a measure of how many sentences that were incorrectly repeated at the beginning were correctly repeated at the end of the treatment).

4.2.2 RESULTS

Since participants underwent different types of treatment, their results will be presented separately.

Acquisition, maintenance and follow-up data are showed in Figures 9 and 10 (KC), and 11 and 12 (DC) with Shewhart chart trend-lines to assist in visual interpretation of data. Effect sizes (Glass's Δ, see Robey et al., 1999) and results of McNemar's Test for significance of changes are also presented.

KC (see Figure 9)

TREATMENT 1 (VParts: primes; VPreps: probes)

Repetition of VPrep probes met Shewhart trend-line (set at .50 for Set 1 VPrep sentences) criterion for significant change from baseline, but not behavioral (i.e. $\geq$ .83) criterion. Effect size from baselines to the end of Treatment 1 for VPrep sentences was 1.35. Thanks to the exposure during treatment, also performance on VParts considerably improved: effect size for VParts in Treatment 1 was 2.65.

TREATMENT 2 (VPreps: primes; VParts: probes)

Behavioral criterion (i.e. $\geq$ .83) was met after 10 treatment sessions, while the Shewhart trend-line (set at .86 for Set 2 VPart sentences) was not reached. Effect size from baselines to the end of Treatment 2 for VPart sentences was 0.96. Effect size for the VPreps in Treatment 2 was 1.97.

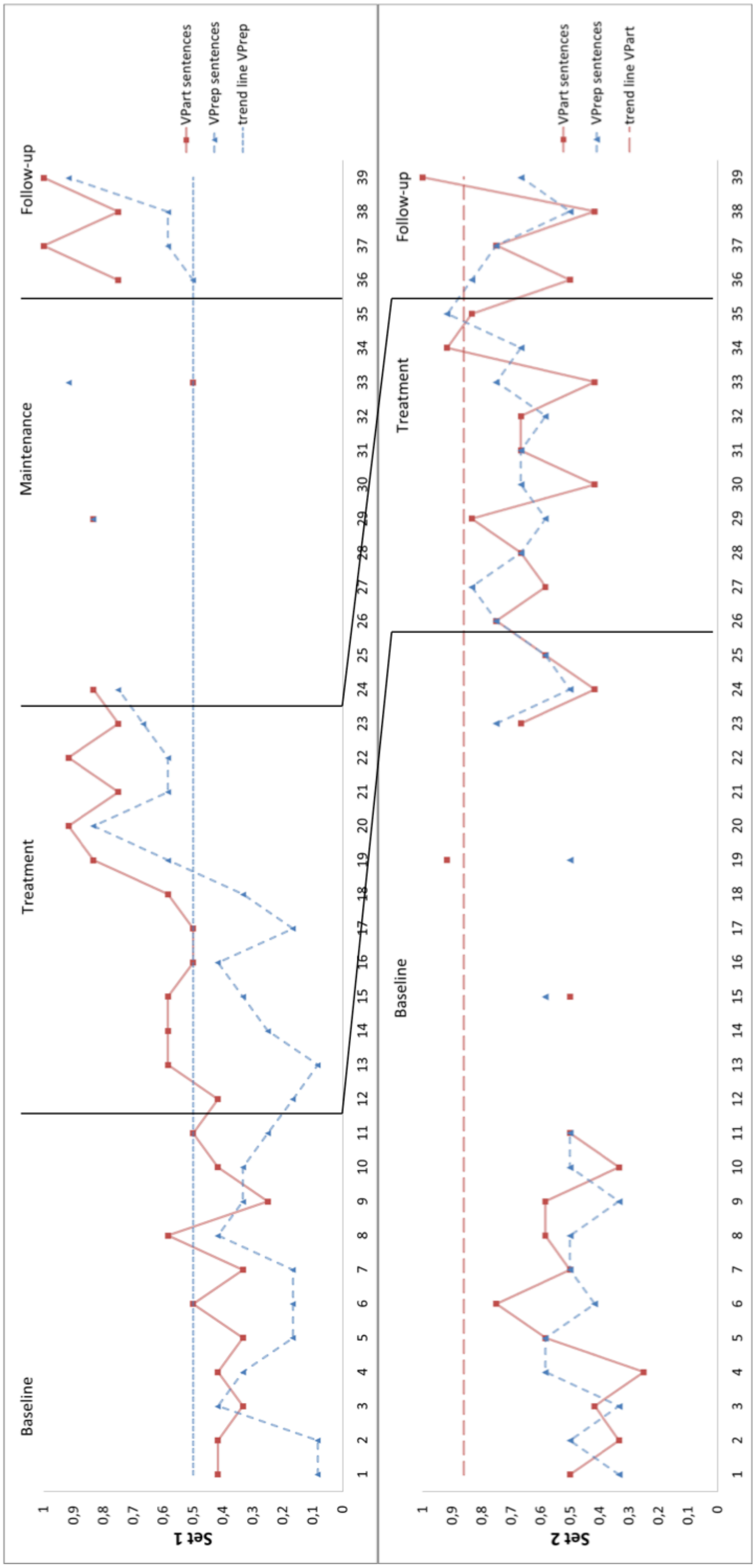

Figure 9. KC's performance (proportion of correctly repeated sentences) on Set 1 and Set 2 sentences during the whole treatment protocol.

FOLLOW-UP

KC's performance on the Full Test (sets 1-2-3) pre-test was compared with his performance on the Full Test post-tests (1-2-4-8 weeks after the end of the treatment) (see Table 3).

The analysis of performances was run with McNemar's test for significance of change. The performances on treated sentences (Set 1 VPreps; Set 2 VParts) before and after the treatment were compared, and the performance on unexposed sentences (Set 3 VParts; Set 3 VPreps) before and after the treatment.

With regards to Set 1 VPrep sentences, the analysis showed a highly significant improvement ($\chi^2 = 6.13$; $p < .05$) in KC's performance at 4-week follow-up, indicating the patient's ability in maintaining the effects of the treatment.

The same was observed for Set 2 VPart sentences: the comparison between KC's performance before the treatment and at 4-week follow-up showed a significant improvement ($\chi^2 = 5.14$; $p < .05$), demonstrating his capacity for maintaining treatment effects.

	Follow-up Test Post-treatment							
	1 week		2 weeks		4 weeks		8 weeks	
Structure Type	χ^2	**p**	χ^2	**p**	χ^2	**p**	χ^2	**p**
Treatment 1								
Set1 VPrep	1.50	0.22	1.50	0.22	**6.13**	**0.01**	1.50	0.22
Treatment 2								
Set2 VPart	1.50	0.22	0.13	0.72	**5.14**	**0.02**	0.80	0.37
Unexposed Set								
Set3 VPart	0.17	0.68	0.00	1.00	3.13	0.08	**4.17**	**0.04**
Set3 VPrep	3.20	0.07	0.25	0.62	**5.14**	**0.02**	3.20	0.07

Table 3. Change in KC's performance between pre-treatment and follow-up administrations. Bolded values are significant according to McNemar's Test of Change.

Set 3 (see Figure 10) was presented at the beginning of the treatment, then before initiating Treatment 2 and then again during the follow-up sessions. There was improvement in repetition of both syntactic structures in this set of sentences: VPart sentences (as a trend at 4-week follow-up: $p < .1$; as a significant improvement at 8-week follow-up: $\chi^2 = 4.17$; $p < .05$) and VPrep sentences (as a trend at 8-week follow-up: $p < .1$; as a significant improvement at 4-week follow-up: $\chi^2 = 5.14$; $p < .05$). The improved performance on Set 3 indicates successful generalization and maintenance of treatment effects from trained to untrained sentences.

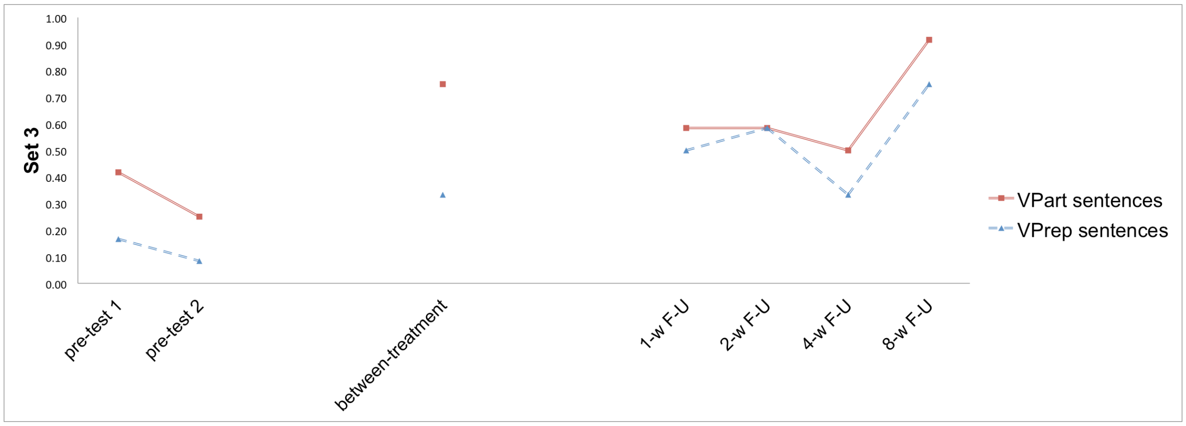

Figure 10. KC's performance on Set 3 sentences during Full-Tests (pre-tests, between-treatment probe, and follow-up sessions).

PRE- AND POST-TREATMENT TESTS

KC's performance on grammaticality judgments, comprehension of reversible sentences, sentence repetition and word repetition span was re-assessed after the end of treatment.

Results are showed in Table 4.

	Pre-treatment	**Post-treatment**	***p* value**
grammaticality judgments	36/60	43/60	.248
reversible sentences comprehension	33/60	44/60	.056
sentence repetition	10/54	18/54	.123
word repetition span	2.2	2.4	

Table 4. KC's performance on pre- and post-treatment tests. P values are calculated by means of two-tailed Fisher's test.

Although all measures improved in the post-treatment testing, no comparison with pre-treatment performance was significant.

DC (see Figure 11)

TREATMENT 1 (VPart: primes; VPreps: probes)

Repetition of VPrep probes met Shewhart trend-line criterion (set at .55 for Set 1 VPrep sentences) for significant change from baseline in ten sessions, but not behavioral criterion (which was $\geq$ .83). Effect size from baselines to the end of Treatment 1 for the trained VPrep sentences was 2.45. Effect size for VParts in Treatment 1 was 1.53.

TREATMENT 2 (VPreps: primes; VPreps: probes)

Because the performance on VParts was already very high, DC was treated on VPrep sentences with a same-structure priming (i.e. using VPrep as primes and probes).

The trend line for VPrep sentences of Set 2 was set at .91.

Behavioral criterion ($\geq$ .83 correct on two consecutive probes) was met for VPrep sentences quickly (Δ = 1.32), but the high Shewhart trend-line criterion was not met.

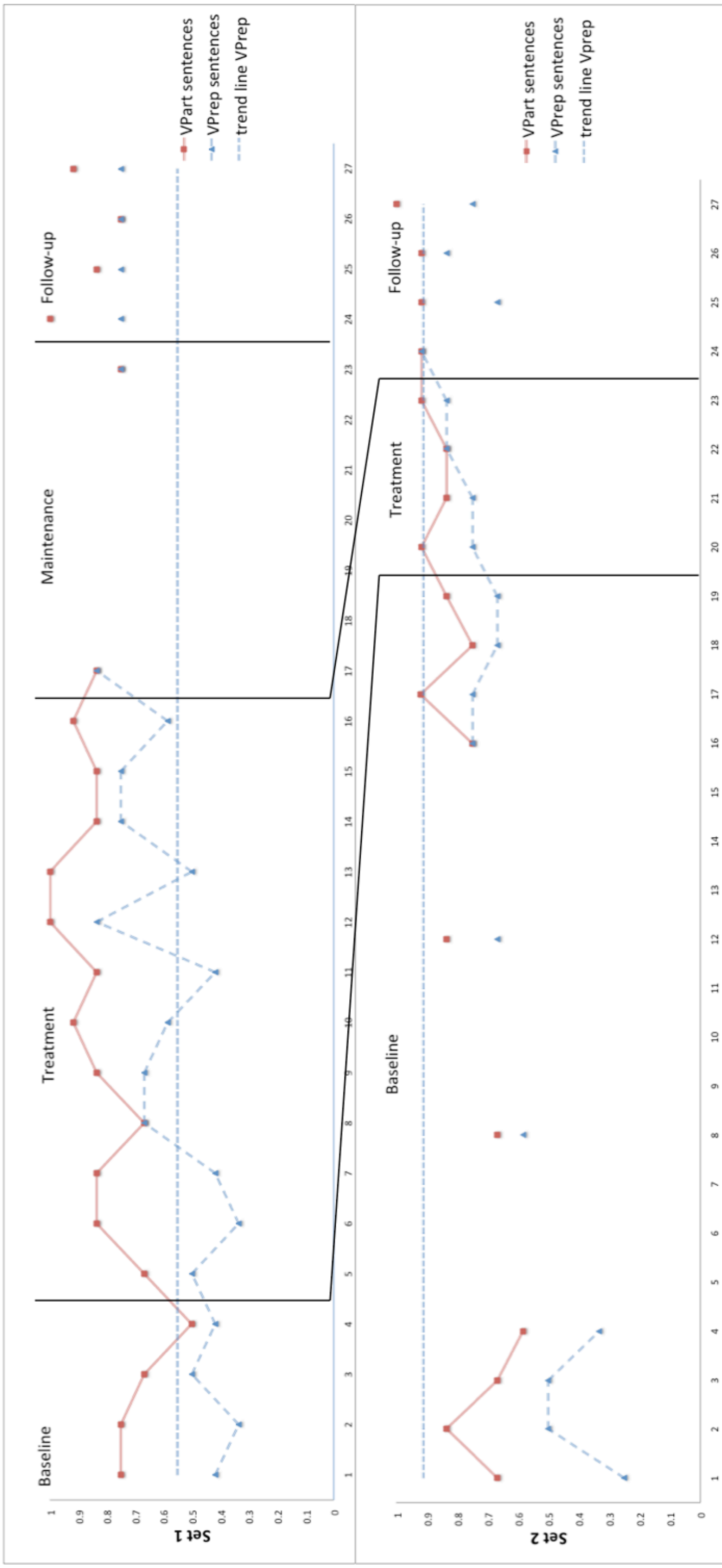

Figure 11. DC's performance (proportion of correctly repeated sentences) on Set 1 and Set 2 sentences during the whole treatment protocol.

FOLLOW-UP

DC's performance on Full Test (sets 1-2-3) pre-test was compared by means of McNemar's test for significance of change with the performance on Full Test post-tests (1-2-4-8 weeks after the end of the treatment) (see Table 5).

	Follow-up Test Post-treatment							
	1 week		2 weeks		4 weeks		8 weeks	
Structure Type	χ^2	*p*	χ^2	*p*	χ^2	*p*	χ^2	*p*
Treatment 1								
Set1 VPrep	1.33	0.25	1.33	0.25	1.33	0.25	1.33	0.25
Treatment 2								
Set2 VPrep	3.20	0.07	0.50	0.48	2.25	0.13	1.33	0.25
Unexposed Set								
Set3 VPart	1.33	0.25	1.33	0.25	1.33	0.25	0.50	0.48
Set3 VPrep	1.33	0.25	1.33	0.25	2.25	0.13	2.25	0.13

Table 5. Change in DC's performance between pre-treatment and follow-up administrations calculated with McNemar's Test of Change.

Although the efficacy of the treatment has been demonstrated using both behavioral criteria and effect sizes, none of the comparisons between pre- and post-tests showed a statistically significant improvement (see Figure 12). This pattern may be due to high rates of correct responses in the Full Test pre-test, which in turn resulted in low numbers of items entered into the McNemar's Test. Two comparisons showed a trend ($p < .1$), indicating a modest maintenance effect: at 1-week follow-up for Set 1 VPart sentences (i.e. prime structure) and Set 2 VPrep sentences (prime & probe structure) approached significance using McNemar's Test.

The effect size of the improvement on Set 3 VPart sentences was Δ = 3.18, while the effect size of the improvement on Set 3 VPrep sentences was Δ = 1.77.

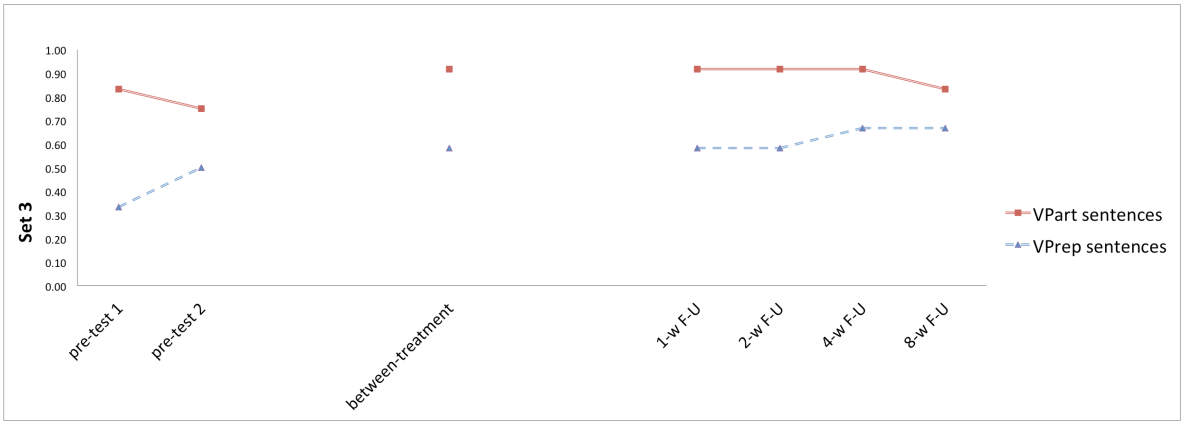

Figure 12. DC's performance on Set 3 sentences during Full-Tests (pre-tests, between-treatment probe, and follow-up sessions).

PRE- AND POST-TREATMENT TESTS

DC's performance on grammaticality judgments, comprehension of reversible sentences, sentence repetition and word repetition span was re-assessed after the end of treatment.

Results are showed in Table 6.

	Pre-treatment	Post-treatment	*p* value
grammaticality judgments	47/60	48/60	1
reversible sentences comprehension	38/61	41/61	.7
sentence repetition	11/54	20/54	.088
word repetition span	2.8	2.2	

Table 6. DC's performance on pre- and post-treatment tests. P values are calculated by means of two-tailed Fisher's test.

Comparing pre- and post-treatment performance, no measure seems to be affected by the treatment.

4.2.3 DISCUSSION

The effect of priming is to make a language representation temporarily more accessible. In the case of structural priming, residual activation of recently used structures presumably makes them more accessible when retrieved again in the short-term. This assumption led to the prediction that structural priming would lead to a significant improvement in the repetition of both verb-particle (VPart) and prepositional transitive (VPrep) sentence types. An overview of the data supports this prediction, showing a general improvement of repetition abilities in both the participants (see Table 7).

Full Test Administration Pre- and Post-Treatment					
Participant	**Pre-Test**	**1 week**	**2 weeks**	**4 weeks**	**8 weeks**
KC	0.38	0.61	0.71	0.51	0.88
DC	0.54	0.85	0.78	0.81	0.82

Table 7. Overall (i.e. VPart+VPrep) proportion of Full Test sentences correctly repeated in the pre-treatment (first administration) and follow-up phases.

Another prediction, according to Kohen et al. (2011), was that verb-particle sentences would be better repeated than prepositional transitives, because they engage fewer processing resources. Indeed, prepositional transitive constructions have a more complex syntactic structure than verb-particle constructions, due to the embedding of a prepositional phrase within the verb phrase. Moreover, the complexity in semantic structure appears to increase in prepositional transitives: in verb-particle sentences, the particle itself does not have an independent semantic force, being part of unitary predicates; whereas in prepositional transitives, the preposition provides an independent contribution of semantic information. Consequently, verb-particle constructions contain essentially three semantic elements, whereas prepositional transitives constructions contain four distinct semantic elements. The prediction deriving from this assumption is supported by results: for both participants, repetition of verb-particle sentences was better than repetition of prepositional transitives, even before (and so, independently of) the treatment (see Table 8).

		Full Test Administration Pre- and Post-Treatment					
Participant	Structure Type	**Pre-Test**	**1 week**	**2 weeks**	**4 weeks**	**8 weeks**	Overall
KC	VParts	0.44	0.61	0.78	0.56	0.97	0.67
	VPreps	0.31	0.61	0.64	0.47	0.78	0.56
DC	VParts	0.64	0.94	0.89	0.86	0.92	0.85
	VPreps	0.44	0.75	0.67	0.75	0.72	0.67

Table 8. Proportion of verb-particle and prepositional transitive sentences correctly repeated in Full Test during the pre-treatment and follow-up phases.

Cross-structural priming from the less complex structure (VPart) to the more complex one (VPrep) works for both the participants. According to the reaching of trend-lines, we can argue that both participants showed a greater impact deriving from the cross-structural priming treatment that used verb-particle sentences as primes for prepositional transitive sentences. Indeed, for KC the effect size of Treatment 1 (VPart prime, VPrep probe) on the targeted (i.e. probed) structure is 1.35, while the effect size of Treatment 2 (VPrep prime, VPart probe) on the targeted structure is 0.96. In DC's case, the effect size of Treatment 1 (VPart prime, VPrep probe) on the targeted structure is 2.45, whereas the effect size of Treatment 2 (VPrep prime, VPrep probe) on the targeted structure is 1.32.

The last prediction was that treatment effects would be evident during post-treatment follow-up assessments. This has been confirmed by KC's performance, which showed a high maintenance level of the effects up to the 8-week follow-up. On the other hand, DC only showed a trend in maintaining the improvements at 1-week follow-up. The lack of strong changes in DC's performance can be due to the fact that his performance on the pre-test Full Test was already fairly high.

4.3 STUDY 4: ITALIAN PATIENT

4.3.1 METHODS

Material (see Appendix 2)

As for the English treatment, stimuli consisted of 72 pairs (unaccusative and reflexive) sentences, matched for length and frequency of use of lexical entries.

Pairs were constructed so that identical subject noun phrases were followed by either a reflexive verb and a prepositional phrase or an unaccusative verb and a prepositional phrase. Sentence pairs consisted then of a reflexive construction ("*La maestra si taglia con le forbici*") and the matched unaccusative sentence ("*La maestra si accorge di un imbroglio*").

Out of the 72 pairs, 36 were selected as experimental stimuli (sentences used during probe sessions), and 36 were used as primes during treatment sessions.

Participant

MTB was a 78-years-old woman with 18 years of education. Six years prior the enrollment in this study, she sustained a left-hemisphere stroke, resulting in amnestic aphasia.

At the time of this testing, her performance in a sentence comprehension battery (*Comprendo*, Cecchetto, Di Domenico, Garraffa, & Papagno, 2012) highlighted a mild impairment (.67 correctly comprehended sentences, n = 100), while in grammaticality judgments test (subtest of *BADA*, Miceli, Laudanna, Burani, & Capasso, 1994) she correctly judged .88 sentences (n = 48). The patient's abilities in repeating sentences were tested by means of BADA subtest (8/14 correctly repeated sentences), and through the repetition of 40 sentences from Comprendo (4 sentences from each structure were selected, and she was able to correctly repeat 3/4 transitive active sentences, 1/4 passive, and 1/4 sentences with coordinated objects). Word repetition span (assessed through the Italian version of TALSA subtests (Benetello, Guerrero, Kalinyak-Fliszar, Kohen, & N. Martin, in prep.)) was 3.8.

Design

The design of the study was a short version (4 treatment sessions for each treatment block) of that used for the English participants.

In the first two sessions, the patient was asked to repeat all 36 probe sentence pairs (Full Test), presented in a randomized order by live voice. According to the performance obtained in the two pre-test Full Tests, sentence pairs were equally divided into 3 sets (12 pairs each).

Four baseline probes (Sets 1 and 2) were administered before the beginning of Treatment 1, and repeated before the second treatment block to establish a stable baseline level of performance.

There were two treatment blocks, consisting of 4 sessions each. Both treatment blocks followed a cross-structural paradigm: during Treatment 1, unaccusative sentences were used as primes, and reflexive sentences were probed. In Treatment 2, the reverse pattern was followed.

Treatment Protocol

During treatment, a sentence was read aloud by the examiner, and the participant had to repeat it. Feedback about accuracy was always provided for the primes.

After three prime sentences, one of the 12 probe sentences was administered for immediate repetition. No feedback was provided for probe sentences.

Each treatment session consisted of 36 prime sentences, and 12 probes. During Treatment 1, reflexive sentences from Set 1 were probed, while during Treatment 2, unaccusative sentences from Set 2 were used.

After the end of each treatment block (4 sessions), the Full Test (sets 1, 2 and 3) was probed, in order to see any possible generalization of the treatment to unexposed sentences. After the end of Treatment 2, follow-up probes on all the 3 sets were administered (1, 2, 8 weeks after the last treatment session), to determine if there were any lasting effects of the treatment.

Data analysis

The dependent variable was the number of correctly repeated unaccusative and reflexive sentences during probe sessions. McNemar's Test was used.

4.3.2 RESULTS

TREATMENT 1 (Unaccusatives: primes; Reflexives: probes)

Shewhart trend-line was set at .39 for Set 1 Reflexive sentences. Repetition of Reflexive probes quickly reached and passed the trend-line during Treatment 1 (see Figure 13), therefore meeting the criterion for significant change from baseline. Effect size from baselines to the end of Treatment 1 for Reflexive sentences was 3.67, whereas it was 0.88 for Unaccusative sentences.

TREATMENT 2 (Reflexives: primes; Unaccusatives: probes)

Shewhart trend-line, set at .53 for Set 2 Unaccusative sentences (see Figure 13), was not reached. Effect size from baselines to the end of Treatment 2 for Unaccusative sentences was 1.11, whereas it was 1.85 for Reflexive sentences.

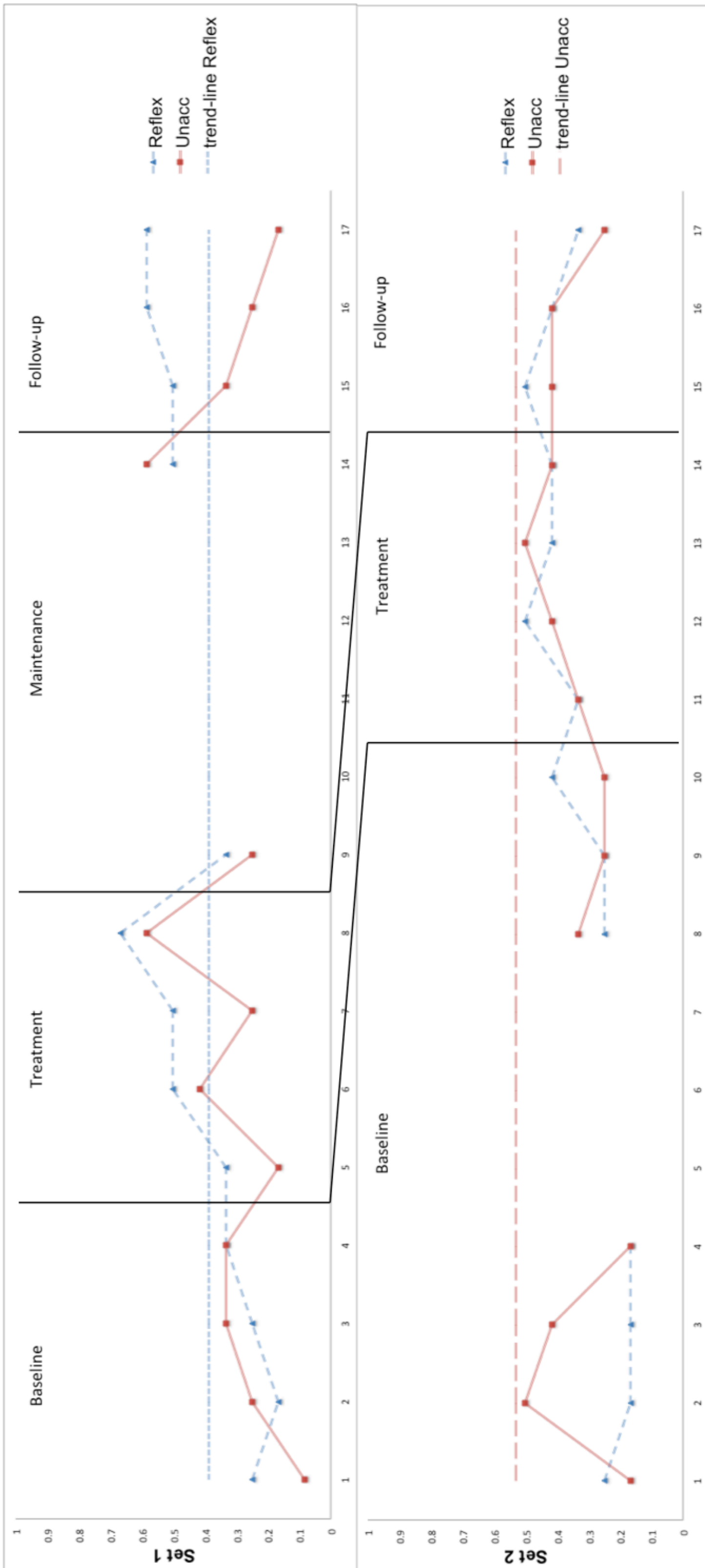

Figure 13. MTB's performance (proportion of correctly repeated sentences) on Set 1 and Set 2 sentences during the whole treatment protocol.

FOLLOW-UP

MTB's performance on Full Test (sets 1-2-3) pre-test was compared by means of McNemar's test for significance of change with the performance on Full Test post-tests (1-2-8 weeks after the end of the treatment) (see Table 9).

	1 week		2 weeks		8 weeks	
Structure Type	χ^2	*p*	χ^2	*p*	χ^2	*p*
Treatment 1						
Set1 Unacc	0	1	0.25	0.62	0	1
Set1 Reflex	*1.16*	*.29*	*.57*	*0.45*	*2.29*	*0.13*
Treatment 2						
Set2 Unacc	*0.57*	*0.45*	*0.57*	*0.45*	*0*	*1*
Set2 Reflex	3.2	0.07	2.25	0.16	1.33	0.25
Unexposed Set						
Set3 Unacc	0.25	0.62	0.17	0.69	0.25	0.62
Set3 Reflex	0	1	0	1	1.33	0.25

Table 9. Change in MTB's performance between pre-treatment and follow-up administrations calculated with McNemar's Test of Change. Data from the probed structures are italicized.

Although during Treatment 1 improvements on the probed structure (Reflexives) were substantial, no result during follow-up testing showed either the maintenance over time (1-2-8 weeks after the end of treatment) or the generalization (unexposed set of sentences, see Figure 14) of the effects of treatment.

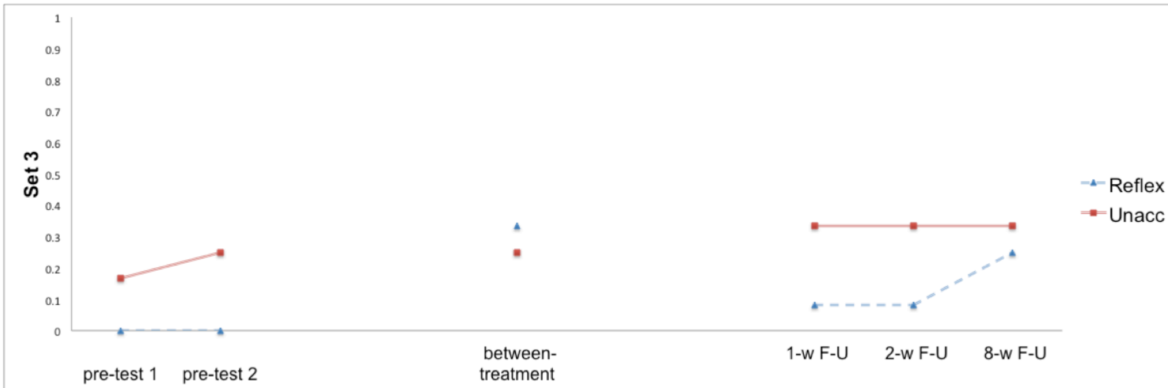

Figure 14. MTB's performance on Set 3 sentences during Full-Tests (pre-tests, between-treatment probe, and follow-up sessions).

PRE- AND POST-TREATMENT TESTS

MTB's performance on grammaticality judgments, sentence comprehension, sentence repetition and word repetition span was re-assessed after the end of treatment.

Results are showed in Table 10.

	Pre-treatment	**Post-treatment**	***p* value**
grammaticality judgments	42/48	44/48	.7
sentence comprehension	67/100	72/100	.5
sentence repetition	5/40	4/40	1
word repetition span	3.8	2.8	

Table 10. MTB's performance on pre- and post-treatment tests. P values are calculated by means of two-tailed Fisher's test.

Comparing pre- and post-treatment performance, no measure seems to be affected by the treatment.

4.3.3 DISCUSSION

Notwithstanding the short version of the treatment (4-session treatment blocks), the patient showed an increase in her ability to repeat sentences, independently of the structure (see Table 11).

Pre-Test	**1 week**	**2 weeks**	**8 weeks**
0.14	0.36	0.35	0.32

Table 11. Overall (i.e. Unaccusatives+Reflexives) proportion of Full Test sentences correctly repeated in the pre-treatment (first administration) and follow-up phases.

Improvements are less substantial than the ones seen for the English participants, and this could be due to various factors. First of all, the duration of the treatment was shorter, and this could have led to weaker effects of the treatment itself. Moreover, the need to match stimuli for frequency of use forced toward the selection of uncommon verbs. This happened because "pure" "unaccusative+si" verbs were selected, which do not allow other constructions: for example, the common "unaccusative+si" verb "*sedersi*" ("take a seat"), also allows the transitive construction "*sedere*", as for example in the sentence "*La madre ha seduto il bambino*" ("the mother sat down the child"). We wanted to keep the possible confounding variable of different possible structures controlled, and the selection of "pure" "unaccusative+si" verbs lowered the frequency rate of both unaccusative and reflexive verbs. Compared to the English verbs used, the Italian ones were much less frequent, and this could have led to a general lower performance of the Italian patient.

Another important observation regards the assumption that unaccusative constructions are easier to process than reflexives. At the first administration of the Full Test (pre-treatment administration), this appeared to be supported by results (see Table 12). However, subsequent data do not confirm this assumption, showing a slightly better performance in repeating reflexive sentences than unaccusatives.

Full Test Administration Pre- and Post-Treatment					
Structure Type	**Pre-Test**	**1 week**	**2 weeks**	**8 weeks**	Overall
Unacc	0.19	0.36	0.33	0.25	0.28
Reflex	0.08	0.36	0.36	0.39	0.30

Table 12. Proportion of unaccusative and reflexive sentences correctly repeated in Full Test during the pre-treatment and follow-up phases.

However, this difference in the performance could be due to the effect of Treatment 1, which gave a strong effect size. The good initial performance on unaccusative constructions could have led to a strong cross-structural priming effect, leading to improvements in the processing of reflexive sentences, while the reverse effect (i.e. reflexives priming unaccusatives) did not take place, because of an initial greater impairment in processing reflexives.

4.4 CONCLUSIONS

Results of these two studies support the idea that superficial similarity can, to some extent, contribute to sentence priming in a sentence repetition paradigm. In one sense, this might not seem particularly surprising. Since priming occurs at all levels of representation - phonological, lexical, syntactic and semantic - here we may be seeing an effect of superficial form identity that overrides the difference in syntactic structure of primes and probes and yields a priming effect. Still, in principle a superficial similarity that masks a structural difference might also be detrimental, as it might create a sort of garden path effect by suggesting an interpretation for the probe sentence that is not correct. So, the very existence of an ameliorating effect is not an obvious result and must be discussed.

In this discussion, one has to keep in mind that the task is just sentence repetition, while sentence comprehension is not controlled, so we do not have direct information on how accurately the patients process the prime and the probe sentences even when they repeat them correctly.

In the study on English patients, it is possible to argue that when using the more complex structure (prepositional transitives, "*The man is blowing on the coffee*") as prime, the structure is possibly not completely activated, or not strongly enough to be maintained long enough to show effects on the simpler other structure (verb-particle, "*The man is blowing up the balloon*"). The prepositional phrase makes the structure more complex than a simple Subject-Verb-Object (SVO) sentence. Moreover, the preposition introduces a functional layer, which is often impaired in people with aphasia (e.g. Caplan, 1987; Miceli, Silveri, Romani, & Caramazza, 1989; Grodzinsky, 2000). The overload of information conveyed by prepositional transitive sentences would make their processing hard, not allowing a complete or good enough activation and maintenance of the structure, and this would prevent a strong priming effect on the less complex structure.

On the other hand, verb-particle transitives can be processed as simple SVO sentences, being the particle part of the predicate. This could allow a stronger activation of the structure, which would reflect in a stronger cross-structural priming effect when using verb-particle transitives as primes. As the phonological representation of the particle is the same when it appears in the phrasal verb and when it is the head of a prepositional phrase, the representation activated by the verb-particle sentence could remain active when the prepositional transitive is presented, then allowing the repetition of the preposition (and of the prepositional phrase), which otherwise would be too hard for these aphasic patients. This can explain the directionality of the beneficial effect (the simpler structure priming the more complex one).

This explanation mutatis mutandis can be applied also on the Italian patient.

Indeed, in Study 4 both structures (reflexives: "*La maestra si taglia con le forbici*", unaccusatives: "*La maestra si accorge di un imbroglio*") share an element (clitic pronoun "si") known to be particularly demanding for people with aphasia (for studies assessing aphasics' performance on clitics, see for example Miceli et al., 1989; Miceli & Mazzucchi, 1990). However, when using the less complex sentence (unaccusative) as prime, there could likely be a better activation of the morpho-phonological structure, maintainable long enough to reflect in a good processing of the reflexive sentence during the cross-structural priming treatment.

However, as noted in the introduction (paragraph 4.1), Bock and Loebell (1990) demonstrated that in typical speakers, superficial similarity does not contribute to priming effects when underlying syntactic structures were different. Results from English patients are in contrast with Bock and Loebell's findings.

How do we reconcile this inconsistency? There are three possibilities to consider.

First, in the illustrated studies, repetition priming was used to prime a repetition response. This was done because the target structures (transitives with verb particles and prepositional phrases; reflexives and unaccusatives+si) were difficult to portray in pictures. In the Bock and Loebell's study, the primed response was a picture description. It is conceivable that a repetition primed – repetition response would be more sensitive to and influenced by superficial similarity, leading to cross-structural priming.

Second, participants to the treatment studies had language impairments due to brain damage, while those in the Bock and Loebell's study were typical speakers. It is plausible that contribution of superficial similarity to structural priming becomes more critical when access to syntactic representations is impaired. This could also explain the lack of a significant change after treatment of the Italian patient, who did not show a specific syntactic impairment.

Third, Bock and Loebell's data were obtained in a single experimental session, whereas cross-structural priming effects were observed in the context of treatment studies. In a working memory treatment study based on repetition of sentences (Francis et al., 2003), it was showed how a shift to greater reliance on short-term memory took place gradually throughout treatment, whereas early stages of therapy repetition probably relied on long-term memory (the patient described by Francis and colleagues showed a better performance on practiced sentences, with no generalization on untrained items, while by the end of treatment her performance on untrained sentences was comparable to performance on practiced items). It is possible that effects of superficial similarity build up over time, leading to the cross-structural priming effects obtained in these treatment studies. This consideration would also explain the weaker efficacy of treatment for the Italian patient, who underwent a shorter version of the treatment.

Our results, together with Kohen et al. (2011)'s findings, highlight the importance of considering linguistic theories and principles of learning as a framework for the development of sentence level treatments. Thompson et al., 2003, for example, have showed that training-induced improvements on a syntactic structure of a certain complexity (e.g., object-relative clause structures) will generalize to improved performance on simpler structures that are related linguistically to the more complex structure (e.g., matrix *who*-questions). In the study on English patients, using a sentence repetition priming paradigm to treat mildly-to-severely impaired participants, sentences do not have to be linguistically related, but to have a strong similarity in superficial appearance. It has been demonstrated that this superficial similarity could promote generalization of training effects from the simpler to the more complex structure, at least for the patients who have greater language impairments. Regarding the Italian patient, it could be the case that her milder language impairment would benefit more from a treatment that involves syntactically related structures, and not only superficially similar.

It is worth investigating in future studies the validity of the paradigm used in these studies on a wider sample of participants, with various types and degrees of syntactic difficulties due to aphasia, and possibly on different sentence structures. This could allow better understanding of processes involved in sentence repetition (and, in general, in sentence processing) at different degrees of impairment, and to develop new rehabilitation instruments for the treatment of people with language impairments.

5. CHAPTER IV

FUTURE PERSPECTIVES FOR SHORT-TERM MEMORY IMPAIRMENT REHABILITATION

So far, the importance of short-term memory in language processing has been discussed and demonstrated.

Therefore, improving short-term memory capacity in people with brain damage could not only be important for patients showing a specific short-term memory impairment, but also for those aphasic patients whose language impairment could be linked to a decrease in their span.

In the last few decades, non-invasive techniques of brain stimulation have been successfully used for cognitive rehabilitation (see Miniussi et al., 2008; Holland & Crinion, 2012 for reviews), but to our knowledge no study has investigated the possible changes in performance on verbal short-term memory by modulating cortical activity by means of tDCS. The effectiveness of such stimulation could be particularly interesting as a potential perspective for the development of new rehabilitation treatments.

In Study 5, in order to verify whether stimulation by means of tDCS could modulate the performance in serial recall task, anodal tDCS was applied over BA 40, a region known to be involved in short-term memory tasks (see paragraph 2.1.4 for references).

5.1 STUDY 5 – tDCS

5.1.1 METHODS

Materials

Participants were trained and tested on the 3 lists of words used in Study 2 (see paragraph 3.3).

Each word of the three lists was matched with a meaning (concrete, that could be visually represented and with the same frequency of use (CoLFIS, Bertinetto et al., 2005)). The meanings, which did not correspond to the actual meaning of the Croatian words, were selected on the basis of criteria as animacy, familiarity with the object, and visual complexity (see Viggiano, Vannucci, & Righi, 2004), and conveyed through the presentation of a black-and-white picture of the object.

All the different sections of the experiment were administered by means of the software *E-Prime 2.0*.

Participants

Eleven (3 males) healthy subjects were tested. Their age ranged between 20 and 38 (mean: 26.91, sd = 7.46), and years of education varied between 13 and 18 (mean: 15.55, sd = 2.5). All subjects were Italian native speakers, and did not suffer from neurological or psychiatric diseases. None of them was familiar with Croatian or any other Slavic language. Their right-handedness was assessed by means of the Edinburgh Inventory Questionnaire (Oldfield, 1971) (mean coefficient = 0.93, sd = 0.09).

Procedure

Participants were tested individually in three different sessions lasting approximately 1 hour each. On each session, subjects were trained on a different list of words and underwent the stimulation of a different brain area (BA 40, BA 22, sham stimulation).

The order of presentation of the lists and the sites of stimulation were counterbalanced across participants.

During the sessions, participants sat in front of a computer at about 0.5 m from the screen. Written instructions were given before each experimental phase, and the examiner was available to provide additional instruction if necessary.

tDCS (see paragraph 2.1.4 for an explanation of the technique)

tDCS was delivered by a battery driven, constant current stimulator through a pair of saline-soaked sponge electrodes (7x5 cm) kept firm by elastic bands. During *real* (i.e. experimental and control) conditions, stimulation intensity was set at 2mA; the duration of stimulation was 20 minutes, which is expected to induce long-lasting effects covering the overall duration (approximately 20 minutes) of the following tasks.

Since the aim was to verify whether tDCS can improve verbal short-term memory performance, the inferior parietal lobule (BA 40) was selected as target area.

The inferior parietal lobule (left BA 40) was localized according to the 10-20 EEG system as the P3 position (for the reliability of localizing a desired cortex region using the 10-20 EEG system, see Herwig, Satrapi, & Shoenfeldt-Lecuona, 2003).

As control condition (in order to verify the specificity of the modulation of BA 40), anodal stimulation was applied on the middle temporal gyrus (BA 22), an area considered to be involved in the semantic processing of stimuli (see Hoffman, Pobric, Drakesmith, & Lambon Ralph, 2012).

For sham condition, montage of electrodes was the same as during BA 22 tDCS, and the current was turned off slowly after 30 seconds of stimulation.

Training Phases

Familiarization with word lists was performed with the same modalities presented for List 1 (phonology plus semantics list) of Study 2.

Words were presented in a random order, and each list was repeated four times.

<u>Tasks administered during stimulation:</u>

After the first exposure to the stimuli, tDCS stimulation started, and participants had to complete the *word retrieval* task, as described for List 1 of Study 2, the only difference being that, instead of a drawing, participants were visually presented with the picture of the object they had to name.

The repetition of the familiarization-word retrieval sequence continued until participants were able to correctly name all the pictures twice consecutively.

To make sure that during the interval between the end of word retrieval and the end of stimulation words were not forgotten, 2 minutes before the end of stimulation the subjects were required to perform an additional word retrieval.

<u>Tasks administered after stimulation:</u>

Before moving to the serial recall, two tasks were administered to have a further measure of the actual knowledge of the words:

- *Lexical decision*: participants were visually and auditorily presented with a word, and had to judge, by pressing a key on the keyboard, whether the word belonged to the list they had just learned or had not been presented before. During this task, 20 items were presented in random order: 10 were the words belonging to the list, and 10 were untrained items.

- *Word-picture matching*: participants were visually and auditorily presented with a word while seeing a picture, and they had to press a key in order to answer whether the word-picture matching was correct. During the task, each drawing was presented in random order three times: once correctly matched with the word, once matched with another word belonging to the same list, and once matched with an untrained item.

The order of presentation of *lexical decision* and *word-picture matching* tasks was counterbalanced across participants.

Experimental task – Immediate serial recall

The words of each list were used to prepare 10 six-item sequences for serial recall.

Administration procedures for this task were the same as described for the immediate serial recall of Study 2.

Control task

A control task was introduced at the end of the immediate serial recall. The aim of this task was to verify whether the stimulation of BA 40 by means of tDCS would generally affect phonological processing of stimuli, or was specific for the retention of a series of items in their correct order.

The *initial sound similarity judgment* task is considered to involve the operation of rehearsal without any relevant contribution from the phonological short-term store (e.g. Paulesu et al., 1993; Vallar et al., 1997; but see Romero Lauro et al., 2006 for a different opinion). If stimulation of BA 40 were specific for the retention of stimuli in their correct order, we would expect this task not to be affected by tDCS. To this aim, participants had to decide whether pairs of words on the screen, beginning with the same grapheme that could be translated into one of two possible sounds according to the following orthographic context, actually began with the same sound or not (e.g. *candela-ciliegia* respectively begin with the sounds “k” and “ch”, while *cilindro-cesta* both begin with “ch”). In each of the three sessions, participants had to compare initial sounds of 40 pairs (20 for the condition “same sound”, and 20 for the condition “different sound”) of words, presented in randomized order on the screen until a response was given by pressing a key on the keyboard.

Stimuli were the same used in Romero Lauro et al. (2006).

Data analysis

Regarding the immediate serial recall tasks, data analysis followed the same procedure as for Study 2.

The dependent variable was the number of errors each subject made on each list (computed first as the overall sum of item plus order errors on each six-item sequence, and then as the separate sum of item errors and order errors).

A random effect analysis of variance (ANOVA) was run, with “number of errors” as dependent variable, “subject” as random factor, and “stimulation” as fixed factor.

With regards to the control tasks, the same analyses with “accuracy” and “reaction times” as dependent variable were conducted.

5.1.2 RESULTS

Familiarization

The number of repetitions required to reach the familiarization criteria did not differ among the three stimulations [F(2,20) = 1.600; *p* > .1] (see Figure 15).

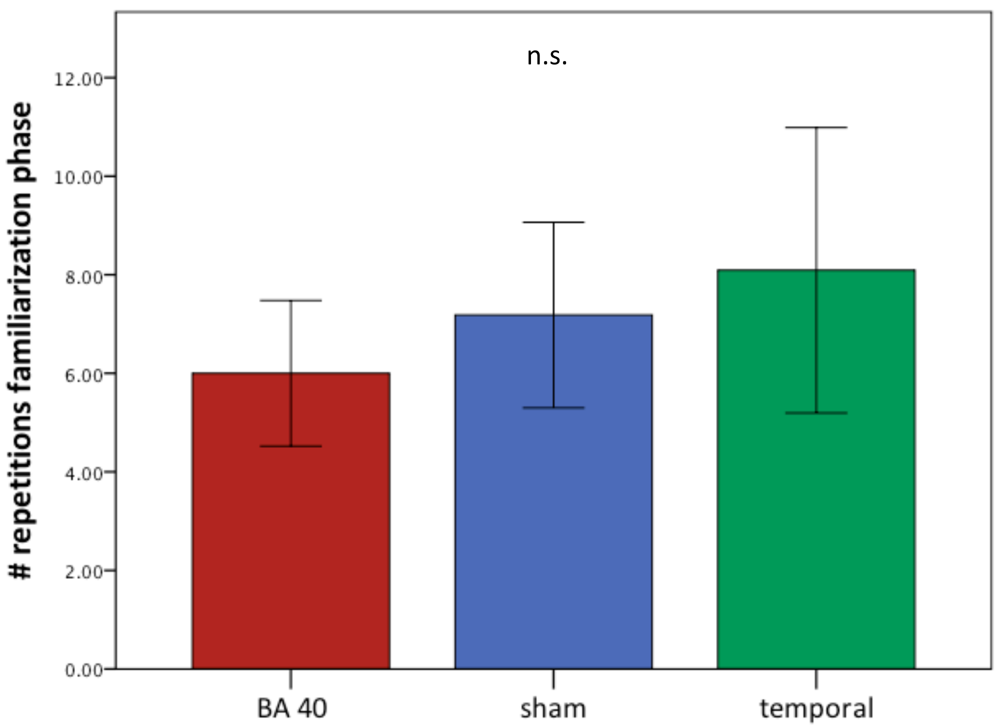

Figure 15. Number of repetitions in the familiarization phase.

Immediate serial recall

The mean number of overall (item plus order) errors following Saint-Aubin and Poirier (1999)'s Method 1 in the sham condition was 21.09 (sd = 6.42), during stimulation of BA 40 was 23.55 (sd = 10.51), and during stimulation of BA 22 was 22.92 (sd = 9.86) (see Figure 16).

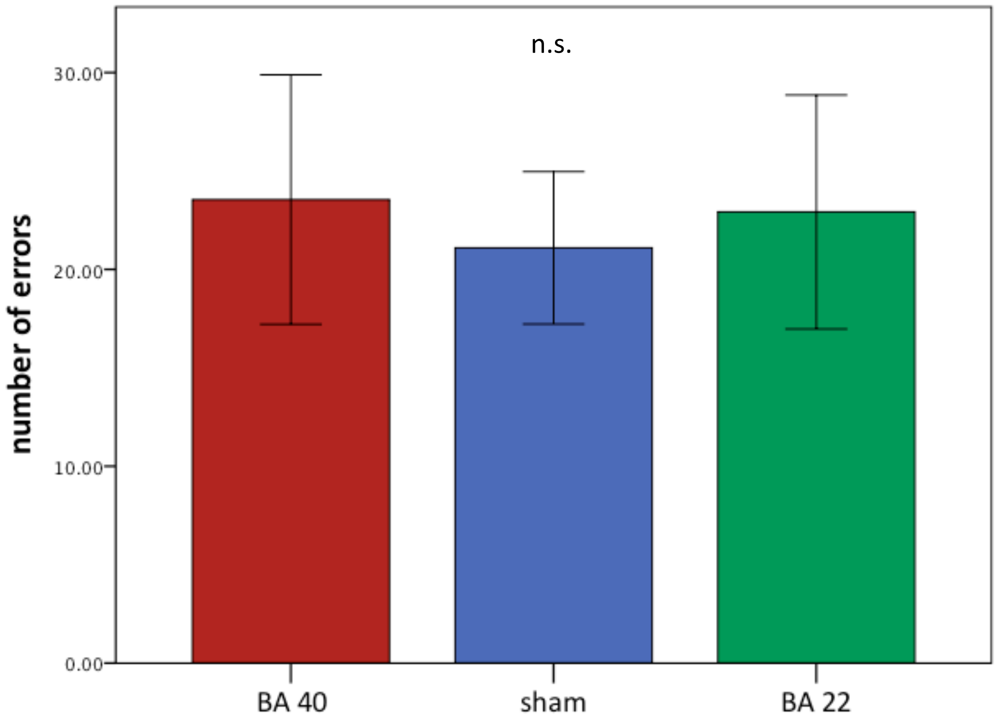

Figure 16. Overall errors (item+order).

The random effect ANOVA revealed no main effect of stimulation [$F(2,20) = .530$; $p > .1$].

The mean number of item errors (following Saint-Aubin and Poirier's method) in the sham condition was 18.82 (sd = 5.86), during stimulation of BA 40 was 22 (sd = 9.91), and during stimulation of BA 22 was 21 (sd = 9.51).

The mean number of order errors in the sham condition was 2.27 (sd = 1.34), 1.55 (sd = 0.93) during stimulation of BA 40, and 1.92 (sd = 1.23) during stimulation of BA 22.

The random effect ANOVA with “number of item errors” as dependent variable did not reveal a main effect of stimulation [$F(2,20) = .807$; $p > .1$) (see Figure 17), whereas the random effect ANOVA with “number of order errors” as dependent variable showed a main effect of stimulation [$F(2,20) = 5.285$; $p < .05$). Post-hoc tests (Bonferroni) indicated that the performance with regards to order errors significantly differed in the comparison between sham condition and stimulation of BA 40 ($p < .05$), whereas all the other comparisons were not significant (see Figure 18).

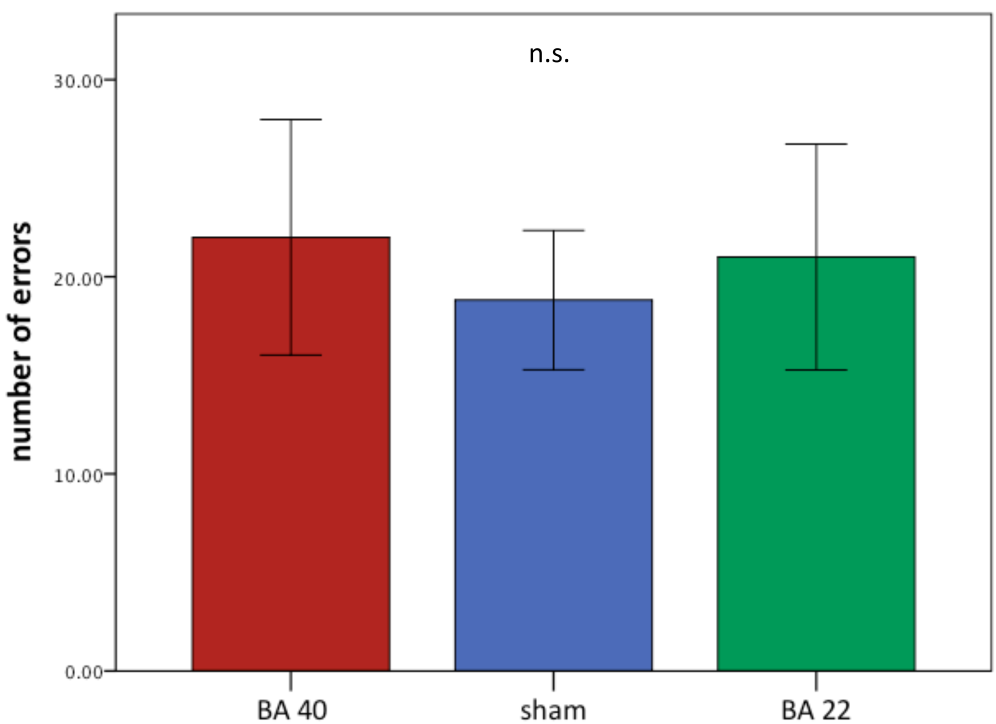

Figure 17. Item errors.

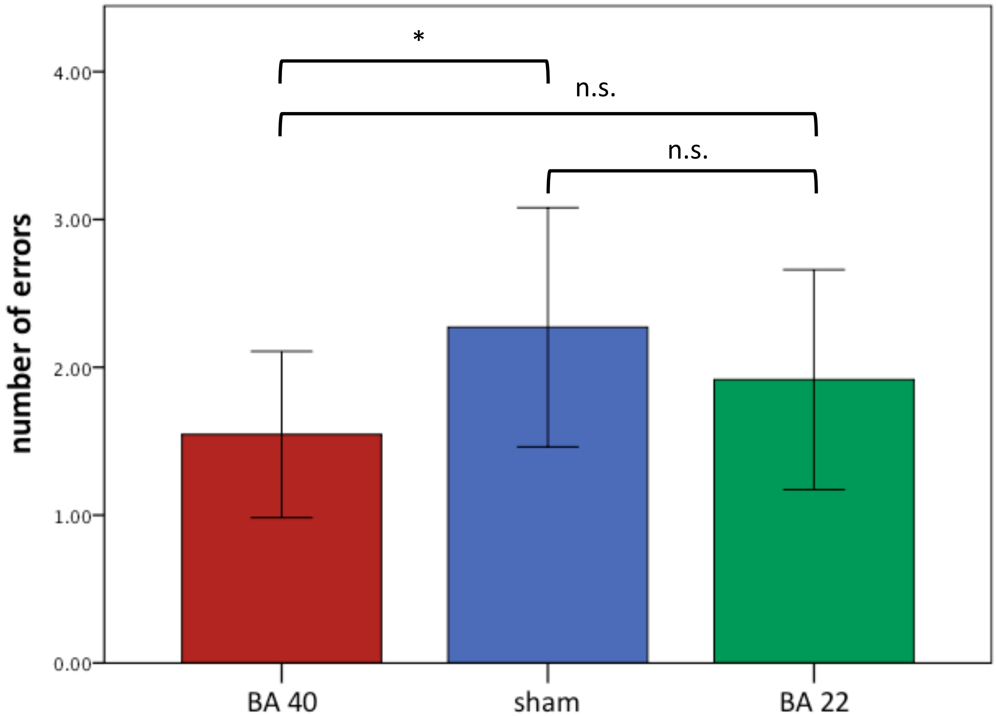

Figure 18. Order errors.

Control task

The mean proportion of correct responses in the initial sound similarity judgment was .88 (sd = .15) in the sham condition, .88 (sd = .13) with stimulation of BA 40, and .93 (sd = .09) with stimulation of BA 22. The random effect ANOVA with “accuracy” as dependent variable did not reveal a main effect of stimulation [$F(2,20) = 2.111$; $p > .1$) (see Figure 19).

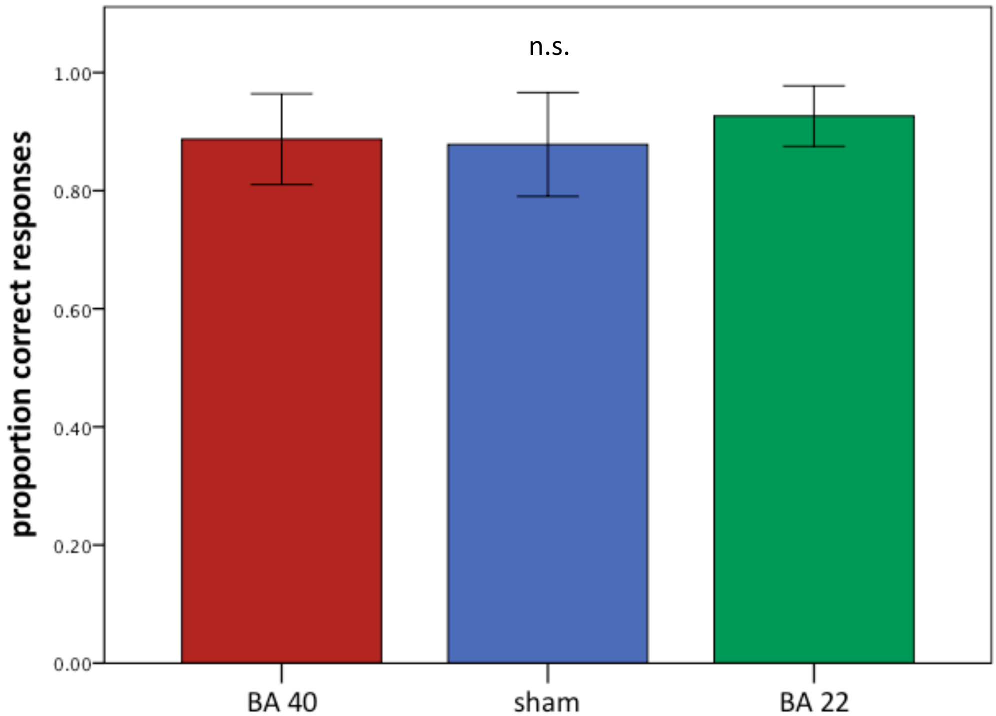

Figure 19. Proportions of correct responses during the initial sound similarity judgment task.

The mean reaction times for accurate responses in the initial sound similarity judgment were 1867.7 msec (sd = 580.49) in the sham condition, 2075.25 msec (sd = 1099.12) with stimulation of BA 40, and 2088.73 (sd = 664.94) with stimulation of BA 22. The random effect ANOVA with "reaction times" as dependent variable did not reveal a main effect of stimulation [$F(2,20) = .882$; $p > .1$) (see Figure 20).

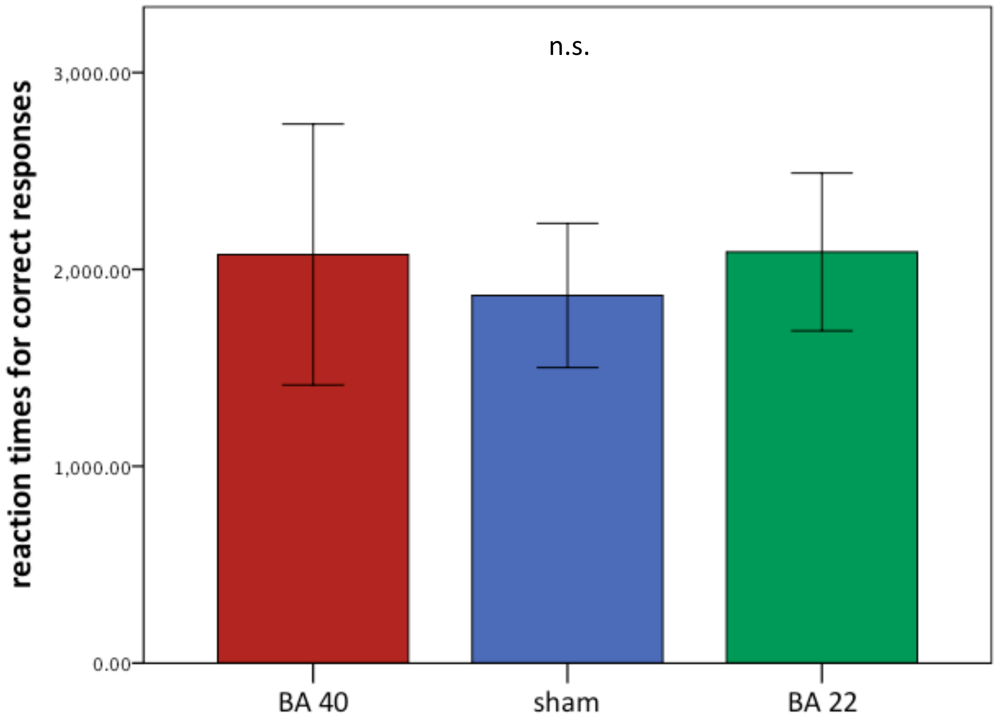

Figure 20. Reaction times for correct responses during the initial sound similarity judgment task.

5.1.3 DISCUSSION

Through the enhancement of cortical excitability by means of anodal tDCS, the possibility to modulate performance on a verbal short-term memory task through the use of tDCS was explored.

Effects of stimulation were positively demonstrated: performance on serial recall improved when BA 40 was stimulated. Non-significant results of the stimulation of BA 22 and during the phonological control task (initial sound similarity judgment) showed that the better performance on the experimental task (immediate serial recall) was not due to a general improvement of cognitive abilities, but to a specific effect of the stimulation on

BA 40 (more specifically, the neural correlate of the phonological short-term store). The effects of stimulation are in line with the retrieval-based hypothesis (Saint-Aubin & Poirier, 2000) and with results of Study 2: the facilitation emerges in terms of decrease of order errors, which is due to the presence of a correct phonological representation of the sequence, and not in terms of item errors, that would imply an enhancement of semantic processing.

This study shows the efficacy of a-tDCS stimulation over BA 40 in enhancing the capacity of the phonological loop, giving interesting hints on the possible use of this technique, for the rehabilitation of patients with verbal short-term memory impairments.

6. GENERAL CONCLUSIONS

In this dissertation I investigated various aspects of the involvement of verbal short-term memory in language processing by means of repetition tasks.

Through a review of the literature, I pointed out how language processing is strictly connected not only with working memory, but also, to some extent, with a specific sub-component of it, namely verbal short-term memory.

In the first series of studies, I focused on the retrieval of words during immediate serial recall tasks, which allow a better understanding of the functioning of verbal short-term memory. Many researches on language acquisition and neurologically impaired patients have investigated the structure and the functions of short-term memory, and how it can affect language processing. A lively ongoing debate regards short-term memory components, in particular the presence of a semantic buffer exploited during short-term memory tasks.

Through the present investigations, which strictly controlled for the familiarity with phonological forms and meanings of the words that participants had to retrieve, I concluded that a semantic buffer does not need to be postulated, since I demonstrated that during an immediate serial recall task only the phonological information of words is exploited, and not their meaning.

This series of studies on immediate serial recall task did not only clarify some aspects of the structure of short-term memory, but also laid the foundations for further investigations on the possibility to use non-invasive techniques of brain stimulation with neurologically impaired subjects.
Indeed, I tested the effects of tDCS, which has been successfully used in cognitive rehabilitation, on the performance during short-term memory tasks, and the modulation of the performance gives interesting hints on the potential efficacy of such stimulation with patients who have short-term memory impairments.

On a second series of studies, I widened the level at which I investigated language processing, shifting from word repetition in serial recall tasks to sentence repetition.
Three patients with aphasia were involved in a treatment study, based on a sentence repetition protocol. Through the manipulation of sentence structures, I assessed the efficacy of a cross-structural priming paradigm.
Partially in contrast with previous findings, which showed effectiveness of treatments only when treatment involved sentences that share deep structural similarities, these results highlighted the efficacy of a treatment based on the repetition of sentences that only shared *superficial* similarities. More in detail, the performance of patients improved when priming the more complex structures with the less complex ones, possibly revealing an effect due to the manipulation of memory load.
These results could represent a first step for the development of new treatment approaches at sentence level for people with aphasia, stressing the importance of accounting for both linguistic theory and memory system.

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8. APPENDIX

8.1 APPENDIX 1: ENGLISH SENTENCES FOR STRUCTURAL PRIMING

8.1.1 PRIME SENTENCES

Verb-particle sentences	Prepositional transitive sentences
The girl is adding up the number	The girl is adding in her head
The boy is asking out the girl	The boy is asking for a loan
The man is asking in the stranger	The man is asking about the weather
The chef is beating up the eggs	The chef is beating with a fork
The man is blowing up the balloon	The man is blowing on the tea
The teacher is calling off the meeting	The teacher is calling on the phone
The woman is calling back the friend	The woman is calling from the store
The man is chopping down a tree	The man is chopping with an axe
The boy is copying down the message	The boy is copying from the board
The boy is drawing up a plan	The boy is drawing on a pad
The girl is dressing up her doll	The girl is dressing in the dark
The boy is drinking up the milk	The boy is drinking from the mug
The girl is eating up the cookies	The girl is eating in the kitchen
The woman is fighting off the man	The woman is fighting with the sword
The boy is filling up the bucket	The boy is filling in the holes
The girl is hanging out the laundry	The girl is hanging out the window
The man is kicking off his shoes	The man is kicking into the net
The man is kicking out the student	The man is kicking from the foul line
The man is knocking out the boxer	The man is knocking with his fist
The man is looking up the address	The man is looking down the street
The woman is measuring out the flour	The woman is measuring with the ruler
The woman is paying off her bill	The woman is paying with a check
The boy is picking up the ball	The boy is picking at the food
The father is picking out a suit	The father is picking on his son
The woman is printing out the paper	The woman is printing with the ink
The dog is pulling down the curtains	The dog is pulling on the leash
The woman is reading off the names	The woman is reading under the tree
The man is running up a bill	The man is running up a hill
The girl is saving up her money	The girl is saving for college
The man is sending off the message	The man is sending for the doctor
The soldier is shooting down the enemy	The soldier is shooting with a rifle
The woman is shouting out the answer	The woman is shouting at the children

The woman is sorting out the mail	The woman is sorting from the pile
The man is throwing out the garbage	The boy is throwing from the mound
The boy is throwing away the paper	The man is throwing into the net
The man is turning over the paper	The man is turning into the driveway

8.1.2 PROBE SENTENCES

Verb-particle sentences	**Prepositional transitive sentences**
The woman is backing up the car	The woman is backing into the spot
The girl is blowing out the candle	The girl is blowing into the whistle
The boy is breaking up the fight	The boy is breaking into the house
The woman is checking out the book	The woman is checking on the baby
The boy is cheering up the child	The boy is cheering for the team
The maid is cleaning up the mess	The maid is cleaning with the rag
The priest is crossing out the name	The priest is crossing at the light
The woman is cutting out the picture	The woman is cutting with a knife
The man is digging up the treasure	The man is digging with a shovel
The boy is dreaming up an alibi	The boy is dreaming about the party
The boy is dropping off the paper	The boy is dropping into the store
The girl is growing out her hair	The girl is growing into her clothes
The girl is hanging up the phone	The girl is hanging on the wire
The idiot is holding up the line	The idiot is holding onto the rail
The policeman in hunting down the robber	The policeman is hunting for a clue
The maid is ironing out a wrinkle	The maid is ironing for her boss
The child is keeping down the noise	The child is keeping off the grass
The man is knocking down the wall	The man is knocking on the door
The man is leaving out the lemon	The man is leaving out the door
The girl is looking over the recipe	The girl is looking into the mirror
The boy is messing up the house	The boy is messing with his friend
The man is moving up the date	The man is moving off the couch
The teacher is passing out the test	The teacher is passing on the dessert
The girl is playing down her award	The girl is playing on the swing
The teacher is pointing out a star	The teacher is pointing to a star
The boy is running over the squirrel	The boy is running into the wind
The girl is screwing up the painting	The girl is screwing with her friend
The boy is seeing off the guests	The boy is seeing up the dress
The man is sitting out the game	The man is sitting on the sofa
The man is splitting up the money	The man is splitting from his wife
The girl is standing up the baby	The girl is standing in the mud
The boy is stopping up the sink	The boy is stopping by the house
The man is thinking over the budget	The man is thinking about the vacation
The driver is turning off the lights	The driver is turning off the road
The boy is washing off the dirt	The boy is washing with a sponge
The boy is writing up the story	The boy is writing with the pencil

8.2 APPENDIX 2: ITALIAN SENTENCES FOR STRUCTURAL PRIMING

8.2.1 PRIME SENTENCES

Unaccusative sentences	Reflexive sentences
La ragazza si abbuffa di biscotti	La ragazza si compatisce per il fallimento
Il giudice si impelaga in una sentenza	Il giudice si infanga con gli schizzi
L’attrice si pavoneggia con il pubblico	L’attrice si abbona a una rivista
Il poliziotto si sbigottisce per il furto	Il poliziotto si camuffa da criminale
La regista si acciglia per il risultato	La regista si pettina con le mani
Il pilota si sbellica per lo scherzo	Il pilota si sporca con la polvere
La bambina si appisola su un cuscino	La bambina si graffia con il giocattolo
Il medico si intestardisce con la cura	Il medico si imbottisce di dolci
La cantante si gingilla in una pausa	La cantante si sfama con la pizza
Il soldato si lagna per la ferita	Il soldato si fascia con la stoffa
L’attrice si destreggia con il ruolo	L’attrice si dondola su un'altalena
Il calciatore si accuccia per il male	Il calciatore si capovolge in un'azione
Lo scrittore si congratula con l'editore	Lo scrittore si incastra in un racconto
La cantante si atteggia con il padre	La cantante si trucca per lo spettacolo
Il professore si indebita per la famiglia	Il professore si macchia di inchiostro
Il poliziotto si incammina sotto il ponte	Il poliziotto si attrezza per l'indagine
Il vigile si accanisce con le multe	Il vigile si gratta sotto il cappotto
La nonna si affeziona a un vicino	La nonna si contraddice con il nipote
Il poeta si addentra in un'opera	Il poeta si colora di rosso
Il musicista si addice a un brano	Il musicista si commuove per il concerto
Il contadino si inginocchia in cortile	Il contadino si distrae da un compito
Il cuoco si impadronisce di un piatto	Il cuoco si cosparge con la farina
La modella si aggrappa a un collega	La modella si spoglia in camerino
L’architetto si imbatte in un ingegnere	L’architetto si sorregge a un tavolo
L’arbitro si scontra con il giocatore	L’arbitro si bagna per la neve
Il calciatore si ribella a un divieto	Il calciatore si sacrifica per la squadra
Il fotografo si arrampica su un lampione	Il fotografo si licenzia da uno studio
La ballerina si arrabbia con il compagno	La ballerina si asciuga in bagno
La segretaria si rifugia su una scala	La segretaria si corregge da un errore
L’arbitro si arrende a una critica	L’arbitro si allena per la partita
Il poeta si pente per il libro	Il poeta si premia con una vacanza
La modella si vergogna per il vestito	La modella si oppone a una foto
L’operaio si fida di un capo	L’operaio si ferisce in cantiere
La sposa si innamora di un testimone	La sposa si pesa per la cerimonia
Il meccanico si affaccia a una porta	Il meccanico si cala in un'auto
L’architetto si accorge di uno sbaglio	L’architetto si taglia con il coltello

8.2.2 PROBE SENTENCES

Unaccusative sentences	**Reflexive sentences**
La nonna si abbuffa con la torta	La nonna si compatisce per la perdita
Il direttore si impelaga in un guaio	Il direttore si infanga in una pozza
La bambina si pavoneggia con l'amica	La bambina si abbona a un fumetto
Il giornalista si sbigottisce per la notizia	Il giornalista si camuffa da clandestino
L'avvocato si acciglia per la proposta	L'avvocato si pettina con la spazzola
La ragazza si sbellica per la battuta	La ragazza si sporca con la vernice
Il professore si appisola in camera	Il professore si graffia con il vetro
L'avvocato si intestardisce su una causa	L'avvocato si imbottisce di medicine
Il vigile si gingilla con il fischietto	Il vigile si sfama in un ristorante
Lo studente si lagna per il voto	Lo studente si fascia con la sciarpa
Il giudice si destreggia con la sentenza	Il giudice si dondola su una sedia
Il pilota si accuccia su una moto	Il pilota si capovolge in una caduta
Il medico si congratula con il paziente	Il medico si incastra in un ascensore
La regista si atteggia con gli attori	La regista si trucca per l'intervista
Il direttore si indebita con la banca	Il direttore si macchia di pomodoro
Il giornalista si incammina su un sentiero	Il giornalista si attrezza per l'inchiesta
Il soldato si accanisce con il nemico	Il soldato si gratta sotto l'orecchio
Lo studente si affeziona a un insegnante	Lo studente si contraddice in una risposta
L'operaio si addentra in una cantina	L'operaio si colora di giallo
Il fotografo si addice a un servizio	Il fotografo si commuove con l'immagine
La sposa si inginocchia su un gradino	La sposa si distrae con gli invitati
Il muratore si impadronisce di un tubo	Il muratore si cosparge con il sapone
La ballerina si aggrappa a una sbarra	La ballerina si spoglia in un angolo
L'infermiera si imbatte in un'amica	L'infermiera si sorregge su un bastone
Il contadino si scontra con il cavallo	Il contadino si bagna di pioggia
La segretaria si ribella a un ordine	La segretaria si sacrifica per i figli
Il muratore si arrampica su un palo	Il muratore si licenzia da un'azienda
Il cuoco si arrabbia con il cameriere	Il cuoco si asciuga su un grembiule
Il musicista si rifugia in un bar	Il musicista si corregge con l'esercizio
La modella si arrende a un insulto	La modella si allena per la sfilata
La maestra si pente per lo schiaffo	La maestra si premia con una collana
Il pompiere si vergogna per l'insuccesso	Il pompiere si oppone a un incarico
Il meccanico si fida di un cliente	Il meccanico si ferisce in officina
L'infermiera si innamora di un dottore	L'infermiera si pesa su una bilancia
Il pompiere si affaccia a una finestra	Il pompiere si cala in un incendio
La maestra si accorge di un imbroglio	La maestra si taglia con le forbici