DISSOCIABLE COMPONENTS OF PHONOLOGICAL AND LEXICAL-SEMANTIC SHORT-TERM MEMORY AND THEIR RELATION TO IMPAIRED WORD PRODUCTION IN APHASIA

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Abstract

This study assesses the dissociability of phonological and lexical-semantic short-term memory (STM) in two aphasic patients, BN and TM, and explores the relationship between their STM deficits and their word production impairment. Picture naming performance suggests phonological language production impairment in BN and lexical-semantic language production impairment in TM. On STM tasks, BN presented phonological STM impairment with preserved lexical-semantic STM, while TM presented the reverse profile. These results reveal a double dissociation between phonological and lexical-semantic STM capacities, and suggest that our patients' STM impairment may be selectively related to their language production deficits.

Keywords: aphasia, verbal short-term memory, phonological short-term memory, lexical-semantic short-term memory, word production impairment

Over the past few decades, a growing literature has shown that aphasia is frequently accompanied by verbal short-term memory (STM) deficits (e.g., Attout, Van der Kaa, George, & Majerus, 2012; Knott, Patterson, & Hodges, 1997; 2000; Majerus, 2009; 2013; N. Martin & Reilly, 2012; N. Martin & Saffran, 1992; N. Martin, Saffran, & Dell, 1996; R. Martin, Lesch, & Bartha, 1999; Murray, 2012). However, the nature of these deficits and their relation to language impairment are still debated.

Research has demonstrated that short-term storage of verbal information strongly interacts with phonological and lexical-semantic language representations stored in long-term memory (LTM). For instance, experimental studies on healthy adults and children have shown that the availability of rich and easily accessible language representations enhances immediate serial recall (ISR) of lists of verbal items, with recall span higher for high-frequency words than for low-frequency words (word frequency effect), for high-imageability words than for low-imageability words (imageability effect), for words than for nonwords (lexicality effect), and for high phonotactic frequency nonwords than for low phonotactic frequency nonwords (e.g., Gathercole, Frankish, Pickering, & Peaker, 1999; Majerus & D’Argembeau, 2011; Majerus & Van der Linden, 2003; Majerus, Van der Linden, Poncelet, & Metz-Lutz, 2004).

Neuropsychological data provide further evidence of strong interactions between long-term representations and STM, and suggest that damage to representations or processes involved in language, either lexical-semantic or phonological, has a negative impact on STM. For instance, Reilly et al. (2012) found that patients with progressive non-fluent aphasia, a deficit affecting phonological representations, showed less sensitivity to phonological variables such as phoneme length on a recall task. Similarly, patients with lexical-semantic representation impairment, as in aphasia or semantic dementia, showed less sensitivity to lexical-semantic attributes such as lexicality and word frequency (e.g., Jefferies, Hoffman, Jones, & Lambon Ralph, 2008; Knott et al., 1997; 2000; Majerus, Norris, & Patterson, 2007; R. Martin et al., 1999; Reilly et al., 2012). However, the view that lexical-semantic language representations influence STM capacities has been recently challenged by Papagno, Vernice, and Cecchetto (2013). The recall performance of their patient with semantic dementia, MC, did not differ between lists of words whose meaning the patient still knew and lists of words whose phonological form the patient recognized as familiar without being able to retrieve their meaning. The authors concluded that the influence of long-term knowledge on STM performance is due to familiarity with phonological representations rather than to semantic knowledge.

A number of proposed language-based models of STM have incorporated strong relationships between temporary storage systems and language long-term representations in order to account for the influence of language representations on STM capacities described hereinabove (e.g., Acheson, Hamidi, Binder, & Postle, 2011; Acheson & MacDonald, 2009a; 2009b; Hickock, 2012; Majerus, 2009; 2013; N. Martin & Saffran., 1992; N. Martin et al., 1996; R. Martin et al., 1999). Most of these models suggest that during STM tasks, decaying temporary traces of the presented verbal information are generated in STM. These decaying STM traces are continuously reactivated through feedback activation from corresponding phonological or lexical-semantic language activations in LTM.

According to some other authors, verbal STM not only interacts with phonological and lexical-semantic language knowledge but has its own distinct temporary storage buffers for phonological and lexical-semantic information. This distinction between phonological and lexical-semantic STM is the core of the model proposed by R. Martin et al. (1999). The authors posit a phonological short-term store that is closely related to phonological language representations and that is distinct from another, lexical-semantic short-term store, which itself is closely connected to lexical-semantic language representations. This distinction is based on neuropsychological case studies of brain-damaged patients with relatively selective impairment of phonological or lexical-semantic information. For instance, R. Martin, Shelton, and Yaffee (1994) reported on two patients, EA and AB, both of whom showed reduced recall spans, but whose STM performance was differently affected by phonological and lexical-semantic variables. Patient EA had a selective impairment of phonological STM, showing reduced phonological effects on word span (i.e., no phonological similarity effect in the visual modality and no word length effect in either visual or auditory modalities) but normal effects of semantic variables (i.e., better word than nonword span). EA also performed a rhyme probe task, which taps phonological STM, and a category probe task, used to assess lexical-semantic STM. The results showed that EA's performance was more impaired on the rhyme probe task than on the category probe task, whereas healthy adult controls showed a substantial advantage on the rhyme probe task. AB's performance, in contrast, was worse on the category probe task than on the rhyme probe task. Another patient, ML, showed the same pattern of results as AB (R. Martin & Lesch, 1996). The study of Majerus et al. (2004) on three patients who had recovered from Landau-Kleffner syndrome offered further evidence of selective impairment of phonological STM. The patients showed reduced phonological effects (i.e., word length, phonological similarity, phonotactic frequency) but normal lexical-semantic effects (lexicality, word frequency, word imageability) on STM, and their performance was impaired on a rhyme probe task but normal on a category probe task.

Functional neuroimaging studies have also provided evidence of a dissociation between phonological and lexical-semantic STM. In the study of Hamilton and Martin (2012) healthy participants were asked to indicate whether a probe word was synonymous with one of the words previously presented in a list. The brain areas activated were the left middle frontal gyrus and the left inferior frontal gyrus. By contrast, when their participants were asked to judge whether a probe word rhymed with one of the words previously presented in a list, activation was seen in the precentral gyrus, along with smaller activations in the inferior parietal lobe and the supramarginal gyrus. Thus, lexical-semantic and phonological STM tasks activated distinct areas, suggesting that processing for the two may indeed involve different brain areas.

The studies mentioned above suggest that phonological and lexical-semantic information may be stored in distinct STM buffers. However, these dissociations are based on relatively few cases in the literature. Moreover, Majerus et al. (2004) noted that even in the double dissociations reported in the STM literature, the patients were impaired in both phonological and lexical-semantic STM, with the claim of a dissociation between the two STM buffers based on relatively greater impairment on one of the two types of task, either the rhyme or the semantic probe task. For instance, R. Martin et al.'s (1994) patient EA had a rhyme probe span of 2.65 and a category probe span of 2.82, while the corresponding figures for patient AB were 4.62 and 2.19; control participants had rhyme and category probe spans above 5. Thus, the question of whether it is possible to have a full double dissociation between phonological and lexical-semantic STM capacities—one STM buffer impaired and the other completely preserved—remains open.

In this study, we conducted a neuropsychological double case study on two aphasic patients, BN and TM. We aimed to provide further evidence of a dissociation between phonological and lexical-semantic STM components, as suggested by the STM model of R. Martin et al. (1999). We expected to find selective impairment of one STM buffer and the complete preservation of the other.

Both aphasic patients presented word production impairment, a very frequent type of dysfunction in aphasia, characterized by the production of paraphasias, circumlocutions, non-responses, the use of indefinite terms (e.g., “thing”), abnormally long response latencies, and inappropriate pauses (e.g., in the middle of a sentence). We explored these difficulties with a picture description task and a picture naming task. Models of speech production generally suggest that word-finding difficulties can result from one or several lesions within the language system. Although word retrieval models vary in their specific architecture, a common feature of various conceptualizations is their differentiation of at least two major stages of word production: lexical-semantic activation and sublexical phonological activation (Goldrick & Rapp, 2007; Laine & N. Martin, 1996; Levelt, Roelofs, & Meyer, 1999; Wilshire, Keall, Stuart, & O'Donnel, 2007). During lexical-semantic selection, the speaker retrieves an abstract lexical-semantic representation of the word that best matches the concept to be expressed, which does not yet specify its form. During sublexical phonological encoding, the speaker generates a complete phonological plan for the word to be produced. These representations contain the phonological information required to engage subsequent articulatory and motor processes. Recent research has used this two-stage framework to analyze word production deficits in aphasic patients. A lexical-semantic impairment leads to semantic and/or other whole-word errors in word production. A patient with a deficit at this stage will be affected by word frequency and age of acquisition. A sublexical phonological impairment leads to phonological errors and induces particular sensitivity to word length (e.g., Goldrick & Rapp, 2007; Laine & N. Martin, 1996; Laine & N. Martin, 2006; Wilshire et al., 2007).

Our second aim was to assess the relationship between our patients' word production impairment and their STM performance. As many language-based STM models suggest (e.g., Acheson et al., 2011; Acheson & MacDonald, 2009a; 2009b; Hickock, 2012; Majerus, 2009; 2013; N. Martin & Saffran., 1992; N. Martin et al., 1996; R. Martin et al., 1999), there are strong relationships between language representations and STM and between language impairment and STM deficits. Moreover, some authors have suggested that there is a relationship between impaired language production and STM deficits, but this relation stands in need of further investigation. For instance, in a study of patients with language production impairment, Knott et al. (1997; 2000) showed that the patients had better recall for lists made up of words that they were still able to name on a picture naming task than for lists of words that they could no longer produce. R. Martin et al. (1999) further suggested that selective impairment within the language production system may be related to selective STM impairment. They reported a patient, MS, with lexical-semantic production impairment, who experienced severe difficulties on picture naming tasks, especially for low-frequency words. When MS was unable to name a picture, he produced a long description of the object (circumlocution). The patient’s language deficit had a negative impact on his STM performance and led to impaired lexical-semantic STM performance—indeed, he showed no lexicality effect in serial recall. MS also produced the same circumlocutions on serial recall tasks as on naming tasks. Finally, he was less likely to succeed at recalling specific items that he failed to produce on picture naming tasks than to recall items that he successfully named. In the present study, we tested the relationship between language production impairment and STM more thoroughly. We hypothesized that impaired naming induced by a phonological deficit may be accompanied by impaired phonological STM, but preserved lexical-semantic STM, and that, conversely, a word production deficit due to lexical-semantic impairment may be linked to impaired lexical-semantic STM and preserved phonological STM.

To test these hypotheses, BN and TM were submitted to an extensive evaluation of their phonological and lexical-semantic STM abilities. The integrity of the patients’ phonological STM was assessed using a rhyme probe task, which has been widely used in the STM literature (e.g., Freedman & R. Martin, 2001; Hamilton & R. Martin, 2012; Majerus et al., 2004; R. Martin et al., 1994; 1999). The preservation of lexical-semantic STM was tested using a category probe task (e.g., Freedman & R. Martin, 2001; Hamilton & Martin, 2012; Majerus et al., 2004; R. Martin et al., 1994; 1999). The influence of sublexical phonological language representations on STM was assessed by comparing recall of high and low phonotactic frequency nonwords (phonotactic frequency effect). The influence of lexical-semantic language representations on STM was assessed by comparing performance on immediate serial recall (ISR) tasks for words and nonwords (lexicality effect) and for high- and low-frequency words (word frequency effect). According to language-based models of STM, patients with phonological impairment cannot rely on phonological representations to boost recall and such patients should therefore show no phonotactic frequency effect. If lexical-semantic representations are preserved, word frequency and lexicality effects should be normal. On the other hand, in case of lexical-semantic impairment, given that lexical-semantic representations cannot boost recall, word frequency and lexicality should not affect recall performance. If phonological representations are intact, there should be a normal phonotactic frequency effect (e.g., Jefferies et al., 2008; Knott et al., 1997; 2000; Majerus et al., 2004; R. Martin et al., 1999; Reilly et al., 2012). Some authors have also suggested that in case of selective impairment, patients may show an over-reliance on the preserved system. On this view, patients with a phonological impairment may show hypersensitivity to lexical-semantic variables such as word frequency or lexicality, while patients with selective lexical-semantic impairment may show hypersensitivity to phonological variables such as phonotactic frequency (e.g., Knott et al., 2000; Reilly et al., 2012).

Case descriptions

Patient BN

Patient BN, aged 62 at the time of testing, is a French-speaking, right-handed woman with 16 years of formal education. She had previously worked as a teacher of English and Dutch in a secondary school. In August 2011, she suffered from an ischemic stroke in the superficial territory of the left middle cerebral artery. A computerized tomography (CT) scan performed in September 2011 indicated cortical and subcortical damage to the left temporo-parietal area as well as sequelae consisting of porencephalic cavities in the right occipital and frontal areas, affecting the corona radiata and the insular lobe. An initial language evaluation in September 2011 showed that the patient was conscious of her language difficulties. She presented word-finding difficulties both in spontaneous language and on a picture naming task (1/10). Her repetition capacities were also impaired: she successfully repeated 1/5 phonemes, 5/10 syllables, 1/10 nonwords and 6/10 words, with greater difficulty repeating long words. She produced phonological paraphasias, repetitive self-correction and neologisms. BN’s word comprehension abilities were preserved (8/9 words), as was her ability to understand short sentences (30/32), but her comprehension of long and grammatically complex sentences (i.e., passive and relative sentences) was impaired (10/16). Finally, the speech therapist also noted that BN showed a reduced STM span (digit span of 3), which has contributed to her impaired performance on repetition tasks and with long and complex sentences. BN began treatment for her language difficulties in September 2011 at the Neuropsychological Rehabilitation Unit of the University Hospital of Liège in Belgium.

Shortly before participating in the study (January 2012), BN was re-examined by her speech therapist. Her sentence comprehension was relatively good (short sentences: 31/32, long and grammatically complex sentences: 14/16). She still had word-finding difficulties, both in spontaneous language and on a picture naming task (28/45), producing phonological paraphasias, repetitive self-correction and neologisms. Her repetition capacities had recovered but remained impaired: she successfully repeated 5/5 phonemes, 5/5 syllables, 4/8 nonwords and 6/8 words. Nevertheless, she dropped out of treatment in March 2012.

Patient TM

TM is a 59-year-old, French-speaking, right-handed man with 16 years of education. He previously worked as a physical education teacher and as a lifeguard in a public swimming pool. In April 2006, he suffered from a left-hemisphere hemorrhagic stroke. An initial CT scan indicated a left frontal intracerebral hematoma with tetraventricular flooding. He was admitted to surgery to drain the hematoma. A second CT scan in June 2006 indicated cortical-subcortical damage affecting the left frontal-parietal areas and the left frontal horn. A third CT scan in September 2006 did not show any evolution in the aforementioned lesions. TM also had an epileptic seizure in July 2006, and an EEG indicated left fronto-temporal damage. His epilepsy was treated, and he is no longer taking antiepileptics.

In April 2006, TM’s speech was agrammatical, and he presented marked word-finding difficulties both in spontaneous language and on a picture naming task (4/31). He produced semantic paraphasias, circumlocutions, perseverations and omissions (i.e., non-responses). He also produced phonetic paraphasias due to a mild dysarthria. TM’s word comprehension was impaired (3/9), and a sentence comprehension assessment could not be performed. His aphasia was treated in the Neuropsychological Rehabilitation Unit of the University Hospital of Liège between 2006 and 2007. In April 2007, a language assessment indicated that TM’s language production and comprehension capacities had improved. He scored 34/45 on a picture naming task and presented a frequency effect. TM’s comprehension of words (9/9) and short sentences (29/32) was good, but he had difficulties with long and grammatically complex sentences (10/16). His repetition of phonemes (5/5), words (8/10) and nonwords (8/10) was within the normal range but he produced two phonetic paraphasias and two lexicalizations of nonwords. His repetition of long sentences was impaired (2/4), and he still produced semantic paraphasias, circumlocutions, perseverations, omissions and phonetic paraphasias. He also suffered from attentional and STM difficulties (digit span of 3), which affected his repetition and sentence comprehension capacities. TM also presented motor difficulties in the form of a right hemiplegia.

In May 2009, TM suffered from a second left-hemisphere hemorrhagic stroke affecting the frontal lobe, which did not leave him with any new language or motor deficits.

TM was re-examined shortly before participating in the study (March 2012). His word and sentence comprehension were relatively good (short sentences: 31/32, long and grammatically complex sentences: 12/16). He still had word-finding difficulties and produced semantic paraphasias, circumlocutions, perseverations and phonetic paraphasias due to his mild dysarthria. On a repetition test, he successfully repeated 5/5 phonemes, 9/10 syllables, 6/8 nonwords and 6/8 words.

Control participants

Each patient's performance was compared to that of a group of 15 healthy adults matched for age (mean age: 60.13; range: 55-65 years), socio-economic level and years of education (all had a total of between 14 and 17 years of education). The participants responded to a questionnaire on their health, and reported no history of neurological, cardiac, neuropsychological or psychiatric disorders, and no uncorrected hearing or visual problems. All participants were native speakers of French. They had been recruited from the general adult population in the Wallonia-Brussels Federation in Belgium. Each participant gave written informed consent before participating in the study.

Methods and results

General procedure

The test sessions reported here took place in February 2012 for BN and in March 2012 for TM. The whole study was conducted in French. The participants were tested individually. The order of the tasks was constant across participants: (1) Picture naming task, (2) Pyramids and Palm Trees Test, (3) Minimal pair discrimination task, (4) Rhyme probe task, (5) Nonword delayed repetition task, (6) Picture description task, (7) Word and nonword ISR, (8) Synonym judgment task, (9) Spoken word-to-picture matching task, (10) High- and low-frequency word ISR, (11) Category probe task. The experiment was performed in five one-hour sessions with BN and TM and in two one-hour sessions with the control participants.

Each patient’s performance was compared to that of the control group using modified *t*-tests (Crawford, Garthwaite, & Porter, 2010). Modified *t*-tests offer an inferential estimate of the distance between the score in a single case and the range of scores of the control group estimated at the population level. A $p < .05$ indicates individual performance significantly outside the control range (i.e., performance at least two standard deviations below or above the mean performance of the control group, for a two-tailed significance test).

Receptive language capacities

Tasks.

Participants’ phonological analysis ability was assessed with a minimal pair discrimination task, and their oral word comprehension was explored using a spoken word-to-picture matching task with phonological distractors.

Minimal pair discrimination task.

This task (adapted from Majerus, Lekeu, Van der Linden, & Salmon, 2001) consisted in the auditory presentation of 56 pairs of consonant-vowel syllables, consisting of the vowel /a/ combined with the consonants /b/, /d/, /f/, /g/, /k/, /l/, /m/, /n/, /p/, /t/, /v/, via headphones connected to a PC. Half of the syllable pairs were identical (example: /va-va/) and half were different (example: /ga-pa/). On “different” trials, the syllable pairs differed by the initial consonant. The participants were asked to indicate whether a pair of syllables were the same or different by pressing a designated key. This task was programmed and presented with the E-Prime 2.0 software (Psychology Software Tools). The percentage of correct responses was computed.

Spoken word-to-picture matching task with phonological distractors.

On this task (*Batterie longue d’évaluation du langage* [Long language evaluation battery], University of Liège and Catholic University of Louvain), each of the spoken words was presented along with a set of 5 pictures: the target and 4 phonological distractors, each differing from the target by one phoneme (example: /dwa/, /rwa/, /nwa/, /twa/, /pwa/, meaning “finger”, “king”, “nut”, “roof”, “pea”). Lip reading was prevented. There were 4 plates of 5 pictures, with 4 trials per plate. All targets and distractors were monosyllabic words, and the position of the differing phoneme varied: on half of the plates the differing phoneme was word-initial, and on the other half it was word-final. The participants were asked to point to the picture corresponding to the spoken word. The percentage of correct responses was computed.

Results.

BN and TM performed within the control range on the minimal pair discrimination task, modified t (19) = 1.63, $p = .12$ and modified t <1 respectively, and gave 100% correct responses on the spoken word-to-picture matching task with phonological distractors, both modified t <1. These results are summarized in Table 1.

(Insert Table 1 here)

Semantic capacities

Tasks.

The participants' semantic abilities were assessed using two tasks chosen to tap different aspects of semantic knowledge through different modalities: the Pyramids and Palm Trees Test (Howard & Patterson, 1992), in a version requiring participants to match together pictures of objects, and a synonym judgment task (adapted from Majerus et al., 2001), which requires the semantic processing of abstract and concrete auditory words.

The Pyramids and Palm Trees Test.

Participants were presented 52 plates of three object-pictures each, with one picture placed above the other two. They were asked to indicate which of the bottom two pictures had the closest semantic relationship to the top picture. Three additional plates were used as warm-ups and were not included in the scoring. The percentage of correct responses was computed.

Synonym judgment task.

Sixty pairs of concrete and abstract words were presented orally, and the participants' task was to decide whether the words of a pair had similar meanings. The pairs were matched for imageability (Desrochers & Bergeron, 2000). Three additional trials were used as warm-ups and were not included in the scoring. The percentage of correct responses was computed.

Results.

Both patients performed normally on the Pyramids and Palm Trees Test, both modified $t < 1$, and on the synonym judgment task, both modified $t(19) = 1.14$, $p = .27$ (see Table 1).

Language production assessment

Tasks.

Picture description task.

Participants were administered The Cookie Theft picture description task from the Boston Diagnostic Aphasia Examination (Goodglass, Kaplan, & Barresi, 2000), a task that is widely used in the study of aphasia and that is considered to be an ecologically valid approximation of spontaneous discourse (Williams et al., 2010). In this task, participants are asked to describe a black and white picture depicting a complex household scene, which includes a child stealing cookies from a high shelf. The test session was recorded and transcribed for analysis. We focused on evidence of word-finding difficulties by analyzing the type of errors produced, the presence of inappropriate pauses (e.g., in the middle of a sentence) and the use of indefinite terms (e.g., “thingy”).

Picture naming task.

We also presented a picture naming task because it provides a well-controlled situation in which a specific lexical item must be retrieved, and thus minimizes the participant's chances of concealing a deficit with circumlocutory responses (Laine & N. Martin, 2006). Moreover, this task allowed us to analyze the effects of psycholinguistic variables such as word frequency, age of acquisition and length, as well as the patients' patterns of naming errors, in order to collect evidence about the possible locus of their word-finding impairment.

We selected 134 black and white line drawings from the set of Bonin, Peereman, Maladier, Méot, and Chalard (2003). Bonin et al. reported a name agreement percentage for each picture, consisting of the percentage of participants who produced the most common name. On the basis of these results, we selected pictures with a name agreement higher than 60%. In the present study, each picture was presented centered on the computer screen using the E-Prime 2.0 software. Participants were asked to name each picture as quickly as possible. The pictures were presented in a pseudo-randomized order. On each trial, a ready signal ("*") appeared at the center of the screen for 500 ms and was followed by a 100-ms tone, which ended at the onset of the picture. The experimenter then pressed a button to begin the next trial. Participants were given a short break after every 30 trials. Fifteen additional pictures were used as warm-ups. Standard phonemic and semantic cues were provided in case of naming failure.

The test session was recorded and transcribed for scoring. Accuracy was measured as the percentage of correctly named items. A response was counted as correct if the participant named the item correctly and spontaneously. Because name agreement on some of the pictures was as low as 60%, we accepted alternative names for the pictures with more than one acceptable name, in keeping with Bonin et al.'s (2003) list. The warm-up trials were not included in the score. Correct naming latencies were analyzed with the Audacity 1.2.6.

software (Mazzoni, 2006) and consisted of the latencies between the presentation of the picture and the correct and spontaneous naming of the items, without any cue.

To analyze the effects of word frequency, subjective age of acquisition and word length, we selected 54 out of the 134 drawings. All selected words were matched on these three variables. Word frequency values were obtained from the LEXIQUE database (New, Pallier, Ferrand, & Matos, 2001). We chose film frequency, which is an estimate of the number of occurrences of the word out of a total of one million in a corpus composed of subtitles from very recent television series and films (New, Brysbaert, Véronis, & Pallier, 2007). Twenty-seven low-frequency words (<5/million) and 27 higher frequency words (>10/million) were selected. Subjective age of acquisition estimates were obtained from Bonin et al. (2003). Participants in that study were asked to estimate the age at which they thought they had learned each of the names in its written or oral form. Morrison, Chapel, and Ellis (1997) showed that such subjective ratings correlate highly with objective measures derived from data on children's vocabulary knowledge ($r = .76$) and concluded that the ratings offer a valid reflection of the real age at which a word is typically learned. The five values on Bonin et al.'s (2003) age of acquisition scale corresponded to three-year age bands with 0-3 at one extreme and 12+ at the other. In our analysis, we divided these measures into two categories, choosing 27 early-acquired words (from 0 to 6 years) and 27 late-acquired words (from 7 to 12 years). Finally, for our analysis of the effect of word length, we selected 18 monosyllabic words, 18 bisyllabic words, and 18 trisyllabic words.

The taxonomy of naming errors was adapted from Au et al. (1995) and Laine and N. Martin (2006). We analyzed each erroneous response, even if the participant self-corrected afterwards. Each erroneous response was coded into one of the following 11 categories: (1) Semantic paraphasia: an erroneous response that is semantically related to the target word (i.e., superordinate, member of the same category, associative relationship across semantic boundaries); (2) Circumlocutions: a multiple-word response defining or describing the target object; (3) Formal paraphasia: a real-word erroneous response that shares at least 50 percent of its phonemes with the target; (4) Mixed errors: a response sharing both semantic and phonological features with the target; (5) Unrelated word: a real-word response with no evident relationship to the target word; (6) Visual error: an erroneous word that shares perceptual features with the target, but no semantic features; (7) Phonological paraphasia: an addition, deletion, substitution, transposition of phonemes in the target word, resulting in a nonword error that shares at least 50 percent of its phonemes with the target; (8) Neologism: a nonword error that shares less than 50 percent of its phonemes with the target; (9) Phonetic paraphasia: the erroneous production of phonemes in the context of non-fluent language, along with articulation difficulties. These errors may be the result of impaired speech motor control, and involve lenition, nasalization, deletion, approximation, and substitution of phonemes, an error in the voicing of a phoneme, or simplifications of complex syllabic structures. The result may even be a phoneme that does not exist in the patient's language; (10) Perseveration: the repetition of a previous correct or incorrect word; (11) Omission: the participant remains silent or indicates his/her inability to name with comments such as "I don't know", "No"…

Results.

On the picture description task, both BN and TM presented signs of word-finding difficulties. BN's speech was fluent, with correct articulation and prosody, but was interspersed with frequent episodes of word-finding difficulties. These difficulties were manifested by frequent inappropriate pauses (in the middle of a sentence), the use of indefinite terms (e.g.,"truc," meaning "thingy") and phonological paraphasias. She also produced repetitive self-corrections. TM's speech was very laborious and non-fluent. He had frequent word-finding difficulties, manifested by frequent inappropriate pauses (in the middle of a sentence), the use of indefinite terms (e.g.,“machin,” meaning “thing”) and semantic paraphasias. These word-finding failures caused TM’s speech to lack meaningful information. He also presented mild dysarthria, leading to phonetic paraphasias.

On the picture naming task, as indicated in Table 2, the performance of both BN and TM was impaired. The patients named significantly fewer items than control participants, with modified t (19) = -7.84, $p < .001$ and modified t (19) = -8.77 $p < .001$ for BN and TM respectively, and their correct naming latencies were longer than those of controls, with modified t (19) = 12.67, $p < .001$ and modified t (19) = 7.90, $p < .001$ for BN and TM respectively.

BN’s length effect (i.e., 1-syllable words named correctly more often than 3-syllable words) was greater than control participants, modified t (19) = 3.14, p=.007, as well as being longer than that of TM (see Table 2). By contrast, she presented no effect of word frequency or age of acquisition, and did not significantly differ from controls on either, with modified t (19) = -1.48, $p = .16$ and modified $t < 1$, respectively. Out of all of BN’s errors, 66.65% were phonological paraphasias, 10.25% were circumlocutions, 7.69% were semantic paraphasias, 7.69% were omissions (i.e., non-responses), 2.56% were neologisms and 12.82% were visual errors. BN also produced repetitive self-corrections. Finally, she showed no beneficial effect from phonemic cues (0%). Since BN’s errors were predominantly phonological paraphasias and since she presented a length effect, these data seem to indicate a word production deficit at the sublexical phonological level (e.g., Caplan & Waters, 1995; Shallice, Rumiati, & Zadini, 2000).

By contrast, TM presented effects of word frequency (i.e., correctly naming high-frequency words more often than low-frequency words) and age of acquisition (i.e., naming early-acquired words more successfully than late-acquired words) greater than those seen in control participants, with modified *t* (19) = 2.56, *p* =.02 and modified *t* (19) = 2.58, *p* =.02, respectively. These effects were also greater than in BN. Contrary to BN, TM did not present a length effect, modified *t* < 1. TM's errors were distributed as follows: 33% were omissions (i.e., non-responses), 27.02% were circumlocutions, 24.34% were semantic paraphasias, and 13.51% were phonetic paraphasias due to dysarthria, and 5.20% were visual errors. Finally, TM did benefit from a phonemic cue, with correct responses following the cue in 42.86% of cases. Since TM presented age of acquisition and word frequency effects, and a majority of TM's naming errors were circumlocutions and semantic paraphasias (51.36% of his errors fell into one of these two categories), we hypothesized that TM's naming impairment was due to a lexical-semantic deficit within the word production system (e.g., Goldrick & Rapp, 2007; Lambon Ralph, Sage, & Roberts, 2000).

(Insert Table 2 here)

Short-term memory assessment

Phonological and lexical-semantic STM : rhyme and category probe tasks

Tasks.

These tasks from Majerus et al. (2004) were based on the probe tasks of R. Martin et al. (1994; 1999). Sequences of 2 to 7 items were presented, followed by a probe word. In the rhyme condition, the participants were asked to judge whether the probe word rhymed with any item in the preceding list; in the semantic category condition, they were asked to judge whether the probe word belonged to the same semantic category as one of the words in the preceding sequence. Responses were given by pressing a designated key. There were 6 trials each of sequence lengths 2 and 3, and 7 trials each for sequence lengths 4 to 7. Each serial position was probed equally often. The prerecorded sequences were presented in ascending order of length, at a rate of one item per second, via headphones connected to a PC, using the E-Prime 2.0 software. For each sequence length and each condition, there were two non-matching probe trials and the remainder (4 for lengths 2 and 3, 5 for lengths 4 to 7) were matching probe trials. A greater number of matching probes was chosen because Majerus et al. (2004) showed in their pilot study that non-matching probes are very easily rejected, while the detection of matching items was more difficult and yielded more variable scores, thus increasing the sensitivity of the task. All words were bisyllabic and of medium frequency (mean: 1692/million for the rhyme probe and 2009/million for the category probe; Content, Mousty, & Radeau, 1990). The categories probed were animals, body parts, clothes, flowers, fruits, furniture, kitchen utensils, profession, tools, vegetables, and transportation. The names of the categories were presented to the participants before the presentation of sequences of lengths 2 and 3, but not for longer sequences, in order to keep participants from using a visual strategy consisting in visually remembering the categories that had already been presented. We computed the percentage of correct yes/no answers on each task by pooling over trials and sequence lengths. Four additional trials with sequence length 1 were used as warm-ups and were not included in the scoring. The aim of these warm-ups was to measure phonological processing ability because they represent a simple rhyme judgment with minimal STM demands. Both BN and TM gave 100% correct responses on both the rhyme and category probe tasks, all modified $ts < 1$. Then, from 2 to 7 items, STM load increases. In the rhyme probe task, the phonological traces of the rhyming word need to have remained activated in STM to make the rhyme judgment possible, while in the category probe task, semantic traces need to have remained activated in STM to allow the semantic category judgment.

These probe tasks have been widely validated in the literature for selectively maximizing the retention of phonological and lexical-semantic information in STM, known as distinct parts of item STM (e.g., Freedman & R. Martin, 2001; Hamilton & R. Martin, 2012;

Majerus et al., 2004; R. Martin et al., 1994; 1999). These tasks have been also shown to minimize the demands of other STM capacities, such as serial order (Majerus et al., 2004; Majerus, Poncelet, Elsen, & Van der Linden, 2006; Majerus, Poncelet, Greffe, & Van der Linden, 2006), another critical component of STM. Indeed, on the rhyme and category probe tasks, the participants had to focus only on whether the probe word rhymed with or belonged to the same category as one of the words in the sequence. The order of presentation of items did not matter. Moreover, Majerus, Poncelet, Greffe et al. (2006) reported that performance on these tasks did not correlate with performance on a serial order reconstruction task.

Results.

As indicated in Table 3, on the rhyme probe task, the test of the integrity of phonological STM, BN's performance was impaired, modified t (19) = -3.94, p = .001. By contrast, she performed normally on the category probe task, which tested the preservation of lexical-semantic STM, modified t (19) = -1.47, p = .16. TM, on the other hand, performed normally on the rhyme probe task, modified $t < 1$, but was impaired on the category probe task, modified t (19) = -2.88, p = .01.

(Insert Table 3 here)

Influences of language representations on STM

Tasks.

Delayed repetition of high and low phonotactic frequency nonwords.

This task (adapted from Majerus & Van der Linden, 2003) consisted of the auditory presentation of 30 high and low phonotactic frequency nonwords via headphones connected to a PC using the E-Prime 2.0 software. The stimuli had a CVC syllabic structure, and all were legal with respect to French phonotactic rules. The mean diphone frequency of the CV segments was 149 (range: 3-524) and the mean diphone frequency of the VC segments was 129 (range: 7-728), according to the database of French phonology by Tubach and Boë (1990). The nonwords were presented in random order. Each was presented in isolation, and followed by a 7-second delay during which the participant counted aloud backwards from 95. This counting task was used to prevent rehearsal during the maintenance delay. At the end of the delay, the experimenter tapped sharply on the desk, indicating that the participant should repeat the target nonword. There were 4 practice trials which were not included in the scoring. We determined the percentage of correctly recalled nonwords. The phonotactic frequency effect was determined by calculating the difference between the scores in the two list conditions.

This task assesses language phonological influences on STM (Majerus & Van der Linden, 2003) and maximizes the retention of phonological item information in STM. A new item was presented on every trial and all nonwords had the same monosyllabic CVC structure, with a predictable phoneme sequence, so that the main requirement was to retain phoneme identity to “fill in” the consonant and vowel positions. At the same time, the fact that the items were monosyllabic and presented in isolation minimizes the requirements for retaining serial order information (Majerus, Poncelet, Greffe et al., 2006).

Immediate serial recall tasks.

The influence of lexical-semantic knowledge on STM performance was assessed by analyzing lexicality and word frequency effects on ISR (see for example Jefferies et al., 2008; Knott et al., 2000; Majerus & Van der Linden, 2003; Majerus et al., 2004; R. Martin et al., 1999).

Lexicality effect.

Two separate lists of 60 monosyllabic CVC words and nonwords were presented (task adapted from Majerus et al., 2004). The words were of high frequency (>200/million; Content et al., 1990) and the nonwords differed from the words by one phoneme. The sequences ranged in length from 1 to 5 items and were presented in ascending order of length, with 4 trials per sequence length. All sequence lengths were presented. The experimenter read out the lists at a rate of one item per second. At the end of each trial, the participants were asked to recall the words in their order of presentation. We computed the percentage of words and nonwords recalled in correct serial position by pooling over trials and sequence lengths.[1] We also measured the lexicality effect (i.e., greater recall performance for words than for nonwords) by calculating the difference between the scores on the different list conditions.

Word frequency effect.

Two lists of 56 bi-syllabic words were constructed (task adapted from Majerus et al., 2004). The items in the two lists were matched for length. The frequency count for the high- and low-frequency lists was >10000 and <200/million respectively (Content et al., 1990). The sequence lengths ranged from 2 to 5. The presentation and recall procedures were the same as in the two other ISR tasks. We computed the percentage of high- and low-frequency words recalled in correct serial position by pooling over trials and sequence lengths.[1] We analyzed the word frequency effect (better recall performance for high-frequency words than for low-frequency words) by calculating the difference scores between the two list conditions.

Contrary to the other tasks, there were serial order requirements on the ISR tasks: the items had to be recalled in their correct order of presentation. However, as Majerus, Poncelet, Elsen et al. (2006) argued, because the items were sampled from an open pool and were new on every trial, this task puts greater demands on item than on serial order STM.

Results.

As shown in Table 4, which gives results from the test of the influence of phonological representations on STM performance, BN showed a reversed phonotactic frequency effect on the nonword delayed repetition task, modified *t* (19) = -3.64, *p* = .002. Thus, BN's STM performance did not seem to be influenced by phonological factors. BN performed below the control range in the high phonotactic frequency nonword condition, modified *t* (19) = -2.50, *p* < .03 but not on low phonotactic frequency nonwords, modified *t* (19)= -1.26, *p* = .23. By contrast, BN presented a normal lexicality effect on the ISR task for words and nonwords, modified *t* < 1, suggesting that lexical-semantic representations influenced her STM performance. BN also presented a higher word frequency effect than control participants, modified *t* (19) = 5.11, *p* < .001. In terms of her overall performance on the ISR tasks, BN was impaired on ISR for both words, modified *t* (19) = -3.06, *p* = .008, and nonwords, modified *t* (19) = -3.34, *p* = .005, as well as for both high-frequency words, modified *t* (19) = -3.06, *p* = .008, and low-frequency words, modified *t* (19) = -7.67, *p* < .001 (see Table 4).

By contrast, on the nonword delayed repetition task, a test of the influence of phonological representations on STM, TM showed a phonotactic frequency effect, modified *t* (19) = 4.52, *p* < .001, indicating that phonological factors influenced his STM performance, in contrast to BN. He also performed below the control range in the low phonotactic frequency condition, modified *t* (19) = -3.95, *p* = .001, but not in the high-frequency condition, modified *t* (19) = -1.98, *p* = .07. On the other hand, TM presented no lexicality effect on the word/nonword ISR task, significantly differing from controls, modified *t* (19) = -2.40, *p* = .02, suggesting that lexical-semantic representations did not influence TM's STM performance as they do in normal subjects. TM also showed a higher word frequency effect than control participants, modified t (19) = 5.45, $p < .001$. Finally, in terms of overall performance, TM was impaired on all ISR tasks and conditions (word ISR, modified t (19) = -5.95, $p < .001$; nonword ISR, modified t (19) = -3.14, $p = .005$; high-frequency word ISR, modified t (19) = -9.45, $p < .001$; low-frequency word ISR, modified t (19) = -14.64, $p < .001$; see Table 4).

(Insert Table 4 here)

We also analyzed the patients' errors. These errors were not compared to the control participants' errors. Indeed, the controls, either made very few errors, or mainly made non-responses. An analysis of BN's errors on the nonword delayed repetition showed that on high frequency nonwords, 75% were lexicalizations of nonwords and 25% were phonemic paraphasias. On low phonotactic frequency nonwords, BN's errors were only phonemic paraphasias. On the ISR tasks, we analyzed both item and order errors, consisting in repeating an item in the wrong serial position. Non-responses were not included. Indeed, the non-responses are difficult to interpret with regards to the processes responsible for these errors. On the ISR task for words, we counted 16.67 % phonemic paraphasias, 5.56% perseverations (i.e., repeating an item that has already been repeated), and 77.78% order errors. On the ISR for nonwords, 44.44% of BN's errors were phonemic paraphasias, 11.11% were lexicalizations, 11.11% were perseverations and 33.33 % were order errors. On the ISR for high frequency words, 7% of BN's errors were phonemic paraphasias, and 93% were order errors. On the ISR for low frequency words 38.46% of BN's errors were phonemic paraphasias and 61.54% were order errors.

An analysis of TM's errors on the nonword delayed repetition showed that on high frequency nonwords, 51.14% were phonetic paraphasias, 14.29% were perseverations and

28.57% were lexicalizations. For low phonotactic frequency nonwords, TM’s errors were mainly phonetic paraphasias (81.82%), along with 18.18% of perseverations. On the ISR task for words, we counted 15.79% perseverations, 5.26% phonemic paraphasias, and 78.94% order errors. On the ISR for nonwords, 33.33% of TM’s errors were phonetic paraphasias, 22.22% were lexicalizations, 18.51% were perseverations and 25.93% were order errors. On the ISR for high frequency words, 9.52 % of TM’s errors were phonetic paraphasias, 9.52% were perseverations and 80.95 % were order errors. On the ISR for low frequency words 100% of TM’s errors were order errors.

Discussion

The aim of this neuropsychological case study conducted on two aphasic patients was to provide further evidence on the hypothesized dissociability of phonological and lexical-semantic STM. This distinction was the hallmark of the STM model of R. Martin et al. (1999), and is currently based on relatively few case studies.

Our two patients presented word production difficulties, which is a pervasive pattern in aphasia. On the picture description task, both patients used many indefinite terms, made frequent inappropriate pauses, and frequently produced paraphasias. However, our findings indicate that the locus of defect responsible for the word production deficit differed between the two patients. On the picture description task and the picture naming task, the majority of BN’s errors were phonological paraphasias. Moreover, on the picture naming task, BN presented a length effect but no word frequency or age of acquisition effect. By contrast, TM’s predominant types of errors were semantic paraphasias and circumlocutions. Furthermore, TM presented word frequency and age of acquisition effects, but no length effect. We concluded that BN’s naming deficit may derive from an impairment in sublexical phonological language representation, while TM’s language production deficit is likely lexical-semantic (e.g, Caplan & Waters, 1995; Goldrick & Rapp, 2007; Lambon Ralph et al., 2000; Shallice et al., 2000).

Language-based models of STM have posited strong relationships between phonological and lexical-semantic language representations and STM (e.g., Acheson et al., 2011; Acheson & MacDonald, 2009a; 2009b; Hickock, 2012; Majerus, 2009; 2013; N. Martin & Saffran, 1992; N. Martin et al., 1996; R. Martin et al., 1999) and some authors have argued that damage to representations involved in language production should also have a negative impact on STM performance (e.g., Knott et al., 1997; 2000; R. Martin et al., 1999). Moreover, R. Martin et al. (1999) also suggested that selective impairment within the language system may be accompanied by a related selective form of STM impairment. Therefore, our second aim was to assess the relationship between our patients' word production impairment and their STM performance. We hypothesized that selective phonological naming impairment may be accompanied by selective phonological STM impairment with preserved lexical-semantic STM and that a selective lexical-semantic language production deficit may be accompanied by impaired selective lexical-semantic STM with preserved phonological STM.

The patients' STM performance was carefully investigated. The rhyme and category probe tasks assessed the integrity of phonological and lexical-semantic STM respectively. BN presented phonological STM impairment, as shown by her impaired performance on the rhyme probe task, but completely normal lexical-semantic STM, as measured by the category probe task. By contrast, TM's lexical-semantic STM was impaired, with degraded performance on the category probe task, but his phonological STM was preserved, as reflected by his normal results on the rhyme probe task. The results here thus seem to indicate a double dissociation between phonological and lexical-semantic STM, and therefore support the framework of R. Martin et al. (1994; 1999). Previously, this dissociation has been defended on the basis of double dissociation studies with patients who were impaired on both rhyme and category probe tasks, but whose impairment was greater on one of these types of STM task than the other (e.g., R. Martin et al., 1994). In our study, we found a stronger double dissociation on these tasks, with impairment on the rhyme or category probe task and completely preserved performance on the other task.

On the ISR for words and nonwords and for high- and low-frequency words, the patients’ overall performance was less dissociated than on the rhyme and category probe tasks, as indicated by the data presented in Table 4. We hypothesize that these results can be explained by the presence of a serial order deficit in both patients. Indeed, the errors that both BN and TM produced on this task were mainly order errors. Because the ISR tasks also included serial order requirements, they offer a less “pure” assessment of item STM than the other STM tasks we used. In order to confirm this assumption, we analyzed patients’ performance on two serial order STM tasks. The first task was a digit serial order reconstruction task (see details in Majerus, Poncelet, Van der Linden, & Weekes, 2008). Participants were auditorily presented sequences of digits (length 3 to 8). At the end of each trial, the participants were given cards on which the digits presented during the sequence were printed and they had to sort the cards according to their order of presentation. On the digit serial order recognition task (see details in Majerus et al., 2009), participants had to judge whether or not two lists of digits (length 3 to 8), presented auditorily, were presented in the same order. On both tasks, the stimuli were known in advance—the participants were told which items would be presented on each trial, and on the digit serial order reconstruction, the digits were also provided at recall. These precautions minimized item phonological or lexical-semantic STM requirements. By contrast, the requirement to retain order information was maximized on both tasks. The results confirmed the presence of serial order impairment in both BN and TM. On the digit serial order reconstruction task, BN gave 47.22% correct responses, modified t (19) = -3.59, p = .001, and TM gave 54.37% correct responses, modified *t* (19) = -2.98, *p* = .007 (*Mean of the controls* = 88.85; *SD* = 11.31). On the digit serial order recognition task, BN gave 59.52% correct responses, modified *t* (19) = -4.74, *p* < .001, and TM gave 64.29% correct responses, modified *t* (19) = -3.87, *p* = .001 (*Mean of the controls* = 85.56; *SD* = 5.36).

Moreover, TM's impaired results with low phonotactic frequency nonwords are quite surprising given that this task involves phonological STM and is supported by phonological language representations, which are preserved in this patient. While analyzing TM's errors, we discovered that TM produced mainly phonetic paraphasias on this type of nonwords. These paraphasias are due to TM's mild dysarthria, and are present on low phonotactic frequency nonwords because these items have less support from phonological language representations than high phonotactic frequency nonwords, and are consequently more difficult to pronounce.

Thus, TM's weaker performance on the delayed repetition of low phonotactic frequency nonwords seems to be due to dysarthria rather than a phonological STM deficit. Moreover, as mentioned above, on the ISR tasks, BN and TM's serial order STM impairment may have interfered with their overall performance. By contrast, the rhyme and category probe tasks have been widely shown in the literature to be effective in selectively assessing phonological and lexical-semantic STM, without requiring other forms of STM processing such as order STM (e.g., Freedman & R. Martin, 2001; Hamilton & R. Martin, 2012; Majerus, Poncelet, Greffe, et al., 2006; Majerus, Poncelet, Elsen, et al., 2006; Majerus et al., 2004; R. Martin et al., 1994; 1999). We thus consider that these tasks offer a reasonably pure assessment of phonological and lexical-semantic STM respectively. These considerations lead us to believe that the patients' dissociated results on these tasks suggest a relatively pure double dissociation between phonological and lexical-semantic STM.

Moreover, the analyses of the influences of language representations on STM on both the nonword delayed repetition task and the ISR tasks for words and nonwords reveal dissociated profiles. This pattern reinforces the evidence of the close relationship between language processing and STM, which is currently based on a small set of cases in the literature (e.g., Knott et al., 1997; 2000; R. Martin et al., 1999; Reilly et al., 2012). BN did not present the expected phonotactic frequency effect on the nonword delayed repetition task, which seems to indicate that, due to her phonological impairment, phonological language representations did not influence her recall performance. By contrast, her normal lexicality effect on ISR indicated that she still relied on her unimpaired lexical-semantic representations for recall. On the other hand, given his lexical-semantic language impairment, TM could not rely on lexical-semantic representations for recall, and indeed he presented no lexicality effect. He did, however, present a phonotactic frequency effect, indicating that he could still rely on his phonological representations for recall. As previously indicated in the STM literature (e.g., Knott et al., 2000; Reilly et al., 2012), in case of selective impairment of language representations, some patients may show an over-reliance on the intact representations and be more sensitive to related variables. This hypothesis could account for BN's reversed phonotactic frequency effect on the nonword delayed repetition task. Because BN mostly relied on her unimpaired lexical-semantic representations to perform the task, she produced many lexicalizations of nonwords. Indeed, 76.9% of her errors were lexicalizations. Given that high phonotactic frequency nonwords are closer to existing words, they were more susceptible to being lexicalized, and thus incorrectly recalled by BN, than nonwords of low phonotactic frequency.

Furthermore, on the ISR tasks, both patients also produced many paraphasias. BN's item errors were mainly phonemic paraphasias, as on the language production tasks. TM's errors were phonetic paraphasias. The fact that the same errors were produced both in language production and on the STM tasks reinforce the hypothesis of a relationship between the two processes.

Some methodological limitations of the present study should be noted. First, in order to confirm the relationship between language and STM deficits, it would have been of interest to use the same items in both our language and STM tasks. This methodology would have allowed us to establish that the same items would have been well processed or not, offering stronger evidence of the link between the two (e.g., Knott et al., 1997; 2000; R. Martin et al., 1999).

Second, the use of a secondary task during the maintenance delay on the nonword delayed repetition task introduced an additional variable in comparison with the other STM tasks, which are “passive” STM tasks that simply require the decoding and maintenance of the memoranda. The secondary task may have recruited additional attentional resources, making this task less “passive” than the others. Therefore, we cannot rule out the possibility that the participants’ attentional capacities played a role in the results obtained on this task.

Finally, the effect of frequency on the ISR tasks also requires further discussion. As in the studies of Jefferies et al. (2008); Knott et al. (2000); Majerus and Van der Linden (2003); R. Martin et al. (1999) and Reilly et al. (2012), we had assumed that frequency effects on ISR reflect the influence of lexical-semantic language representations on STM. However, according to other authors, the loci of frequency effects are more widespread, and such effects may reflect the influence of both lexical-semantic and phonological levels of language representations (e.g., Ellis & Lambon Ralph, 2000; Hodgson & Ellis, 1998; Kittredge, Dell, Verkuilen, & Schwartz, 2008)—despite the fact that some phonological STM deficit patients do not show frequency effects (see e.g., R. Martin et al., 1994). We assume that this higher frequency effect is due to over-reliance on the intact representation system. However, it would be of interest to further examine the frequency effect on ISR tasks and its relation to language phonological or lexical-semantic impairment.

In conclusion, our study revealed a double dissociation between phonological and lexical-semantic STM. These data support STM models that postulate separate phonological and lexical-semantic short-term stores, such as that of R. Martin et al. (1994; 1999). Furthermore, our data provide further evidence that selective short-term memory impairment may be related to selective word production deficits.

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There are no conflicts of interest affecting this manuscript.

Footnotes

[1] If the participant forgot an item but recalled the other items in the correct serial position, the participant had to give the position of the missed item to be credited with a point for the recalled items.

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Table 1

Performance (percentage correct) on language reception and semantic tasks

	BN	*TM*	*Controls*		
			Mean	SD	Range
Language reception					
Minimal pair discrimination	96.43	100	99.52	1.84	92.86 - 100
Spoken word-to-picture matching	100	100	100	0	100 - 100
Semantic					
Pyramids and Palm Trees	98.08	96.15	97.44	2.88	90.39 - 100
Synonym judgment task	100	100	96.89	2.66	90.00 - 100

Table 2

Picture naming task performance

	BN	*TM*	*Controls*		
			Mean	SD	Range
Accuracy (%)	56.72*	52.24*	94.28	4.64	84.33 - 100
Correct naming latencies (ms)	4464*	3328*	1447.16	230.56	1120.14 - 1803.87
Psycholinguistic variables					
Frequency					
Low (%)	55.56*	70.37*	92.83	3.83	85.19 - 96.30
High (%)	55.56*	81.84*	97.04	3.49	88.89 - 100
Frequency effect	0	11.47*	4.20	2.75	0 - +7.41
Age of Acquisition					
Early acquired (%)	55.56*	77.78*	93.83	5.88	85.19 - 100
Late acquired (%)	55.56*	66.67*	94.07	6.49	77.78 - 100
Age of acquisition effect	0	11.11*	-0.25	4.30	-11.11 - +7.41
Length					
1 syllable (%)	72.22*	72.22*	93.70	7.53	77.78 - 100
3 syllables (%)	44.44*	72.22*	92.22	7.21	77.78 - 100
Length effect (%)	27.78*	0	-1.48	9.02	-16.67 - +11.11

Note. * Indicates performance significantly different from controls (Crawford et al., 2010).

Table 3

Performance (percentage correct) on the rhyme probe task and on the category probe task

	BN	*TM*	*Controls*		
			Mean	SD	Range
Rhyme probe task (%)	72.73*	86.36	88.33	3.83	81.82 - 93.18
Category probe task (%)	75	65.91*	84.55	6.27	72.73 - 95.46

Note. * Indicates performance significantly different from controls (Crawford et al., 2010).

Table 4

Performance (percentage correct) on the nonword delayed repetition task, the ISR of words and nonwords and the ISR of high- and low-frequency words

	BN	*TM*	*Controls*		
			Mean	SD	Range
Nonword delayed repetition					
High-frequency nonwords	46.67*	53.33	78.67	12.40	60 - 100
Low-frequency nonwords	60.00	26.67*	75.56	12.00	53.33 - 93.33
Phonotactic frequency effect	-12.33*	26.66*	5.07	4.66	0.00 - +13.33
ISR					
Word ISR	61.67*	40.00*	84.56	7.25	68.33 - 93.33
Nonword ISR	36.67*	38.33*	61.20	7.11	50.00 - 73.33
Lexicality effect	25	1.67*	18.44	6.80	11.67 - +38.33
High-frequency word ISR	78.57*	42.86*	95.83	5.47	85.71 - 100
Low-frequency word ISR	53.37*	16.07*	94.40	5.22	85.71 - 100
Word frequency effect	25.20*	26.79*	1.43	4.54	-5.35 - +14.29

Note. * Indicates performance significantly different from controls (Crawford et al., 2010).