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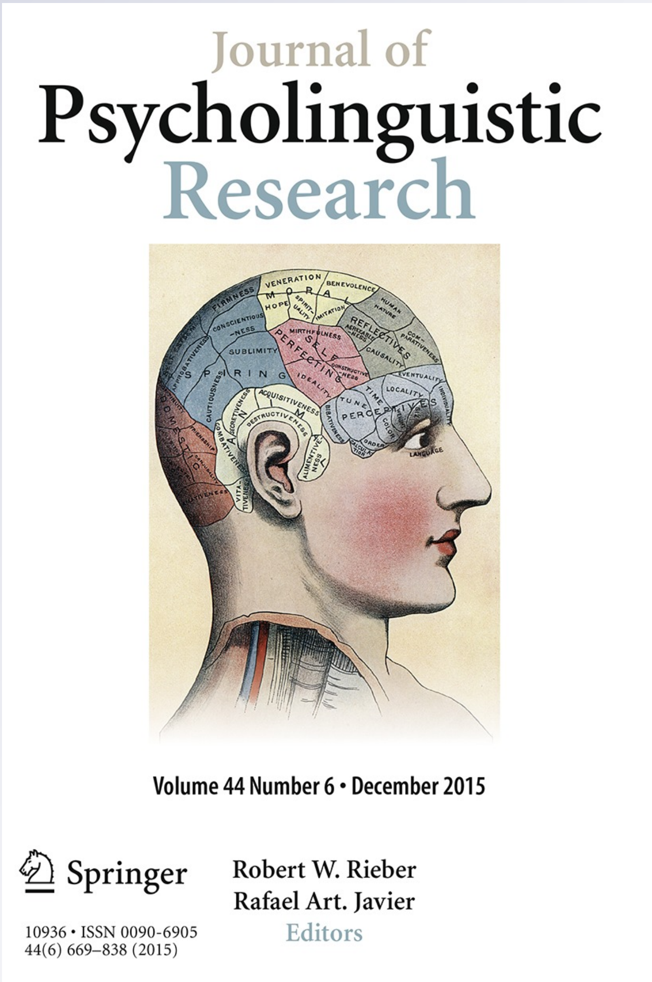

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Verbal Neuropsychological Functions in Aphasia: An Integrative Model

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Abstract A theoretical framework which considers the verbal functions of the brain under a multivariate and comprehensive cognitive model was statistically analyzed. A confirmatory factor analysis was performed to verify whether some recognized aphasia constructs can be hierarchically integrated as latent factors from a homogenously verbal test. The Brief Aphasia Evaluation was used. A sample of 65 patients with left cerebral lesions, and two supplementary samples comprising 35 patients with right cerebral lesions and 30 healthy participants were studied. A model encompassing an all inclusive verbal organizer and two successive organizers was validated. The two last organizers were: three factors of comprehension, expression and a "complementary" verbal factor which included praxia, attention, and memory; followed by the individual (and correlated) factors of auditory comprehension, repetition, naming, speech, reading, writing, and the "complementary" factor. By following this approach all the patients fall inside the classification system; consequently, theoretical improvement is guaranteed.

Keywords Acute aphasia · Early diagnosis · Language functions · Modeling · Validity

Introduction

Broca and Wernicke were pioneers in the development of language neuropsychology and aphasia research. However, from 1861 to date, not enough progress has been done in relation

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to aphasia theoretical and technical consistency (Crary and Wertz 1992; Crockett et al. 1981; Crosson et al. 2007; Démonet et al. 2005; Devido-Santos et al. 2012; Grodzinsky 2006; Judas and Cepanec 2007; Keller et al. 2009; Kuest and Karbe 2002; Poeppel and Hickok 2004; Price et al. 2011; Rohrer et al. 2008; Roth 2002; Smits et al. 2012).

The attempt of classifying aphasia symptoms and syndromes involves major methodological challenges in neuropsychology because verbal language is a complex function and its categories and sub-categories need to be clearly defined in order to be related to its biological conditions. Studying the presence and magnitude of both a general verbal deficit and its specific symptoms is part of the aphasia diagnosis. This is so, independently of the age and etiology of the condition.

A general and dominant verbal language dimension mainly associated to severity of impairment has been recognized in some factor analyses of aphasia tests (Cohen et al. 1977; Crockett et al. 1981; Schuell et al. 1962; Shewan and Kertesz 1980; Viglieсca et al. 2011b). Nevertheless, and in order to identify more specific verbal impairments from such general dimension, an analysis of higher order is necessary. For instance, if a battery consists of tests, then the test components can be analyzed trying to find in this way the proposed sub-categories. Once such more specific verbal dysfunctions (i.e. the basic verbal constructs or symptoms) have been identified, the next step will be to study whether some particular combinations of symptoms are more relevant than others to deserve being considered as typical. Unfortunately, most of the clinical definitions of typical syndromes have passed down from generation to generation based on tradition and agreement rather than on demonstration.

Aphasia classification by symptoms and syndromes remains ambiguous. Part of this ambiguity is due to the lack of valid definitions for the symptoms.

The notion of bio-physiological dimensions for verbal language (and aphasia) involves the notion of neuropsychological functions and the need of validation.[1] Although the interaction between the verbal system and its constitutive parts is not certainly simple, confirmatory factor analysis (CFA) with structural equation modeling may turn out a fertile approach in the attempt to find theoretically plausible neuropsychological patterns. Factor analysis is a useful statistical tool which helps to verify, for example, the content and conceptual validity of a theoretical proposal, i.e., whether some observed measures can be satisfactorily explained by hypothetical factors. Unlike exploratory factor analysis, where individual factors are searched for the first time, CFA not only examines the individual factors, but also their organization in one specific way. This is so because there are antecedents which suggest that those factors/patterns exist and can explain the observed measures. Factors denote the underlying constructs which account for the relationship among variables. Like exploratory factor analysis, CFA with structural equation modeling is based on linear relationships.[2]

The present work is about aphasia and the verbal neuropsychological functions in aphasia. CFA was only used as the statistical tool for verifying the validity of those functions and their organization.

There are no studies for adults which have used CFA to investigate whether several well-known aphasia neuropsychological constructs can be hierarchically integrated as latent factors in a homogenously verbal aphasia test.

[1] It is a common expression to say that a test measures certain neuropsychological functions. Yet, those functions are concepts which need to be empirically validated.

[2] 'A structural model with linear relations is only an approximation. The world is unlikely to be linear. Indeed, the true relations between variables are probably nonlinear. Moreover, many of the statistical assumptions are somewhat questionable as well. The real question is not so much, "Does the model fit perfectly?" but rather, "Does it fit well enough to be a useful approximation to reality, and a reasonable explanation of the trends in our data?' (StatSoft, Inc., 2004).

The constructs of verbal comprehension and verbal expression are among the most widely used in literature (see, for example, Démonet et al. 2005; Price 2010; Wilson et al. 2011). Impairments in such domains may be related to comprehensive and expressive aphasias. However, the interaction among verbal comprehension, verbal expression and other well known verbal domains such as repetition, naming, reading, writing, phonological processing, spelling, and verbal memory (Anthony et al. 2007; Buchsbaum et al. 2011; Chen et al. 2008; Crockett et al. 1981; de Oliveira and Damasceno 2011; Goodglass and Kaplan 1996; López-Barroso et al. 2013; Mano and Osmon 2008; Nadeau 2001; Rohrer et al. 2008; Tomblin and Zhang 2006; Shewan and Kertesz 1980; Sinanović et al. 2011; Waters and Caplan 2003; Weems and Reggia 2006) needs to be elucidated.

The verbal visual modality represents a later acquisition in human development and a more culturally biased factor. Maybe for this reason, aphasia examiners usually pay more attention to the spoken production or oral interaction than to the written one (Shewan and Kertesz 1980; Sinanović et al. 2011). In spite of that, the inclusion of reading and writing as part of the verbal neuropsychological functions is unquestionable.

Conversely, attention, memory and praxia, even if explored in the verbal modality, are not necessarily part of pure language evaluations; for example, attention, memory and praxia may be part of global cognitive evaluations in which verbal language only represents the circumstantial stimulus for interaction (Vigliecca et al. 2012). However, when those three functions are included within a language evaluation they actually represent verbal constructs (De Renzi et al. 1966; Goodglass and Kaplan 1996; Hassibi and Breuer 1980; López-Barroso et al. 2013; Vigliecca et al. 2011a, b; Ziegler et al. 2012). Considering previous language studies with CFA, the functions of phonological processing, spelling and verbal working memory were independently studied as verbal ones (Anthony et al. 2007; Buchsbaum et al. 2011; Chen et al. 2008; Mano and Osmon 2008; Waters and Caplan 2003). There are no CFA studies which have analyzed all those verbal functions together.

It is well known that the longer the psychological tests, the better the psychometric properties. But long tests are not suitable for many cognitive impairments and/or acute cerebral conditions.

Short tests, which have been developed just to detect pathology, lack of enough subtest variance in healthy participants because of the ceiling effect. Alternatively, and considering the systemic nature of complex (high-level) cognition (Vigliecca and Aleman 2000), the functional structure of intact brains might not be the same of injured ones: Depending on the situation, the cognitive dimensional structure of patients with aphasia or dementia for example, might not be identical to that observed in healthy participants because the essence of the difference could be qualitative (Vigliecca 2008). If only a difference in degree is triggering the problem, and the psychological tests cover a wide range of difficulty, then the same dimensional structure could be found in impaired and non impaired samples.

Johnson et al. (2008) propose a hybrid approach for Alzheimer disease which is similar to the hybrid approach used for intelligence. They affirm that the presence of a general factor maximizes the detection of dementia, whereas more specific factors reveal the heterogeneity of the cognitive deficits associated with dementia. By using CFA these authors describe two models for people with and without Alzheimer disease, the first model having a correction in two Alzheimer-specific indices of episodic memory. A similar two-model approach could be adopted for short aphasia tests which have been developed just to detect pathology: On the one hand, a hybrid (mixed) model with more specific and heterogeneous factors could be proposed for patients with injuries in the verbal dominant hemisphere while, on the other hand, a single (general) model could be used when people with preserved language are involved. The first model could be used to characterize the quality of the syndrome and its specific symptoms, while the second model (i.e., the general verbal one) could be used to detect aphasia and its magnitude by comparing, for example, patients with injuries in the verbal dominant hemisphere versus people with preserved language.

The Brief Aphasia Evaluation (BAE) was designed to examine the minimum verbal performance (i.e. the basic verbal functioning) of patients with aphasia. Previous exploratory factor studies with patients and healthy participants have demonstrated that all the BAE subtests represented one verbal homogeneous construct (Vigliecca et al. 2011a, b). But there are no CFA studies which have explored the viability of this instrument to reveal more specific components or symptoms so that such symptoms, expressed in the subtests, could be used to characterize aphasia. Factor analyses carried out with the BAE (Vigliecca et al. 2011b) indicated that people with preserved verbal language (i.e. patients with right hemisphere lesions and healthy participants) may lack of enough subtest variance to be separately studied from patients with left hemisphere lesions. Such lack of variance may be worse if the subtests components, instead of the subtests, are analyzed. Besides, if CFA is carried out to detect symptoms, then patients injured in the verbal dominant hemisphere will be the first option for suitable CFA modeling.

Mungas et al. (2011) studied, through CFA, a sample of elderly people whose cognitive function spanned a broad range from normal, to mildly impaired, to demented. A similar sample could be thought for CFA aphasia studies by adding to the sample of patients with left hemisphere lesions, a group of patients with right hemisphere lesions and a group of healthy participants. A bigger sample, which includes the different levels of impairment usually analyzed in aphasia research, could facilitate CFA and provide more stable information for data interpretation.

In the present study, CFA was chosen as the most appropriate analysis to discover relevant underlying dimensions and their organization by groups and subgroups because, and unlike exploratory factor analysis, CFA forces components to load on only certain factors (Leak 2011). Consequently, the dissociation among not mutually excluding components (which are common components of psychological tests) may become clearer. In other words, not only the subtests but also the structure on which such subtests sit can be discovered by means of CFA. As those subtests are verbal constructs and their underlying structure involves a complex conceptual organization, the plausibility of such theoretical framework can also be analyzed by CFA.

The objective of the present study was to verify whether some recognized aphasia constructs can be hierarchically integrated as latent factors from a homogenously verbal test. BAE was selected for this characteristic. Additionally, and considering the length of the BAE, the viability of assessing aphasia condition with a multivariate perspective and a short test was also verified.

In summary the specific objective of the present aphasia study was to analyze, by means of CFA, whether the constructs and the conceptual organization described in section "CFA Modeling" (a–c) can be identified as latent factors of the BAE components.

Material and Methods

CFA Modeling

The subtest components (Table 1) were analyzed as manifest variables. They were the observed measures of this factor analysis. The subtest components represented the categories with the main subsets of items. Before CFA, such categories were ordered by difficulty

Table 1 Subtest components (manifest variables) and its latent factors

Manifest variables
(1) Auditory comprehension by pointing at real objects and by interviewee–interviewer interaction
(2) Auditory comprehension by pointing at pictures
(3) Repetition of either series of words or single words
(4) Repetition of sentences
(5) Completion of sentences by active naming
(6) Active naming of single objects
(7) Saying verbal automatisms
(8) Spontaneous speech
(9) Visual discrimination of simple written expressions (letters, digits, and one stimulus among four options)
(10) Reading aloud and reading comprehension (confrontation with pictures; written commands)
(11) Writing verbal automatisms
(12) Dictation and spontaneous writing
(13) Orophonatory praxia (imitation of a mouth movement)
(14) Phonemic synthesis (recognition of a spelled word)
(15) Phonemic analysis: discrimination by auditory cancellation, spelling, and reversed spelling
(16) Delayed repetition or memory (recall of words which have been previously said)
Abbreviations
(1) compr_1
(2) compr_2
(3) repet_1
(4) repet_2
(5) naming_1
(6) naming_2
(7) autom_sp
(8) spont_sp
(9) reading1
(10) reading2
(11) writing1
(12) writing2
(13) praxia
(14) phon_sy
(15) phon_an
(16) recall
Latent factors and their maximum scores (in brackets)
(a) VERBAL (216)
(b1) VERBAL COMPREHENSION (120)
(b2) VERBAL EXPRESSION (72)
(b3) COMPLEMENTARY VERBAL FUNCTIONS (PRAXIA, ATTENTION AND MEMORY) (24)
(c1) COMPREHENSION (63)
(c2) REPETITION (15)
(c3) NAMING (15)

Table 1 continued

(c4) SPEECH (9)
(c5) READING (57)
(c6) WRITING (33)
(c7) COMPLEMENTARY (24)
Abbreviations
(b1) VERBAL_COMPR
(b2) VERBAL_EXPRES
(b3) VERBAL_COMPL

within each individual subtest. As far as possible, some tasks initially composed of only one item (such as praxia and memory) were reorganized into subgroups of more items for better structural analyses.

CFA was carried out to see if the constructs and the hierarchical organization described below as hypothetical factors could indeed be confirmed as latent/explanatory factors of the manifest variables (Table 1).

(a) A general verbal factor, which was incorporated as a common latent factor for all the subtest components;
(b) The factors of comprehension {i.e. auditory comprehension (components 1 and 2), and reading (components 9 and 10)}; expression {i.e. repetition (components 3 and 4), active naming (components 5 and 6), saying verbal automatisms along with spontaneous speech (components 7 and 8), and writing (components 11 and 12)}; as well as some "complementary" verbal functions {i.e. orophonatory praxia, phonemic synthesis, phonemic analysis, and memory (components 13–16)};
(c) The specific/individual factors of auditory comprehension, repetition, naming, speech, reading, writing, as well as the "complementary" one.

All the specific/individual factors were modeled as correlated with each other.[3] As explained before, patients with injuries in the verbal dominant hemisphere were necessarily studied in first place. Patients with right hemisphere injuries and healthy participants were complementarily incorporated into the analysis.

Participants and Material

Data were obtained from a sample of 130 Argentine right handed volunteers, native Spanish speakers. Data from the first sample studied by CFA were obtained from consecutive patients (88 % inpatients) with focal and unilateral left cerebral lesions (LC). Bilateral damage was excluded. Only pre-surgery evaluations were reported. The sample was recruited from the Neurological and Neurosurgery Service of the Cordoba Hospital, a public hospital for adults. Lesions were confirmed by CT scan and/or MRI techniques. None of the patients suffered from any other (previous or simultaneous) associated neurological disease. Patients who suffered from visual agnosia, who were not able to point at objects or cards, or who did not have a minimum and clear comprehension and expression of affirmative and negative

[3] Several models were proved (results available upon request). The model reported here was the one with the best fit according to the present validity index (see below).

answers, either verbal or non-verbal were excluded. Data from supplementary samples were obtained from 35 consecutive patients with focal and unilateral right cerebral lesions (RC) as well as 30 healthy participants (HP).

RC (83 % inpatients) shared the same characteristics described above for LC except for the side of injury. HP were community-dwellers, independent and adapted to daily life demands, without any known neurological or psychiatric disease. They were recruited from cultural, recreational and retirement centers of Cordoba province. Recruitment method was better described elsewhere (Vigliecca et al. 2011a, b).

The three groups were matched (see below) according to gender (men's frequency: 51 % in the total sample), years of age and education (mean (SD): 47.59 (14.35) and 8.26 (3.75), respectively, in the total sample).

Both groups of patients were compared in the type and site of lesion, time since diagnosis, risk factors, presence of hemianopsia and hemiparesis, and number of hospitalized patients. With this purpose, lesions were divided into hemispheric anterior (frontal) lesions (A) versus hemispheric posterior (temporal, parietal or occipital) lesions (P); as well, lesions located in inferior structures (such as thalamus, basal ganglia, internal capsule, etc) were classified as subcortical (SC) lesions; and lesions located in the frontal lobe and any of the posterior lobes, or in regions located between the frontal lobe and the posterior lobes, were classified as antero–posterior (AP) ones.

The BAE did not represent any risk for the participants who, in all cases, were alert and willing to complete the whole test, independently of their relative capacity to perform some of the sub-tests or items in particular. Participants did not receive any payment for their contribution. In order to carry out this research, the participants' written informed consent (or the patient's caregivers'), the approval of the Research and Ethics Committee of the Cordoba Hospital, and the support of the CONICET were all collected. This study was performed pursuant to the ethical standards established in the 1964 Declaration of Helsinki (World Medical Organization 1996).

The BAE, which is freely offered by her author in English and Spanish (Vigliecca 2000a, b), is usually administered at the patient's bed-side and consists of 72 aphasia items scored from 0 to 3 (maximum score 216).

The BAE is part of the battery of "Neuropsychological Tests Abbreviated and Adapted to Spanish-Speakers" (Vigliecca and Aleman 2000; Vigliecca 2004; Vigliecca and Aleman 2010) and represents a valid and reliable aphasia scale (Vigliecca et al. 2011a, b). Previous studies from the laboratory (Vigliecca et al. 2011b) have demonstrated that the BAE represented a valid verbal instrument to differentiate LC from RC, as well as LC from HP. The discrimination of patients injured in the verbal dominant hemisphere is the most unquestionable property of aphasia tests. The subtest-verbal homogeneity described earlier was demonstrated for all the samples taken together and for HP, patients, and LC separately (Vigliecca et al. 2011a, b).

The functions of comprehension; repetition; naming, speech; reading; and writing; along with orophonatory praxia; attention (phonemic synthesis, phonemic analysis); and memory were designed to be studied by this test. Previous studies indicated an internal consistency of 0.99 for the total score and 0.88 or above for any of the subtests when LC, RC and HP were simultaneously analyzed through the Cronbach's alpha coefficient (Vigliecca et al. 2011b). The functions of orophonatory praxia, attention, and memory represented items of some mental status screening tests which were included in the BAE with the attempt to study their contribution to verbal processing. The BAE was developed 14 years ago (Vigliecca 2000a, b, c).

Statistical Analysis

Descriptive sample data were analyzed by ANOVA for quantitative variables or by Chi square (χ^2) for qualitative ones.

CFA was carried out with the structural equation modeling (SEPATH) module of the Statistica software (StatSoft Inc., 2004). Covariances were analyzed. The discrepancy function used as parameter estimator in this case was the Generalized Least Squares estimation followed by the Maximum Likelihood Estimation. In the present study, goodness of fit (p level >0.01) was evaluated by means of a Chi-square test and the discrepancy function value. At once, other criteria were used in order to check both successful iteration and how well the model fit the data (StatSoft Inc., 2004). These criteria were: Maximum Residual Cosine close to zero; Invariant under a Constant Scaling Factor (ICSF) criterion close to zero; Invariant under Changes of Scale (ICS) criterion close to zero; the Root Mean Square Standardized Residual (RMSSR) close to zero; the Bentler–Bonett Normed Fit Index (NFI) close to one, and the Root Mean Square Error of Approximation (RMSEA) close to zero.

According to the Statistica software (StatSoft Inc., 2004), Maximum Residual Cosine becomes small when parameter values have stabilized; it is close to zero if iteration was successful. ICSF criterion should be close to zero if model fit does not change when all variables are multiplied by the same constant (most structural models are invariant under a constant scaling factor). ICS criterion should be close to zero if model fit does not change by rescaling the variables. RMSSR must be close to zero (below 0.05) for the fit to be satisfactory in a practical sense. NFI (Bentler and Bonett 1980) is a single sample goodness-of-fit index which measures the relative decrease in the discrepancy function caused by switching from a "null model" or baseline model, to a more complex one; it approaches the value of one as the fit becomes perfect. RMSEA is a non-centrality-based index of fit (Steiger and Lind 1980); values closer to 0 indicate better fit. Preferred values for RMSEA are below 0.09 (Johnson et al. 2008).

The fact that the model satisfactorily fit the data of the three samples successively added was also taken into account. These criteria were expressed as a summary statistics for each successive sample and all together considered as the validity index.

Just as complementary information, the significance levels ($p < 0.10$) for the T statistics model-output specific estimators in the biggest sample were reported. These indices were shown in a diagram so as to see more clearly the CFA structural configuration (the path pattern) and the relative contribution of each component on each sub-organization.[4] Also as additional information the statistical power (for a population RMSEA $= 0.09$) and the Mardia-based Kappa Index of multivariate normal distribution [which should be close to zero (Bentler and Wu 1993)] were provided with the diagram.

Results

Sample Data

Table 2 shows the matched demographic data for the three studied samples.

Table 3 shows the patients' lesion classification based on its type and side. Malignant tumours represented the most frequent type of lesion. By grouping the cells with fewer cases

[4] Rejecting the hypothesis for each elementary contributor would imply that its value is not zero and should be included. The validity of the general model is, however, the defining criterion for inclusion (see above).

Table 2 Demographic data

Group	Age	Education	Gender (Men's frequency)	N
LC	47.25 SD 15.10	8.25 SD 4.07	32	65
RC	47.97 SD 13.35	8.12 SD 4.04	20	35
HP	47.90 SD 14.26	8.50 SD 2.70	14	30
Total	47.59 SD 14.35	8.26 SD 3.75	66	130
	$F(2, 127) = 0.04$	$F(2, 127) = 0.09$	$\chi^2 = 0.83$; *df* 2	
	$p < 0.96$	$p < 0.91$	$p < 0.66$	

Table 3 Classification of the focal cerebral lesions based on their type and side

Lesion	Side	
Type	Left	Right
AVM	6	2
SDH	1	1
BEN TU	6	3
MAL TU	33	16
ANEU	3	1
MTS	2	1
ISQ STR	4	3
HEM STR	4	4
CYST	2	2
TBI	2	1
TEM LOB	2	1
Total	65	35
	$\chi^2 = 2.24$; *df* 10; $p < 0.99$	

AVM arterio-venous malformation, *SDH* sub-dural hematoma, *BEN TU* benign tumor, *MAL TU* malignant tumor, *ANEU* aneurysm, *MTS* mesial temporal sclerosis, *ISQ STR* ischemic stroke, *HEM STR* hemorrhagic stroke, *CYST* brain cysts, *TBI* traumatic brain injury, *TEM LOB* temporal lobectomy

Table 4 Classification of the focal cerebral lesions based on their cerebral site and side

Lesion	Side	
Site	Left	Right
A	16	9
P	20	11
AP	24	11
SC	5	4
Total	65	35
	$\chi^2 = 0.56$; *df* 3; $p < 0.90$	

A frontal, *P* posterior (temporal, parietal or occipital), *AP* antero–posterior, *SC* subcortical

(i.e. the cells which represented to the rest of the lesions) a non-significant difference between LC and RC was observed when malignant tumors were compared with the rest of the lesions ($\chi^2 = 0.23$; *df* 1; $p < 0.63$).

Table 4 shows the lesion classification based on its site and side. As shown, a non-significant difference was observed between LC and RC for those four sites of lesions.

Considering differences between LC and RC according to the site of lesion for each type of lesion (i.e., the classification based on side × site × type of lesion) all differences were non-significant (all $\chi^2 \leq 4.00$; *df* 3; $p \geq 0.26$). Considering differences between LC and RC according to the site of lesion for lesions divided into malignant tumors versus the rest of the lesions, results were the following: malignant tumors: $\chi^2 = 0.47$; *df* 3; $p = 0.924$, rest of the lesions: $\chi^2 = 1.67$; *df* 3; $p = 0.642$.

Both groups of patients did not differ either in their time since diagnosis (divided in months) (LC: 11.20 ± 25.20, RC: 11.26 ± 27.96 ($F(1, 98) = 0.01$, $p < 0.99$)), or in the presence of any additional risk for cognitive impairment (malnutrition, frequent contact with toxic agents, hypertension, heart disease, obesity, diabetes, genetic component of the illness, alcohol or drug consumption, etc.) (LC: 1.80 ± 1.56, RC: 2.34 ± 1.55 ($F(1, 98) = 2.76$, $p < 0.10$)). The presence of hemianopsia, (LC: 11 %, RC: 11 %; $\chi^2 = 0.01$; *df* 1; $p < 0.92$) and hemiparesis (LC: 45 %, RC: 43 %; $\chi^2 = 0.28$; *df* 1; $p < 0.86$) as well as the number of hospitalized patients (LC: 88 %, RC: 83 %; $\chi^2 = 0.44$; *df* 1; $p < 0.51$) was also similar for both groups.

A two-way ANOVA with side of lesion and type of lesion as independent variables, and time since diagnosis as dependent variable indicated a significant main effect of type of lesion ($F(10, 78) = 3.97$, $p < 0.001$). However, no main effect of side of lesion ($F(1, 78) = 0.03$, $p < 0.99$), or interaction between side of lesion and type of lesion ($F(10, 78) = 0.94$, $p < 0.497$) was observed. When type of lesion was divided into malignant tumors versus the rest of the lesions, the effect of these two types of lesions was non-significant (($F(1, 96) = 0.66$, $p < 0.419$); as well, neither main effect of side of lesion ($F(1, 96) = 0.00$, $p < 0.99$) nor interaction between type of lesion and side of lesion ($F(1, 96) = 0.22$, $p < 0.635$) was observed. These results indicated that time since diagnosis was not finally affected by the laterality of the lesion even if type of lesion was included in the analysis. Results were even less significant when the lesions were divided into malignant tumors versus the rest of the lesions. Alternatively, when malignant tumors and the rest of the lesions were crossed with the presence of mass effect and side of lesion (i.e., type of lesion × mass effect × side of lesion), differences between LC and RC in the mass effect were non-significant (malignant tumors: $\chi^2 = 0.59$; *df* 1; $p = 0.444$; rest of the lesions: $\chi^2 = 0.73$; *df* 1;$p = 0.392$). These results indicated that the laterality of the lesion was not associated with the type of lesion and the presence of mass effect. All together these results also indicated that the relation among: (a) type of lesion, (b) two effects associated with those lesions (i.e., time since diagnosis and mass effect), and (c) side of lesion was absorbed by the relation between type of lesion and side of lesion, which was shown above.

According to a one-way ANOVA, all the BAE subtests components produced significant differences among LC, RC and HP ($F(2, 127) \geq 16.17$, $p < 0.001$). According to the Newman–Keuls's test for post hoc comparisons, only the Recall component turned out to be significantly different between any pairs of groups ($p < 0.001$ for all comparisons). The rest of the components only produced significant differences when the LC group was compared to any of the other two groups ($p < 0.001$ for all the significant post hoc comparisons). On the contrary, RC and HP did not produce statistically significant differences in 15 of the 16 subtest components ($p \geq 0.309$ for all the non-significant post hoc comparisons). According to a one-way ANOVA, all the BAE subtests produced significant differences among LC, RC and HP, considering the "complementary" factor as another subtest ($F(2, 127) \geq 18.05$, $p < 0.001$). According to the Newman–Keuls's test for post hoc comparisons, significant differences were only obtained when the LC group was compared to any of the other two groups ($p < 0.001$ for all the significant post hoc comparisons). On the contrary, RC and HP did not produce statistically significant differences in any of the subtests ($p \geq 0.221$ for all the non-significant post hoc comparisons). In general terms, and as expected when analyzing verbal performance, the patients showed a poorer performance than HP, and LC showed a poorer performance than RC: Considering the total BAE score, RC showed a poorer verbal performance than HP (RC:

Table 5 Confirmatory factor analysis summary statistics

	LC	LC, RC	LC, RC, HP
ML Chi-square	53.77	65.57	69.92
df	52	52	52
p level	0.41	0.10	0.05
Discrepancy function	0.84	0.66	0.54
Maximum residual cosine	0.00	0.00	0.00
ICSF criterion	0.00	0.00	0.00
ICS criterion	0.00	0.00	0.00
RMSSR	0.03	0.02	0.01
NFI	0.96	0.97	0.98
RMSEA point estimate	0.00	0.03	0.05
RMSEA 90 % confidence interval	0.00–0.07	0.00–0.07	0.00–0.08

ML maximum likelihood, *ICSF* Invariant under a Constant Scaling Factor, *ICS* Invariant under Changes of Scale, *RMSSR* Root Mean Square Standardized Residual, *NFI* Normed Fit Index, *RMSEA* Root Mean Square Error of Approximation

205.09±13.26, HP: 213.53±3.38 ($F(1, 63) = 11.52$, $p < 0.002$)) while LC (140.21±65.19) showed both a poorer verbal performance than RC ($F(1, 98) = 33.74$, $p < 0.001$) and a poorer verbal performance than HP ($F(1, 93) = 33.67$, $p < 0.001$).[5]

Confirmatory Factor Analysis

As a summary statistics (Table 5), all the proposed latent factors were confirmed by CFA. They were: the general verbal factor; the three factors of comprehension, expression, and the "complementary" factor; as well as the seven individual factors of auditory comprehension, repetition, naming, speech, reading, writing, and the "complementary" factor. The solutions were convergent and satisfactory for the three supplementary samples. Thus, the validity index was verified. Although the LC sample showed a better fit according to the Chi-square and RMSEA criteria, other estimates of the summary statistics indicated better fit according to sample-size increments: As indicated by the Discrepancy Function, RMSSR and NFI criteria, the total sample showed a better fit than the sample of LC with RC, while the sample of LC with RC showed a better fit than the sample of LC alone.

Complementary CFA Information

The path pattern is shown in Table 6. Three sections specified by horizontal lines are described in a diagram. The three sections went from the most general latent factor in the upper part to the most specific/individual ones in the lower part. Significance levels indicated that the "complementary" factor (VERBAL_COMPL) fit better as part of the last seven factors (i.e., the specific/individual ones) than as part of the three intermediate ones. Considering the manifest variables in particular (see also Table 1), some very simple tasks like auditory comprehension by interviewee–interviewer interaction [compr_1], repetition of words [repet_1], and writing verbal automatisms [writing1] produced non-significant results in the three-factor intermediate classification; however they produced significant results in the specific/individual factors of the lower part of the diagram. On the contrary, the visual discrimination of simple written expression [reading1] produced non-significant results in the reading specific/individual

[5] All significant pairwise comparisons were also confirmed with the non parametric test of Kruskal–Wallis ANOVA by Ranks, and a significance level of $p < 0.001$ (results available upon request).

factor of the lower part of the diagram (READING) while it produced significant results in the three-factor intermediate classification as part of the verbal comprehension factor (VERBAL_COMPR).

Conclusion and Discussion

Conclusion

The theoretical framework proposed in this study, turned out to be a valid explanatory model for the neuropsychological characterization of aphasia and encompassed:

(a) An all inclusive verbal organizer from which two successive organizers emerged. The two successive organizers were:
(b) A more general classification which essentially included verbal comprehension and expression, in addition to a "complementary" verbal factor which included praxia, attention, and memory.
(c) A more specific classification which included the individual (and correlated) constructs of auditory comprehension, repetition, naming, speech, reading, writing, and the "complementary" functions.

At once, present results indicated that the BAE was adequately designed to identify the constructs described above, which is encouraging for diagnosing aphasia in patients who cannot undergo extensive evaluations.

This is the first comprehensive study addressed to obtain better definitions for verbal functions and sub-functions including: (a) their organization under a hierarchical model, (b) a lesion-based approach, and (c) the analysis of a homogenously verbal and short aphasia test.

By following this approach (where the aphasia patterns are exhaustively analyzed) all the patients fall inside the classification system; consequently, the gradual improvement of the aphasia theory is guaranteed. On the contrary, when only certain types (and number) of aphasias are considered as valid, without empirically demonstrating why other combinations of symptoms are not, the double dissociation which otherwise would be explicit becomes impossible to verify. The present probabilistic approach allows verifying this type of dissociation because any combination of symptoms is detected (and shown) and the theoretical interpretation is not left to chance.

Discussion

Independently of the test used in this study, present results also suggest that short tests can be suitable tools (if adequately constructed) for discriminating both the verbal function as a whole and the sub-verbal functions. Short tests are particularly useful for acute conditions.

In patients with chronic aphasia, it is easy to find consistent results, reliable diagnoses and satisfactory psychometric indices (Shewan and Kertesz 1980; Turkeltaub et al. 2011). However, it is too late to begin with an efficient therapy. It is well-known that the shorter the period between the aphasia occurrence and the treatment process, the better the language recovery. Consequently, developing valid and reliable aphasia tests for acute conditions are necessary.

BAE has previously proved to be an efficient (valid, reliable and short) instrument for this purpose. Other brief tests have been developed with the same objective but the methodology

Table 6 Model path representation and probability levels of estimates

(VERBAL)-1→[compr_1]	0.000*
(VERBAL)-2→[compr_2]	0.000*
(VERBAL)-3→[repet_1]	0.000*
(VERBAL)-4→[repet_2]	0.000*
(VERBAL)-5→[naming_1]	0.000*
(VERBAL)-6→[naming_2]	0.000*
(VERBAL)-7→[autom_sp]	0.000*
(VERBAL)-8→[spont_sp]	0.000*
(VERBAL)-9→[reading1]	0.000*
(VERBAL)-10→[reading2]	0.000*
(VERBAL)-11→[writing1]	0.000*
(VERBAL)-12→[writing2]	0.000*
(VERBAL)-13→[praxia]	0.000*
(VERBAL)-14→[phon_sy]	0.000*
(VERBAL)-15→[phon_an]	0.000*
(VERBAL)-16→[recall]	0.000*
(VERBAL_COMPR)-17→[compr_1]	0.424
(VERBAL_COMPR)-18→[compr_2]	0.001*
(VERBAL_COMPR)-19→[reading1]	0.003*
(VERBAL_COMPR)-20→[reading2]	0.048*
(VERBAL_EXPRES)-21→[repet_1]	0.897
(VERBAL_EXPRES)-22→[repet_2]	0.030*
(VERBAL_EXPRES)-23→[naming_1]	0.004*
(VERBAL_EXPRES)-24→[naming_2]	0.045*
(VERBAL_EXPRES)-25→[autom_sp]	0.006*
(VERBAL_EXPRES)-26→[spont_sp]	0.000*
(VERBAL_EXPRES)-27→[writing1]	0.405
(VERBAL_EXPRES)-28→[writing2]	0.001*
(VERBAL_COMPL)-29→[praxia]	0.607
(VERBAL_COMPL)-30→[phon_sy]	0.598
(VERBAL_COMPL)-31→[phon_an]	0.844
(VERBAL_COMPL)-32→[recall]	0.617
(COMPREHENSION)-33→[compr_1]	0.004*
(COMPREHENSION)-34→[compr_2]	0.002*
(REPETITION)-35→[repet_1]	0.000*
(REPETITION)-36→[repet_2]	0.000*
(NAMING)-37→[naming_1]	0.000*
(NAMING)-38→[naming_2]	0.000*
(SPEECH)-39→[autom_sp]	0.000*
(SPEECH)-40→[spont_sp]	0.000*
(READING)-41→[reading1]	0.297

Table 6 continued

(READING)-42→[reading2]	0.000*
(WRITING)-43→[writing1]	0.000*
(WRITING)-44→[writing2]	0.000*
(COMPL)-45→[praxia]	0.039*
(COMPL)-46→[phon_sy]	0.065*
(COMPL)-47→[phon_an]	0.000*
(COMPL)-48→[recall]	0.000*

Only the relation between latent and manifest variables is shown. N = 130; $^{*}p < 0.10$. General model power (RMSEA = 0.09): 0.79;
Mardia-based Kappa (multivariate normal distribution): 0.17)

applied to verify the psychometric properties (e.g., the way of assessing validity and reliability, the control of the clinical criterion on patients' selection, the matching conditions in the groups of brain injured patients, the use of objective parameters for construction and validation) was different from the one used in the BAE (Allibrio et al. 2009; Biniek et al. 1992; Salter et al. 2006; Viglieccca et al. 2011a, b).

Patients with acute aphasia require agile interventions. In order to achieve this goal, the first step in the intervention has to be addressed to diagnose (and stimulate) the patients without overwhelming them.[6] The BAE has demonstrated to count on the properties for quickly detecting the presence and magnitude of the aphasia condition as well as its characteristics (the aphasia components or symptoms). The effects of fatigue, performance fluctuations, discomfort, etc., which patients suffer during the earliest stages of aphasia, are reduced by the briefness of the test. Besides, the BAE properties described above are useful to: (1) begin with an immediate rehabilitation therapy, (2) organize a better neuropsychological evaluation in order to find complementary cognitive resources, and, therefore, (3) improve prognosis and resilience in this vulnerable group of patients.

By following the BAE approach, which allows that any combination of the latent language impairments can be recognized, neurorehabilitation professionals will be able to work with the particular characteristics of the patient, without being forced to follow a predetermined diagnosis typology.

It should be noted that, except for the "complementary" factor, the most specific/individual constructs of the present theoretical framework have been specially used by the so-called classical (clinical-neuroanatomical) approach. According to this approach (Goodglass and Kaplan 1996; Shewan and Kertesz 1980), auditory comprehension, repetition, naming, speech, and, additionally, reading and writing have been studied as the main factors which hypothetically discriminate aphasia types (Viglieccca et al. 2011b). Although present findings do not necessarily imply that each verbal function might be linked to one aphasia type, they may help to elucidate the validity of the aphasia syndromes in future studies. The model proposed here may represent a valid tool in the attempt to find new classifications or constructs for aphasia disorders (and their biological causes) beyond some widespread definitions and typologies.

The inclusion of the "complementary" functions of orophonatory praxia, phonemic synthesis, phonemic analysis, and verbal memory to aphasia tests may turn out to be useful to

[6] When short tests have been well designed it is expected that patients show improvement even during the course of the evaluation. In the case of the BAE, some strategies were implemented trying to make the administration more pleasant. Some of these strategies are: the initial presentation of the test as a natural conversation, the attention to the rapport and to the minimal signs of patient's distress, the ordering of the items by difficulty and by its appearance in ontogeny (from comprehension to expression), the possibility of skipping items, the presentation of the test as a fun interaction with permanent reinforcements to successful responses, and the standardization of the command repetitions to avoid the feeling of failure on the part of the patient.

detect subtle language impairments and early diagnoses. Considering extensive tests (with more items in each task), the inclusion of those motor, attention, and memory functions may help to understand not only their contribution to aphasia disorders but also to other verbal impairments still not well understood such as verbal apraxia. The validity of the general model proposed in the present study demonstrated that such 'complementary' functions were, in fact, essential components to complete the structure.

The verbal neuropsychological functions in aphasia are linked to the notions of gnosia, praxia, attention, memory, and global cognition. A previous study with the BAE (Vigliecca et al. 2012) demonstrated that global cognitive impairment can be confounded with aphasia when verbal and nonverbal functions are not equally considered in an evaluation. In clinical settings the use of nonverbal tests, which are as independent as possible from verbal ones, is crucial to analyze which of those evaluated domains is primary, secondary or equivalent in its deleterious effect. But in order to do that, other neuropsychological and biological measures have to be included in the diagnosis (Vigliecca and Aleman 2010; Vigliecca et al. 2012).

Aphasia needs to be accurately assessed in order to get better diagnoses, treatments and theoretical inferences. As present results only represent a step forward on this direction, the development of other evidence-based theoretical models is encouraged. Considering that many of the CFA statistics are sensitive to sample size, new findings are in fact expected with bigger samples, in particular, with bigger samples of LC and more specific lesions.

Additional Information

As the present test was developed to examine verbal language impairment in patients with brain injuries, CFA could not have been carried out without the presence of patients injured in the verbal dominant hemisphere. Maybe for this reason some of the indices of the summary statistics fit better for the LC. However, by adding subsamples with major presence of language preserved, the goodness-of-fit indices remained satisfactory. This finding turns out stimulating for future studies dealing with verbal language extensive tests; specifically, for studies dealing with tests with a broad range of performance so that, for example, the verbal ability/variance of healthy participants could also be discriminated by the subtests. Under such technical conditions, CFA studies could be carried out for LC, RC and HP as separate samples, thus providing more complete information. CFA studies for patients with brain injuries demand new methodological perspectives because most of the CFA verbal studies have been carried out with healthy subjects.

To the best of our knowledge, there are no antecedents in the aphasia literature where all types of lesions and their intervening variables have been described in the way which has been used here. Yet, some limitations need to be considered. Even if the present work was carried out with patients with unilateral cerebral lesions, and only pre-surgery evaluations, it cannot be unequivocally stated that malignant tumor cells have not yet spread to the other hemisphere at a histological level. If there is one subgroup of patients with bilateral lesions (or dysfunctions) which has been equivocally included within a group with unilateral lesion, the first group will increase the statistical error thus decreasing the final verbal cognitive difference between LC and RC. Without discarding such histological source of error, which acts in any direction, the real between-group differences might have diminished thus hindering the recruitment of purer samples with unilateral cerebral lesions.

Considering the relative contribution of each component on each sub-organization, auditory comprehension by interviewee–interviewer interaction, on the one hand, and repetition of words along with writing verbal automatisms, on the other hand, appeared to be poorly sensitive for confirming comprehensive and expressive abilities, respectively. Further research would be necessary to see if such simple components, which are highly used by physicians at the patient's bed-side, are indeed useful for characterizing, for example, comprehensive and expressive aphasias. Regarding other indices within this detailed analysis, the group of the "complementary" functions apparently fit better as an individual/specific factor than as an intermediate one. Therefore, verbal comprehension and expression appeared to be dominant for this intermediate factor. This finding would be in agreement with those authors who consider that verbal comprehension and expression are the most relevant underlying constructs to describe aphasia or language measures. Additionally, and considering the two components of reading, it seems that its easiest one showed a more significant contribution to the broader factor of verbal comprehension than to the individual/specific factor of reading. Some of these partial results may have been due to the fact that patients have, in this test, different options for answering: Beyond directly speaking, patients can also point at the target stimulus thus probably interchanging the auditory/spoken and the visual/written modalities.

Anyhow, the BAE does not attempt to assess the score on each subtest component specifically but rather the score on each subtest as a whole. For example, reading as an individual construct would include its both components together. i.e., as the information provided by the isolated components was successfully organized by the general model proposed, such model represents an improvement in the component diagnostic values.

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