Acalculia in Aphasia

Rafael Gonzalez1, Macarena Rojas1, Mónica Rosselli2, Alfredo Ardila3,4,*

1Departamento de Neurología y Neurocirugía, Hospital Clínico de la Universidad de Chile, Santiago, Chile
2Department of Psychology, Charles E. Schmidt College of Science, Florida Atlantic University, Davie, FL, USA
3Institute of Linguistics and Intercultural Communication, I.M. Sechenov First Moscow State Medical University, Moscow, Russia
4Psychology Doctoral Program, Albizu University, Miami, FL, USA

*Corresponding author at: 12230 NW 8th Street, Miami, FL 33182, USA. E-mail address: ardilaalfredo@gmail.com (A. Ardila).

Received 22 April 2020; revised 15 July 2020; Accepted 15 August 2020

Abstract

Background: Patients with aphasia can present a type of acalculia referred to as aphasic acalculia. Aims: To investigate the correlation and to test regression models for one- and two-digit calculation skills using verbal and nonverbal predictors.

Methods and Procedures: We selected an aphasia sample of 119 men and 81 women with a mean age of 57.37 years ($SD = 15.56$) and an average level of education of 13.52 years ($SD = 4.08$). Spanish versions of the Western Aphasia Battery and Boston Diagnostic Aphasia Examination, plus a Written Calculation test, were individually administered. The calculation section of the Western Aphasia Battery and the Written Calculation tests were used to pinpoint calculation difficulties.

Outcomes and Results: Calculation difficulties were more severe in Global and Mixed non-fluent aphasia; they were very similar in Broca, Conduction, and Amnesic Aphasia. All correlations between the two calculation subtests and the other subtests of the Western Aphasia Battery were statistically significant. Calculation subtests correlated negatively with age and positively with schooling. Sex and time post-onset did not show any correlation with the calculation scores. Education, Reading, Block Design, and Raven’s Colored Progressive Matrices were significant predictors of Western Aphasia Battery Calculation. Writing was the only significant predictor of the Written Calculation scores.

Conclusions: Nonverbal abilities were predictors of calculation tests, whereas agraphia defects were predictors of the Written Calculation test. Therefore, calculation abilities can be regarded both as written language-dependent and verbal language-independent.

Keywords: Acalculia; Aphasia; Western Aphasia Battery; Spanish

Introduction

Numerical knowledge can be regarded as a multifactor ability, involving at least language, spatial abilities, executive functions, and somatic knowledge (Ardila & Rosselli, 2002). Consequently, it is not surprising that aphasic patients frequently present mathematical difficulties that can go from simple counting deficits to complex arithmetical problem solution (Ardila & Rosselli, 1990a, 1990b, 2002, 2019; Basso, Burgio, & Caporali, 2000; Rosselli & Ardila, 1989, 2020). This disorder has been usually termed “aphasic acalculia” (Ardila & Rosselli, 2002). As an illustration of these difficulties, De Luccia and Ortiz (2016) compared to non-brain damage participants, the numerical and computational abilities of 32 patients with aphasia resulting from a single vascular lesion of the left hemisphere. Aphasic patients presented errors in simple count (i.e., 1, 2, 3 . . .), in performing automatic series (to count adding or subtracting three, or ten) and in both forward (i.e., 3, 6, 9, 12 . . .) and backward (e.g., 50, 40, 30, 20 . . .) counting. In addition, the aphasics showed difficulties in naming and writing to dictation arithmetic signs.
disorders (Ardila & Rosselli, 1989).

Errors in written operations associated with two-digit numbers, or following rules (e.g., “borrowing” in subtraction or “carrying” in addition) were the most challenging for division. However, the addition portion was easier than the other three operations; the most difficult were division and subtraction, language disorders presented lower scores on oral and written arithmetic operations of addition, subtraction, multiplication, and division. However, the addition portion was easier than the other three operations; the most difficult were division and subtraction, particularly using two-digit numbers. More complex written calculations that included, for example, the addition of decimals, two-digit numbers, or following rules (e.g., “borrowing” in subtraction or “carrying” in addition) were the most challenging for aphasics compared to normal age controls with an equivalent educational level. Errors in written operations associated with visual-spatial problems (placing one number below another in the correct column) are also evident in patients with aphasic disorders (Ardila & Rosselli, 1989).

Several classifications of acquired calculation disturbances are found in the literature. Luria (1977) distinguished three types of acalculia: optic acalculia, frontal acalculia, and primary acalculia. Hecaen, Angelergues, and Houiller (1961) also refer to three variants of acalculia: alexia and agraphia for numbers, spatial acalculia, and anarithmetia or primary acalculia. However, the most frequent distinction found in contemporary literature includes primary acalculia and secondary acalculias. Ardila and Rosselli (2002) proposed a comprehensive classification of acalculias. They distinguished six different types acalculia: (1) primary acalculia or anarithmetia, (2) aphasic acalculia, (3) alexic acalculia, (4) agraphic acalculia, (5) dysexecutive (frontal) acalculia, and finally (6) spatial acalculia. Primary acalculia corresponds to anarithmetia. The remaining types of acalculia are considered secondary. Therefore, acalculia can result from not only primary disturbances in numerical abilities, but also from executive function impairments, spatial disturbances, and oral and written language defects.

Variations in the frequency and severity of mathematical difficulties have been observed in aphasic patients. The level and characteristics of the impairments in calculation abilities vary across the different types of aphasia. Patients with global aphasia present the most severe mathematical alteration, followed by patients with Wernicke and Broca’s aphasias; patients with amnestic or anomic aphasias present less severe mathematical disorders (Delazer et al., 2003; Baldo & Dronkers, 2007; González, Rojas, & Ardila 2020). Gerstmann (1940) described a clinical syndrome associated with damage in the angular gyrus of the left hemisphere, which included four different clinical signs: finger agnosia, right–left disorientation, agraphia, and acalculia. Gerstmann syndrome has been a polemic syndrome that has been interpreted in different ways (e.g., Ardila, 2014; Rusconi et al., 2010). Nonetheless, it clearly suggests that acalculia has a certain commonality not only with the body spatial dimensions (right–left discrimination), body knowledge mediated by the language (finger knowledge), but also writing ability. These associations emphasize the multifactor nature of calculation abilities.

It has been suggested that language and numerical knowledge are supported by partially shared mechanisms. For example, a significant correlation has been found between arithmetic and language comprehension performance in patients with aphasia (Baldo & Dronkers, 2007). Deloche and Seron (1982) compared error types in two number transcoding tasks (from spelling code to Arabic, and vice versa) in seven patients with Broca’s aphasias and seven patients with Wernicke’s aphasias. They observed that Broca’s aphasics, who often present a syntactic language deficit, made syntactic errors, and Wernicke’s aphasics, with lexical language disorders, had lexical errors. The authors concluded that the language deficits in Broca’s and Wernicke’s aphasias parallel their number-processing deficits, suggesting that they result from damage to a shared cognitive component between language and calculation skills.

Basso and colleagues (2000) criticized the proposal that there are shared mechanisms for language and calculation abilities disturbances in aphasia. These authors analyzed numerical and computational skills in 16 patients with Broca’s aphasia and 18 with Wernicke’s aphasia using an extensive mathematical test battery. They found that the pattern of numerical and mathematical deficiencies was not different between the two groups of aphasics. The only thing that differentiated Wernicke’s patients from Broca’s was the type of errors in code translation tasks (verbal <→> Arabic). Wernicke’s aphasics had more lexical errors, but syntactic errors were not exclusive to Broca’s aphasia as they were also observed in Wernicke’s aphasia. Deloche and Seron (1982) and Delazer and colleagues (2003) found more lexical errors in Wernicke’s aphasia and a greater number of syntactic errors in Broca’s aphasia, maintaining the language deficit pattern. Damhen et al. (1982) found that Wernicke’s aphasics were significantly more impaired than Broca’s aphasics in all arithmetic tests, this difference being particularly large in more “spatial” tasks. Rosselli and Ardila (1989) also emphasized spatial representation deficits as a possible explanation for the errors presented by patients with Wernicke’s aphasia; these deficits can be particularly evident in tasks that require spatial organization such as placing numbers in columns according to their place value (units, tens, and hundreds).

Rosselli and Ardila (1989) analyzed mathematical impairments in 32 patients diagnosed with aphasia, distributed as follows: 5 with Broca’s aphasia, 13 with Wernicke’s aphasia, 6 with conduction aphasia, 4 with anomic aphasia, and 4 with global aphasia; they also included three patients with alexia without agraphia (pure alexia). Participants received a test battery including 12 subtests that assessed oral and written numerical skills of various types. The groups with Broca’s, conduction, Wernicke’s, and global aphasia presented errors on all subtests, but the distribution was different. Patients with global aphasia had errors on all subtests, as well. Patients with anomic aphasia did not have errors in the reading of signs or in the count in progression.
Likewise, those who were diagnosed with pure alexia showed no errors neither in the reading of arithmetic signs nor in the count in regression or progression, nor in the writing of numbers.

In conclusion, previous studies suggest that patients with aphasia can present with aphasic acalculia (Ardila & Rosselli, 2002). It is unclear, however, whether the severity of these mathematical deficits seen in aphasia correlates with the severity of the patients’ oral and written language difficulties and/or with other nonlinguistic deficits such as praxis and constructional abilities. The current study aims to fill the gap in knowledge by studying these correlations and testing regression models for one- and two-digit calculation skills using verbal and nonverbal predictors. We hypothesized that positive correlations would be found in aphasia patients between arithmetic skills and verbal (oral and written) and nonverbal visuospatial abilities. The two arithmetic tests used in the current study were formatted differently. The SWAB-R calculation test included simple arithmetic problems, and responses were through multiple-choice selection. Performance in this task was expected to be primarily related to reading and nonverbal visuoconstructional and reasoning abilities. The second arithmetic test was Written calculation; it included more challenging problems (most of them two digits) and it was expected to be primarily affected by the patients’ writing skills. Complex arithmetical operations, mental operations, and written operations are difficult for patients with Broca, Wernicke, Conduction, and Global Aphasia (Rosselli & Ardila, 1989). Therefore, aphasia severity was expected to be significantly related to both types of arithmetic problems.

It remains controversial whether oral and written linguistic variables predict most of the calculation score variance in aphasia patients. Most previous studies have used small samples; this study will overcome this limitation by testing a large sample of aphasia patients.

Method

Participants

The Cognitive Communicative Speech-Language Pathology Unit at the Clinical Hospital University of Chile in Santiago of Chile (Unidad de Patología del Habla y Lenguaje Cognitivo Comunicativo del Hospital Clínico de la Universidad de Chile). This unit receives patients presenting speech and language disorders associated with brain pathology. This Unit has evaluated 1,404 aphasia cases during a period of more than 11 years (2008–2019); 915 (65%) of these patients’ records have been entered into a database. All patients were assessed using the revised Spanish version of Western Aphasia Battery (SWAB-R) (González, Hornauer-Hughes, Leyton, Neumann, & Vera, 2015; translated and adapted to Spanish by González, 2008), and the Spanish version of the Boston Diagnostic Aphasia Examination (SBDAE; Goodglass, 2005). This study was initiated with prior approval from the Hospital Clínico de la Universidad de Chile’s Institutional Ethics Committee.

For the current study, 200 adults with vascular aphasia were selected from the above database using the following inclusion criteria: (1) Patients whose evaluations included both the SWAB-R Part 1 and Part 2 were selected (504 patients); this reduced the sample to 231 cases; (2) Native Spanish speakers equal or over the age of 18 and who suffered from aphasia due to first-ever left hemisphere stroke. Thirty-one participants were excluded because they met one of the following exclusion criteria: (1) aphasia caused by intracranial hemorrhage; (2) premorbid psychiatric pathologies; (3) premorbid dementia significant cognitive disturbances, congruent with a dementia process; and (4) significant nonlinguistic cognitive disturbance impairing the language evaluation.

The 200 vascular aphasia patients were evaluated on average 6.58 months (SD = 12.94) post-onset. All patients had localized brain vascular lesions in the left hemisphere according to CT or Magnetic Resonance Imaging (MRI) scans. All imaging findings were evaluated by an experienced certified neuroradiologist from the Radiology Department of the University of Chile Clinical Hospital (Hospital Clínico de la Universidad de Chile). There were 119 men and 81 women with a mean age of 57.37 years (SD = 15.56) and mean level of education of 13.51 years (SD = 4.08) corresponding to high school (according to the Chilean education system). The sample included 195 (97.50%) right-handed participants. Handedness was determined based on direct clinical observation and/or a brief questionnaire answered by a close family member or by the patient him/herself, when possible. No patient had any previous neurological condition. All patients had a level of education high enough to solve the simple calculation tests that were administered.

Materials

Two different aphasia test batteries were administered: the SWAB-R and SBDAE, plus a written calculation ability test.

The Spanish version of the Western Aphasia Battery (SWAB) is based on the original WAB translated and adapted to Spanish by Kertesz, Pascual-Leone, and Pascual-Leone in 1990. Later, the revised SWAB (SWAB-R) was available and included the Reading and Writing subtests (Gonzalez, 2008). The validity of the SWAB-R was tested with the Boston Diagnostic Aphasia
Table 1. Spearman correlations between the two calculation subtests and AQ from the SWAB-R Part 1

<table>
<thead>
<tr>
<th>Subtest</th>
<th>Calculation SWAB-R</th>
<th>Written Calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>AQ</td>
<td>.572**</td>
<td>.617**</td>
</tr>
<tr>
<td>Spontaneous Speech</td>
<td>.516**</td>
<td>.571**</td>
</tr>
<tr>
<td>Auditory Verbal Comprehension</td>
<td>.623**</td>
<td>.564**</td>
</tr>
<tr>
<td>Repetition</td>
<td>.442**</td>
<td>.526**</td>
</tr>
<tr>
<td>Naming</td>
<td>.571**</td>
<td>.595**</td>
</tr>
</tbody>
</table>

Note. AQ = Aphasia Quotient

*Correlation significant at the 0.01 level (2-tailed)

Examination (Goodglass, 2005) and the Porch Index of Communication Ability (PICA-Porch, 1981; Hornauer-Hughes & González Victoriano, 2015). The SWAB-R validity coefficients are .93 and .94, respectively (Gonzalez et al., 2015).

The SWAB-R includes two sections.

(a) SWAB-R Part 1 was used to determine aphasia severity. We administered four subtests: Spontaneous Speech, Auditory Verbal Comprehension, Repetition, and Naming. An Aphasia Quotient (AQ) was calculated based on these four scores using the following formula: AQ = (Spontaneous speech + Comprehension + Repetition + Naming) / 4. According to the AQ, aphasia severity is interpreted as follows: 0–25 = very severe, 26–50 = severe, 51–75 = moderate, and 76 and above = mild. In our sample, the mean AQ was 59.26 (SD = 30.03). The AQ was used instead of individual subtests scores because it is a summary score that indicates global severity of oral language impairment. Additionally, Spearman rank order correlations between the SWAB-R Part 1 subtests and the arithmetic tasks showed very similar correlations to those found between the arithmetic tasks and AQ (see Table 1). Therefore, we considered it redundant to include a separate analysis of oral language subtests. Furthermore, by using an overall score, we reduced the probability of Type I error due to multiple comparisons.

(b) SWAB-R Part 2 is a supplementary instrument that included the following subtests: Reading, Writing, Praxis, Drawing, Block Design, Calculation, and Raven’s Colored Progressive Matrices (RCPM). The calculation subtest includes 12 items: three additions (5 + 4; 6 + 2; 4 + 3), three subtractions (6 – 2; 9 – 7; 8 – 3), three multiplications (4 × 3; 5 × 6; 3 × 7), and three divisions (8 ÷ 4; 6 ÷ 8; 18 ÷ 3). Each arithmetical operation is presented visually on a card with four possible answers and the patient had to select the correct one. Participants can answer orally or by pointing in order to minimize errors secondary to language problems. Each correct answer receives two points for a total score of 24 points.

(2) The SBDAE was used in determining the type of aphasia. The distribution of the number of patients with each of the type of aphasia was as follows: Global = 11 patients (5.50%), Broca = 31 patients (15.50%), Wernicke = 30 patients (15.00%), conduction = 22 patients (11.00%), transcortical sensory = 17 patients (8.50%), transcortical motor = 3 patients (1.50%), amnesic or anomic = 54 patients (27.00%), and mixed non-fluent = 32 patients (16.00%). Mixed non-fluent aphasia refers to patients with a significantly impaired expressive language and auditory comprehension deficits (below 50.00%). In Broca’s aphasia, Auditory Comprehension was above 50%, whereas in global aphasia, it was below 25%.

In order to extend the calculation assessment, an additional test was used:

**Written Calculation.** A letter-size paper including four basic arithmetical operations presented in Arabic numbers (14 + 22; 34 – 9; 16 × 5; 45 ÷ 9) and a pencil were given to the patient with the following instructions: “Please write the correct answers to the following arithmetical problems.” Participants had to start by solving the addition, followed by the subtraction, multiplication, and finally, the division problems. This subtest was scored on a 3-point scale according to the number of correct responses: 3 points for three or four correct answers, 2 points corresponding to two correct answers, 1 point corresponding to one correct answer; a zero was given when no correct answers were obtained.

**Statistical Analysis**

IBM SPSS STATISTICS 25 was used. Spearman’s correlations explored the relationship between the oral and written calculation scores and the scores on other subtests of the SWAB-R (AQ, Reading, Writing, Praxis, Drawing, Block Design, and RCPM) and the association between calculation scores and demographic variables (age, sex, and schooling) and time post-onset.

The performance of the aphasic groups on each of the arithmetic test was compared using one way analysis of variance. The three participants with Transcortical Motor aphasia were removed from these analyses. Because the assumption of homogeneity of variance was violated, we used Welch’s t-test to determine the statistical significance of the group effect over the SWAB-R.
R. Gonzalez et al. / Archives of Clinical Neuropsychology 00 (2020); 1–10

Table 2. Scores (means and standard deviations) on different variables for the total sample and the different aphasia types

<table>
<thead>
<tr>
<th>Variable/Aphasia</th>
<th>Broca (n = 31)</th>
<th>Wernicke (n = 30)</th>
<th>Conduction (n = 22)</th>
<th>Transcortical Sensory (n = 17)</th>
<th>Transcortical Motor (n = 3)</th>
<th>Amnesic (n = 54)</th>
<th>Global (n = 11)</th>
<th>Mixed Non-fluent (n = 32)</th>
<th>All Aphasias (N = 200)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age Mean (SD)</td>
<td>55.77 (16.88)</td>
<td>61.57 (15.55)</td>
<td>52.59 (17.39)</td>
<td>64.18 (15.87)</td>
<td>54.00 (14.00)</td>
<td>57.37 (13.80)</td>
<td>57.45 (13.99)</td>
<td>54.94 (15.72)</td>
<td>57.37 (15.56)</td>
</tr>
<tr>
<td>Schooling Mean (SD)</td>
<td>13.74 (3.49)</td>
<td>12.17 (4.54)</td>
<td>13.64 (3.72)</td>
<td>14.06 (4.98)</td>
<td>12.00 (2.00)</td>
<td>13.61 (3.99)</td>
<td>12.82 (4.58)</td>
<td>14.41 (4.00)</td>
<td>13.51 (4.08)</td>
</tr>
<tr>
<td>Time post onset Mean (SD)</td>
<td>8.76 (22.16)</td>
<td>6.80 (13.07)</td>
<td>6.67 (10.38)</td>
<td>4.62 (4.70)</td>
<td>3.16 (2.01)</td>
<td>5.18 (12.16)</td>
<td>4.51 (2.58)</td>
<td>8.65 (9.26)</td>
<td>6.58 (12.94)</td>
</tr>
<tr>
<td>AQ Mean (DS)</td>
<td>67.01 (24.14)</td>
<td>47.83 (18.40)</td>
<td>71.03 (13.68)</td>
<td>67.07 (19.39)</td>
<td>33.40 (34.35)</td>
<td>87.67 (9.37)</td>
<td>4.23 (2.72)</td>
<td>23.61 (13.75)</td>
<td>59.26 (30.03)</td>
</tr>
<tr>
<td>Reading Mean (SD)</td>
<td>77.85 (17.76)</td>
<td>46.55 (26.09)</td>
<td>76.02 (12.02)</td>
<td>59.59 (21.73)</td>
<td>23.17 (40.13)</td>
<td>83.15 (18.30)</td>
<td>11.27 (13.30)</td>
<td>37.16 (19.06)</td>
<td>61.84 (29.22)</td>
</tr>
<tr>
<td>Writing Mean (SD)</td>
<td>64.78 (24.59)</td>
<td>34.52 (23.79)</td>
<td>60.93 (17.68)</td>
<td>50.94 (21.11)</td>
<td>14.00 (11.82)</td>
<td>77.20 (18.18)</td>
<td>4.00 (4.93)</td>
<td>23.45 (15.44)</td>
<td>51.28 (30.04)</td>
</tr>
<tr>
<td>Praxis Mean (SD)</td>
<td>45.90 (10.19)</td>
<td>37.60 (12.29)</td>
<td>49.64 (7.31)</td>
<td>45.24 (9.66)</td>
<td>34.33 (15.95)</td>
<td>52.09 (5.43)</td>
<td>15.45 (13.71)</td>
<td>27.78 (9.69)</td>
<td>41.94 (14.06)</td>
</tr>
<tr>
<td>Drawing Mean (SD)</td>
<td>20.02 (5.54)</td>
<td>16.20 (7.75)</td>
<td>20.98 (6.07)</td>
<td>18.38 (4.04)</td>
<td>10.33 (6.66)</td>
<td>21.61 (5.56)</td>
<td>5.59 (6.16)</td>
<td>14.88 (7.54)</td>
<td>18.08 (7.39)</td>
</tr>
<tr>
<td>Block Design Mean (SD)</td>
<td>7.71 (2.15)</td>
<td>6.60 (2.36)</td>
<td>7.45 (2.06)</td>
<td>6.82 (1.81)</td>
<td>6.33 (3.06)</td>
<td>7.20 (2.64)</td>
<td>2.82 (3.52)</td>
<td>6.75 (2.51)</td>
<td>6.86 (2.70)</td>
</tr>
<tr>
<td>RCPM Mean (SD)</td>
<td>26.65 (8.48)</td>
<td>20.83 (7.85)</td>
<td>25.64 (7.16)</td>
<td>20.41 (7.16)</td>
<td>12.67 (6.11)</td>
<td>25.72 (7.11)</td>
<td>11.82 (9.92)</td>
<td>22.88 (7.81)</td>
<td>23.26 (8.50)</td>
</tr>
</tbody>
</table>

Note. AQ = Aphasia Quotient, maximum score = 100; RCPM = Raven Colored Progressive Matrices, maximum score = 100; Reading maximum score = 100; Writing maximum score = 100; Praxis maximum score = 60; Drawing maximum score = 30; Block Design maximum score = 9.

Table 3. Scores (means, standard deviations and percent correct) in the calculation subtests for the total sample and the different aphasia types

<table>
<thead>
<tr>
<th>Calculation SWAB-R</th>
<th>Written Calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Broca (n = 31)</td>
<td>20.77</td>
</tr>
<tr>
<td>Wernicke (n = 30)</td>
<td>14.73</td>
</tr>
<tr>
<td>Conduction (n = 22)</td>
<td>20.36</td>
</tr>
<tr>
<td>Transcortical Sensory (n = 17)</td>
<td>15.24</td>
</tr>
<tr>
<td>Transcortical Motor (n = 3)</td>
<td>12.67</td>
</tr>
<tr>
<td>Amnesic (n = 54)</td>
<td>20.11</td>
</tr>
<tr>
<td>Global (n = 11)</td>
<td>4.91</td>
</tr>
<tr>
<td>Mixed non-fluent (n = 32)</td>
<td>13.78</td>
</tr>
<tr>
<td>All Aphasias (N = 200)</td>
<td>17.06</td>
</tr>
</tbody>
</table>

Note. Oral calculations maximum score 24. Written calculations maximum score: 3

Calculation and Written Calculation scores. Dunnett’s post hoc tests were used to for comparing multiple aphasia groups. To control for Type I error due to multiple comparisons, only those with p < .001 were considered significant.

The predictive value of the verbal and nonverbal subtests to oral and written calculation scores was assessed with two linear regressions. The predictors in each regression analysis were AQ, Reading, Writing, Praxis Drawing, Block Design, and RCPM. Demographic variables (age and schooling) were also included in the regression models.

Results

The average scores of each aphasia group on the oral and written language and nonverbal language subtests are presented in Table 2. The AQ, Reading, and Writing, Praxis, and Drawing scores were highest in Amnesic aphasia, indicating fewer symptoms of aphasia, alexia, agraphia, and apraxia in this group compared to the other aphasia types. The highest scores for Block Design and RCPM scores were found in the Broca’s aphasia group.

Table 3 presents the scores of the two calculation subtests for the total sample and the different aphasia types. Calculation difficulties were more severe in the more extended types of aphasia, Global, and Mixed non-fluent. Participants with these two types of aphasia had, on average, 20.45% and 57.41% correct responses in Calculation SWAB-R and 12.00% and 29.00% in written calculations. However, there were also particularly severe impairments in the Transcortical Motor aphasia group. Calculation scores were very similar in Broca’s, Conduction, and Amnesic aphasia. Welch’s t-test showed a significant effect of the type of aphasia on the Calculation SWAB-R, F(6, 60, 158) = 15.518, p < .001 and the Written calculations scores, F(6, 63, 559) = 18.537, p < .001. Dunnett’s post hoc test comparing Calculation SWAB-R scores between aphasia types showed: (1) significantly higher scores in Broca compared to Wernicke (p = .018) and compared to Global and Mixed non-fluent (p = .001); (2) Wernicke had lower scores than Conduction (p = .046), Amnesic (p = .025) and Global (p = .007); (3) Conduction had higher scores than Mixed non-fluent (p = .001) and Global (p < .001); (4) Global was significantly lower scores than all the other aphasia types (p < .001); and (5) Transcortical Sensory had significantly higher scores than Global (p = .007).
R. Gonzalez et al. / Archives of Clinical Neuropsychology 00 (2020); 1–10

compared to Wernicke (aphasia scores were significantly higher than Global aphasia scores (\(p < .001\)) and to all other aphasia types (\(p < .001\)) except Conduction and Anomic; (2) Wernicke’s aphasia scores were significantly higher than Global aphasia scores (\(p = .050\)) and significantly lower than Anomic (\(p < .001\)); (3) Conduction aphasia scores were significantly higher from Global (\(p = .003\)) and non-fluent Mixed (\(p = .023\); (4) Transcortical Sensory was more impaired than Broca (\(p < .001\)) and Anomic (\(p < .001\)) in this test.

Table 4 presents the correlations between the two calculation subtests, SWAB-R Part 1 (AQ) and the other subtests of the SWAB-R Part 2 (Reading, writing, praxis, drawing, block design, and RCPM). All correlations were statistically significant. In general, SWAB-R calculation correlations were higher than Written Calculation correlations, ranging from .550 to .737, and .378 to .611, respectively. The highest correlations of SWAB-R calculations were with Reading and Writing and the lowest with Block design and RCPM. The correlation between both calculation scores was .60 (\(p < .001\)).

The correlations between calculation subtests and demographic variables are included in Table 5. Age showed a significant negative correlation with both calculation subtests indicating that the older the participant was, the worse the calculation score. This association was stronger with the SWAB-R scores than with the written calculation scores. A significant positive correlation between SWAB-R calculation and years of schooling was also found. Individuals with high scores in this subtest had more years of education. Sex and Time post-onset did not show any correlations with the calculation scores.

The regression models are presented in Table 6. These models predicted 43% of the variance in SWAB-R calculations (\(p < .001\)), and 15% of the variance in Written Calculations (\(p < .001\)) for the whole aphasia sample. Education, Reading, Block Design, and RCPM were significant predictors in the first model, and AQ and Writing in the second model.

### Table 4. Spearman correlations between the two calculation subtests and demographic variables (n = 200)

<table>
<thead>
<tr>
<th></th>
<th>Calculation SWAB-R</th>
<th>Written Calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>AQ</td>
<td>.572**</td>
<td>.617**</td>
</tr>
<tr>
<td>Reading</td>
<td>.737**</td>
<td>.587**</td>
</tr>
<tr>
<td>Writing</td>
<td>.714**</td>
<td>.611**</td>
</tr>
<tr>
<td>Praxis</td>
<td>.639**</td>
<td>.560**</td>
</tr>
<tr>
<td>Drawing</td>
<td>.657**</td>
<td>.463**</td>
</tr>
<tr>
<td>Block Design</td>
<td>.550**</td>
<td>.378**</td>
</tr>
<tr>
<td>RCPM</td>
<td>.643**</td>
<td>.415**</td>
</tr>
</tbody>
</table>

Note. AQ = Aphasia Quotient; RCPM = Raven Colored Progressive Matrices.

**Correlation significant at the 0.01 level (2-tailed)**

### Table 5. Spearman correlations between the two calculation subtests and demographic variables (n = 200)

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>Sex</th>
<th>Schooling</th>
<th>Time post on set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculation (SWAB-R)</td>
<td>−.338**</td>
<td>.082</td>
<td>.333**</td>
<td>−.106</td>
</tr>
<tr>
<td>Written Calculation</td>
<td>−.143*</td>
<td>.005</td>
<td>.106</td>
<td>−.135</td>
</tr>
</tbody>
</table>

Note: *\(p < 0.05\); **\(p < 0.001\) (2-tailed)

### Table 6. Linear regression analyses predicting calculation scores

<table>
<thead>
<tr>
<th>Predictors</th>
<th>B</th>
<th>SE</th>
<th>t</th>
<th>p</th>
<th>Predictors</th>
<th>B</th>
<th>SE</th>
<th>t</th>
<th>p</th>
<th>VIF</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>−0.004</td>
<td>0.023</td>
<td>−0.008</td>
<td>−0.153</td>
<td>.879</td>
<td>Age</td>
<td>0.003</td>
<td>0.066</td>
<td>0.972</td>
<td>0.332</td>
<td>1.507</td>
</tr>
<tr>
<td>Education</td>
<td>0.172</td>
<td>0.085</td>
<td>0.100</td>
<td>2.037</td>
<td>.043</td>
<td>Education</td>
<td>−0.010</td>
<td>0.013</td>
<td>−0.050</td>
<td>−0.769</td>
<td>0.443</td>
</tr>
<tr>
<td>AQ</td>
<td>−0.010</td>
<td>0.023</td>
<td>−0.042</td>
<td>−0.422</td>
<td>0.673</td>
<td>AQ</td>
<td>0.008</td>
<td>0.004</td>
<td>0.281</td>
<td>2.153</td>
<td><strong>0.033</strong></td>
</tr>
<tr>
<td>Reading</td>
<td>0.093</td>
<td>0.024</td>
<td>0.387</td>
<td>3.844</td>
<td>&lt;.01</td>
<td>Reading</td>
<td>0.000</td>
<td>0.004</td>
<td>−0.004</td>
<td>−0.027</td>
<td>0.978</td>
</tr>
<tr>
<td>Writing</td>
<td>0.032</td>
<td>0.025</td>
<td>0.135</td>
<td>1.253</td>
<td>0.212</td>
<td>Writing</td>
<td>0.009</td>
<td>0.004</td>
<td>0.341</td>
<td>2.392</td>
<td><strong>0.018</strong></td>
</tr>
<tr>
<td>Praxis</td>
<td>0.020</td>
<td>0.043</td>
<td>0.041</td>
<td>0.633</td>
<td>.226</td>
<td>Praxis</td>
<td>−0.003</td>
<td>0.007</td>
<td>−0.056</td>
<td>−0.494</td>
<td>0.622</td>
</tr>
<tr>
<td>Drawing</td>
<td>0.058</td>
<td>0.071</td>
<td>0.061</td>
<td>0.814</td>
<td>0.417</td>
<td>Drawing</td>
<td>−0.001</td>
<td>0.011</td>
<td>−0.006</td>
<td>−0.065</td>
<td>0.948</td>
</tr>
<tr>
<td>Block Design</td>
<td>0.445</td>
<td>0.149</td>
<td>0.170</td>
<td>2.992</td>
<td><strong>0.003</strong></td>
<td>Block Design</td>
<td>0.019</td>
<td>0.023</td>
<td>0.063</td>
<td>0.843</td>
<td>0.400</td>
</tr>
<tr>
<td>RCPM</td>
<td>0.135</td>
<td>0.060</td>
<td>0.162</td>
<td>2.258</td>
<td><strong>0.025</strong></td>
<td>RCPM</td>
<td>0.018</td>
<td>0.009</td>
<td>0.183</td>
<td>1.926</td>
<td>0.056</td>
</tr>
</tbody>
</table>

Note. AQ = Aphasia Quotient; RCPM = Raven Colored Progressive Matrices.

### Dunnett’s post hoc test also demonstrated the following: (1) significantly higher scores in Written Calculations in Broca compared to Wernicke (\(p < .001\)) and to all other aphasia types (\(p < .001\)) except Conduction and Anomic; (2) Wernicke’s aphasia scores were significantly higher than Global aphasia scores (\(p = .050\)) and significantly lower than Anomic (\(p < .001\)); (3) Conduction aphasia scores were significantly higher from Global (\(p = .003\)) and non-fluent Mixed (\(p = .023\); (4) Transcortical Sensory was more impaired than Broca (\(p < .001\)) and Anomic (\(p < .001\)) in this test.
In the first model, the AQ was not a significant predictor, suggesting that aphasic patients with more years of education, more reading skills, higher scores in Block design, and better performance in RCPM have higher probabilities of performing better in SWAB-R calculations, independently of the severity of the aphasia. The second regression model suggested that participants with higher AQ (less severe aphasia), and more preserved writing skills had a higher chance of performing better in the written arithmetic operation test. To rule out the possibility that calculation ability on this task was confounded by agraphia, rather than revealing the nature of calculation deficits, a stepwise linear regression was performed. Writing scores were entered as predictors in step 1 and all the remaining predictors were entered in step 2. Results showed that writing scores alone explained 38% of the variance (adjusted $R^2 = .38$; $F(1,199) = 124.969; p < .001$). The percentage of variance added by the additional predictors was 2% (adjusted $R^2 = .40$; $F$ change (9,189) = 1.59; $p = .121$). Once writing ability was controlled for, the contributions of verbal and nonverbal performance on calculation ability were nonsignificant. It is important to state that the writing ability test included, among other items, writing numbers 1 to 20 and writing to dictation of numbers 5, 61, 32, 700, and 1867. Score on these items accounted for 15% of the total score in the writing ability test.

The variance inflation factor (VIF) values for each predictor in the regression models are shown in Table 5. All VIFs are below 10, suggesting that multicollinearity between the predictors did not influence the reliability of the model’s results. Because the predictors and the sample are equivalent for both regression models, the VIFs values are presented on the table once. The correlation coefficients between the predictors included in the linear regression models were below .50. Medium correlations with values between ±0.30 and ±0.49 were found between writing and reading, writing, and AQ, age and RCPM, and praxis and drawing scores. Small correlations with values between ±.23 and ±.29 were observed among AQ and both level of education and reading and between RCPM and four variables: education, Block design, drawing, and reading.

Discussion

This study illustrates the calculation difficulties found in aphasia due to a unilateral left hemisphere vascular event. It describes the relationships between acquired language difficulties and performance in simple one-digit and written two-digit arithmetical operations. Calculation difficulties in both calculation tests were registered in all aphasia subgroups, but the severity of these difficulties varied across aphasia groups. Global and Mixed Non-fluent aphasia had the most severe problems, whereas deficits were minimal in Amnestic aphasia. These results are partially congruent with previous research.

Delazer et al. (2003) reported that in solving single-digit problems presented visually, 3 out of 10 amnestic aphasics made no errors, and Broca’s and Global aphasics answered without errors. They also found a similar profile in the written calculations, with 4 out of 10 patients with Amnestic aphasia performing without errors, whereas all Wernicke and Global patients with aphasia had errors. In their sample, more participants with Broca’s aphasia had difficulties in solving visually presented basic arithmetic facts than with Wernicke’s aphasia, but when solving written arithmetical problems, the difficulties were more evident in Wernicke’s than in Broca’s patients. Noteworthy, calculation abilities in the current study were more preserved in Broca’s than Wernicke’s aphasia. Differences in sample size may contribute to the discrepant results between the two studies. Delazer et al.’s sample of Broca’s and Wernicke’s patients was less than half the sample of the current study; this difference in sample size provides a stronger statistical power to the current study. In addition, the present study included the category of Mixed Non-fluent aphasia not used in Delazer et al.’s study; these patients often have a profile similar to Broca’s but with more severe symptoms. It is possible that some of the participants in our sample with a profile equivalent to Broca’s profile in Delazer et al.’s study were a part of the Mixed non-fluent aphasia group, leaving the Broca group with less severe cases of non-fluent aphasia.

Our results stating the superior arithmetic performance of Broca’s over Wernicke’s patients in one-digit basic operations support previous observations. Damhen et al. (1982) analyzed the ability of a group of aphasia patients in solving arithmetic problems similar to the problems used in the current study. In their study, Broca’s patients had a mean correct score of 14.6 (range: 12–18) out of 20 (73% correct) in pointing to the correct answers compared to Wernicke’s patients, who had a score of 9.6 (range: 7–13; 48% correct). Therefore, in their study as well as in the current study, Broca’s participants had scores (range: 12–18) out of 20 (73% correct) in pointing to the correct answers compared to Wernicke’s patients, who had a score (range: 7–13; 48% correct). Differences in sample size may contribute to the discrepant results between the two studies. Delazer et al. (2003) reported that in solving single-digit problems presented visually, 3 out of 10 amnestic aphasics made no errors, and Broca’s and Global aphasics answered without errors. They also found a similar profile in the written calculations, with 4 out of 10 patients with Amnestic aphasia performing without errors, whereas all Wernicke and Global patients with aphasia had errors. In their sample, more participants with Broca’s aphasia had difficulties in solving visually presented basic arithmetic facts than with Wernicke’s aphasia, but when solving written arithmetical problems, the difficulties were more evident in Wernicke’s than in Broca’s patients. Noteworthy, calculation abilities in the current study were more preserved in Broca’s than Wernicke’s aphasia. Differences in sample size may contribute to the discrepant results between the two studies. Delazer et al.’s sample of Broca’s and Wernicke’s patients was less than half the sample of the current study; this difference in sample size provides a stronger statistical power to the current study. In addition, the present study included the category of Mixed Non-fluent aphasia not used in Delazer et al.’s study; these patients often have a profile similar to Broca’s but with more severe symptoms. It is possible that some of the participants in our sample with a profile equivalent to Broca’s profile in Delazer et al.’s study were a part of the Mixed non-fluent aphasia group, leaving the Broca group with less severe cases of non-fluent aphasia.

Our results stating the superior arithmetic performance of Broca’s over Wernicke’s patients in one-digit basic operations support previous observations. Damhen et al. (1982) analyzed the ability of a group of aphasia patients in solving arithmetic problems similar to the problems used in the current study. In their study, Broca’s patients had a mean correct score of 14.6 (range: 12–18) out of 20 (73% correct) in pointing to the correct answers compared to Wernicke’s patients, who had a score of 9.6 (range: 7–13; 48% correct). Therefore, in their study as well as in the current study, Broca’s participants had scores 25% higher than Wernicke’s participants. Similarly, Ardila and Rosselli (1989) found that the percentage of errors in mental problems similar to the problems used in the current study. In their study, Broca’s patients had a mean correct score of 14.6 (range: 12–18) out of 20 (73% correct) in pointing to the correct answers compared to Wernicke’s patients, who had a score (range: 7–13; 48% correct). Therefore, in their study as well as in the current study, Broca’s participants had scores 25% higher than Wernicke’s participants. Similarly, Ardila and Rosselli (1989) found that the percentage of errors in mental operations in Broca’s aphasia was 55%, whereas, in Wernicke’s aphasia, it was 66%.

In the present study, we found significant correlations between the performance of aphasia participants on basic calculation skills and the performance on oral (Spontaneous Speech, Auditory Verbal Comprehension, Repetition, and Naming) and written (Reading and Writing) language tasks. This observation supports the existence of shared mechanisms in language and numerical abilities (Baldo & Dronkers, 2007; Nakai & Okanoya, 2018). However, our findings also suggest that this shared mechanism is not uniform across aphasia types. Some aphasia groups disclosed severe arithmetic deficits (i.e., global, whereas other types ranged from medium [i.e., Wernicke] to mild deficits [i.e., Broca and Amnestic]). Therefore, there is only a partial cognitive overlap between language and numerical abilities in this sample of diverse aphasic patients. Previous research has described preserved numerical capacities even in patients with significant left hemisphere lesions and severe aphasia (Varley et al., 2005).
Functional neuroimaging has identified several common brain areas for calculations. In a meta-analyses, Arsalidou and Taylor (2011) found that addition, subtraction, and multiplication problems activated occipitotemporal visual areas, parietal areas, frontal and prefrontal regions, as well as other subcortical structures. Multiplication problems were associated additionally with the activation of temporal areas. Brain activity was greater in the left hemisphere, particularly for additions. Some brain areas identified in this calculation circuitry overlap with language peri-sylvian areas (Ardila & Rosselli, 2002). Several functional MRI studies have found that arithmetic and language share the neural basis for processing syntactic structures in the left inferior frontal gyrus (Nakai & Okanova, 2018). Moreover, aphasia patients share brain networks for arithmetic and language comprehension (Baldo & Dronkers, 2007). All participants in the present study had a confirmed vascular lesion in the left hemisphere, and although we did not analyze the location of these lesions, we made this assumption by looking at the language deficits and concluding that the damage was mostly circumscribed to the perisylvian area (Benson & Ardila, 1996) and involved the overlapping arithmetic brain circuit.

We also found significant correlations between calculation ability and scores on nonverbal tests (Block Design, Drawing, and RCPM). This second observation supports the involvement of spatial visualization abilities in solving arithmetical problems, as reported by Danhem et al. (1982). These authors used a principal component analysis including several arithmetic and spatial visualization test scores (i.e., two-dimensional figure completion, determination of surfaces making up a three-dimensional figure, and construction of three-dimensional figures) obtained from aphasic and right hemisphere patients and normal controls. The scores loaded onto two main factors and explained 83.4% of the total variance. The first factor accounted for 78.9% and the second for 21.1% of the common variance. Most arithmetic tests were included in the first factor, whereas the three tests of spatial visualization as well as the arithmetic tests with a strong spatial component (comprehension of operational signs with tasks given as circle arrays, digits, and number words), loaded onto the second factor. The authors concluded that there were distinctions between two groups of arithmetic tests, specifically some with a stronger visuo-spatial component (i.e., tests assessing the comprehension of the elementary arithmetic operational signs), whereas other tests included a stronger numeric-symbolic component (i.e., tests assessing number comprehension). The test of elementary operation, similar to the one-digit arithmetic (Calculation SWAB-R) used in the current study, loaded onto both factors with higher loading in the first (.83) than in the second factor (.36). Our results confirm previous findings that calculation abilities are language-dependent and language-independent, as different authors (e.g., Ardila & Rosselli, 2002; Boller & Grafman, 1983; Spiers, 2018) have suggested.

Age presented significant negative correlations with both calculation subtests, indicating that older participants performed worse than younger subjects. This negative association between numerical abilities and age emphasize the idea that arithmetical abilities significantly decrease during the aging process (Ardila & Rosselli, 1989). In conclusion, calculation deficits associated with language brain pathology seem to be more evident in older patients.

Despite the strong significant associations between calculation scores and oral verbal tests, our results showed that about two-thirds of the variance of the performance on simple basic arithmetic skills (adding, subtracting, multiplying, and dividing one-digit numbers) were predicted from the aphasic patients’ educational level and abilities to read and perform complex nonverbal tests (such as building designs with blocks and completing matrices independently from the aphasia symptoms). Indeed, aphasia severity (AQ) did not significantly predict scores on the Calculation section of the SWAB-R. These findings give additional support to the independence of oral language and numerical abilities in aphasia as well as support the association between reading and arithmetic. A recent meta-analysis showed that arithmetic and reading test performance during the school age share, on average, 30.3% of the variance (Singer & Strasser, 2017). Additionally, years of education significantly contributed to the regression model supporting the role of this demographic variable in basic cognitive processes (Ritchie & Tucker-Drob, 2018).

The variables included in the regression model for two-digit written calculation predicted about 40% of the scores’ variance; AQ and writing skills were significant predictors. However, when writing skills were controlled for in a stepwise regression model, the AQ did not contribute additional variance to the model. Consequently, the severity of the aphasia did not affect this second calculation test once writing was controlled for; participants with agraphia were more likely to have low scores on the two-digit calculation test. This finding supports the co-occurrence of acalculia with agraphia after left hemisphere damage (Benson & Cummings, 1985). Because the majority of patients with aphasia also experience writing deficits (Basso, Taborelli, & Vignolo, 1978), the agraphia associated with acalculia in the current sample could originate from diverse sources, including motor agraphia, apraxic agraphia, or aphasic agraphia (Benson & Ardila, 1996).

Our findings seem to suggest that the language mediation of calculation operations in aphasic patients depends on the type of task, whereas nonverbal visuospatial skills and reading abilities play a very important role in the performance of basic arithmetic abilities. Acalculia due to the inability to solve simple mathematical tasks (Calculation subtest of the SWAB-R) in aphasia patients seems to take place independently of aphasia severity. However, written language deficits in these patients will be relevant during acalculia testing with increasingly complex written arithmetical problems.
Due to the evident constraints of the current study, certain associations were not examined. Considering the demands that numerical calculations place on working memory systems (Cragg et al., 2017), it would have been particularly interesting to include working memory as a predictor. Needless to say, it would have been informative to look at the relationship between syntactical comprehension and calculation abilities (Nakai & Okanoya, 2018). Furthermore, the use of the classical classification of aphasia is limiting, and it might be more informative to use aphasia features as predictors. These questions may be examined in future studies.

Our study has a diversity of shortcomings that should be recognized. The most significant is the limited number of numerical tasks that were used. We did not administer a comprehensive calculation ability test battery, including the different types and levels of numerical knowledge (e.g., comprehension of numbers and arithmetic signs, magnitude estimation, solving oral and written mathematical problems, transcoding, etc.) done by others (Ardila & Rosselli, 1989; Danhem et al., 1982; Delazer et al., 2003). Furthermore, the specific types of errors found in the different aphasia groups were not analyzed, and the two most significant demographic variables—education and age—were not balanced.

However, regardless of these limitations, our study included a large sample of aphasic patients representing eight distinct types of aphasia. To our knowledge, no previous study has analyzed calculation skills in such a large number of patients with aphasia, allowing not just validation of previous findings but suggesting new regression models with strong statistical power. Results from the current study advance our understanding of the calculation disturbances found in aphasia and the variables that can potentially predict the scores in calculation tests in patients with language disturbances.

Future research should extend these findings using a more complete calculation battery including more diverse complex numerical operations. Forthcoming studies should also distinguish types of errors in arithmetical operations and their association with specific language disturbances, such as paraphasias, grammatical impairments, word-finding difficulties, etc. Theoretical models integrating our current knowledge about the brain organization of calculation abilities are undoubtedly required.

Conflict of Interest

None declared.

Acknowledgements

Our gratitude to Adriana Ardila and Valeria Torres for their editorial support.

References


