circular canal could cause a spontaneous downward drift of the eyes and compensatory upward saccades, resulting in primary position upbeat nystagmus. A tonic imbalance in vertical vestibulo-ocular signals in our

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Acalculia Following a Dominant-Hemisphere Subcortical Infarct

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• A 60-year-old, right-handed woman experienced persistent impairment of calculating ability following a subcortical infarct involving the head of the left caudate nucleus, the anterior superior putamen, and the anterior limb of the internal capsule extending superiorly into the periventricular white matter. Acalculia resulted from defects of numerical syntax, the loss of ability to manipulate mathematical concepts, and impaired working memory.

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Acalculia, or impaired calculating ability, has been described as a consequence of cerebral cortical lesions usually affecting the dominant hemisphere. Acalculia is generally associated with other neuropyschological deficits, most frequently aphasia, spatial disorganization, and

impaired short-term memory. We assessed a patient who had acalculia following a dominant-hemisphere subcortical infarct.

REPORT OF A CASE Patient Description

A 60-year-old, right-handed woman, a department store executive, experienced the sudden onset of speech arrest that improved over three hours. Her family physician noted her to be hypertensive (blood pressure, 240/140 mm Hg), con-

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fused, and aphasic, but with no limb weakness. Two months later the patient underwent neurologic assessment. She had returned to work but complained of persisting impairment of memory and wordfinding with particular difficulty in calculating, which was a major component of her work. On examination she had minimal right-sided facial weakness but no additional cranial nerve deficits. Examination of the limbs demonstrated normal power, tone, coordination, and sensation. Muscle reflexes were brisk and symmetric. The right plantar response was extensor. The patient was alert and oriented, and there was no obvious speech disorder. She recalled three paired objects at three minutes. She made some mistakes on finger naming, but there was no left-right disorientation, and color naming was intact. The patient was unable to calculate serial subtraction of sevens and calculated serial subtraction of fives with several mistakes. She could not perform simple multiplication and when asked to multiply, added numbers by counting on her fingers. She repeated five numbers forward and reversed these correctly after two attempts.

A computed tomographic scan demonstrated an infarct involving the head of the left caudate nucleus, the superior anterior portion of the putamen, and the anterior extremity of the internal capsule extending superiorly into the periventricular white matter (Figure).

The patient underwent formal neuropsychological assessment six months following her stroke. She still complained of difficulty calculating, but she could otherwise perform her job satisfactorily, and an assistant had been assigned to carry out all of her calculations.

Neuropsychological Assessment

Numbers can be written in two notation systems: alphabetic and digital. Linguistic components of acalculia were investigated by studying the patient's ability to transcode from alphabetic to digital notation and the reverse.1 Our patient was presented with a list of numbers in digital form and transcoded these verbally to alphabetic form. In transcoding larger numbers the patient tended to use a termby-term strategy, eg, 5, 201, 701 was transcoded to "five million and two hundred and one and seven zero one." Errors made were errors in the syntactic structure of the serial organization of numerals. The patient was presented with numbers in alphabetic form verbally and then transcoded these to digital form. Again the patient used a term-by-term transcoding strategy for larger numbers, eg, forty thousand, one hundred ninety-nine was coded to 40 000 99. There was impairment in handling the syntactic structure of numerical strings. Syntactic errors of this type are often seen in association with Broca's aphasia.2

The patient's ability to comprehend the numerical difference between multidigit numbers was investigated by presenting a series of multidigit numbers and request-



Computed tomographic scan shows area of decreased density involving left caudate nucleus, anterior superior putamen, and anterior limb of internal capsule extending superiorly into periventricular white matter.

ing that she indicate the larger of the two numbers. An element of conflict was introduced when the smaller number of the pair contained higher digits in all categories below the highest.³ The patient performed this task without difficulty, indicating that her assessment of numerical value was based on the categorical structure of the number rather than evaluation of the component digits.

The patient's ability to perform serial arithmetic operations was studied. She was able to count to 20 and then backward to zero without error. Three errors were made in counting backward from 20 by threes. She was unable to advance past 93 in serial subtraction of sevens from 100. Serial subtraction requires concentration, the ability to sequence arithmetical tasks, and stability of memory.

The patient was asked to calculate the number of items in a continuous or discontinuous series of dots. In some series the dots were divided into equal groups. The patient counted all of the series correctly. A multiplication strategy was employed in counting grouped items, indicating an ability to use this operation spontaneously and appropriately.

Oral arithmetic was tested by giving the patient a series of simple examples using each of the four basic operations. Errors were made in each of the operations, but were most frequent with division.

Written arithmetic was tested. Addition was well performed with few errors. Subtraction proved to be more difficult, with errors occurring predominantly in borrowing functions. Multiplication was performed accurately when it involved simple use of the multiplication tables. More complex multiplication caused greater difficulty with frequent errors. Importantly, there was no evidence for spatial disorganization, and a proper arrangement of columns was used. Division caused the greatest difficulty. The patient substituted other operations for division and could not correct her errors when prompted.

Complex arithmetical functions with less dependence on automatic processes were tested. Serial arithmetical operations involving three components, eg, 12 + 9 - $6 = \dots$ require memorized retention of part of the operation. The patient was unable to perform these serial operations without writing down the intermediate result. Arithmetical problems including the answer but excluding the sign rule out the possibility of automatic performance, eg, $10 \dots 2 = 8$. The patient was unable to complete these problems even when shown examples. The patient was also unable to perform calculations when the answer and sign were given but one component was excluded, eg, 12 - ... = 8.

Assessment by the Boston Diagnostic Aphasia Evaluation⁴ demonstrated a normal profile with no aphasic deficit. Separate tests of oral comprehension demonstrated slight impairment. The patient complained that difficulty concentrating and poor memory accounted for impaired comprehension test results.

The patient was tested with the Wechsler Adult Intelligence Scale-Revised,5 and she performed within the average range expected for her age on all subsets but three. The exceptions were Arithmetic, Similarities, and Object Assembly. Her full-scale IQ was 82, and there was evidence to suggest this was below her premorbid intellectual ability. She performed within the normal range on the Williams Delayed Recall Test.⁶ She performed poorly on the Trail Making Test,⁷ with apparent impaired visual scanning skills and difficulty with sequential thinking. Performance on the Benton Visual Retention Test-Revised Form⁸ was significantly impaired. The patient's performance when tested with the Wisconsin Card Sorting

Test⁹ was markedly impaired, with many perseverative errors and an inability to achieve any categories.

COMMENT

The patient demonstrated a numerical linguistic defect with disturbance of syntax in transcoding large numbers. Comprehension of the categorical structure of multidigit numbers was not disturbed. She retained her ability to perform simple, relatively automatic calculations, but there was impairment of more complex nonaucalculations, impaired tomatized working memory for calculations, and loss of ability to manipulate mathematical concepts. The patient showed impairment with a range of psychometric tasks with impaired immediate nonverbal memory, impaired visuospatial skills, and difficulty with sequential thinking. A computed tomographic scan obtained four months following her stroke demonstrated a subcortical lesion involving the head of the left caudate nucleus, the anterior superior putamen, and the anterior limb of the internal capsule extending superiorly into the periventricular white matter (Figure). It was presumed but not conclusively demonstrated that this lesion was an infarct in the territory of a lateral lenticulostriate vessel and that there was no additional cortical lesion.

A classification of acquired disorders of calculation based on the mechanisms presumed responsible has been proposed by Hécaen¹⁰: (1) alexia and agraphia for digits and numbers; (2) acalculia resulting from spatial defects; and (3) anarithmetria—acalculia due to inability to perform arithmetical operations. Alexia and agraphia for numbers is generally associated with other aphasic deficits. This has been the result of either a lesion of the dominant hemisphere or bilateral cerebral disease. Acalculia of the spatial type is the result of impaired

spatial organization of numbers. Associated neuropsychological disturbances included spatial agnosia and visuoconstructive apraxias. The corresponding cerebral lesions involved the nondominant hemisphere or were bihemispheric. Anarithmetria is associated with additional neuropsychological deficits but excludes alexia and agraphia for numbers and spatial disorganization of numbers. In most cases the associated cerebral lesions involved the dominant hemisphere, but occasionally isolated, nondominant hemisphere pathologic features were seen.

Our patient experienced difficulty calculating that was disproportionate to other areas of cognitive dysfunction. Calculation is a complex psychological procedure that may be disturbed at many levels. Our patient demonstrated intact ability to perform elementary arithmetical operations but difficulty with more complex calculations with defective numerical syntax, loss of ability to manipulate mathematical concepts, and impaired working memory best classified as anarithmetria. Impaired performance on the Trail Making Test and the Wisconsin Card Sorting Test indicated that defective conceptual thinking and working memory were not confined to calculation. Other authors have reported defects of memory¹¹ or general cognitive impairment' associated with anarithmetria.

Acalculia has previously been described as a consequence of cerebral cortical lesions. A single case of acalculia following a deep, left hemispheric infarct involving the anterior and posterior lentiform nucleus, superior caudate nucleus, and the adjacent white matter has been reported by Whittaker et al.¹² Both the described location of the lesion and the resulting acalculia are similar to those in our patient.

Animal studies have indicated the impairment of complex behavior following bilateral lesion of the heads of the caudate nuclei.13 Caudate lesions impair performance on tasks involving spatial choice and memory and disrupt responses to reinforcement and conditioning. Similar behavioral changes are produced by ablation of the corresponding frontal cortical areas that project to the caudate. Our patient had marked impairment of performance on the Wisconsin Card Sorting Test, a task generally accepted to reflect frontal lobe function. Impairment of calculation with defects of complex calculations, particularly those involving serial procedures, but intact elementary arithmetical operations has been described with frontal cortical lesions.³ Thus, our patient's lesion may have resulted in calculation disturbance by disrupting frontal cortical projections.

Other neuropsychological deficits have been described as the result of focal lesions involving the striatum. Aphasic syndromes have been described with circumscribed infarctions of the anterior limit of the internal capsule and the adjacent striatum of the dominant hemisphere.¹⁴⁻¹⁶ The resulting aphasia could not be classified in terms of the classic cortical aphasic syndromes. The anatomy of this region and its relevance to aphasic syndromes has been reviewed by Damasio et al.¹⁶ The locus of the lesion in our patient does not fully overlap that of the atypical aphasias. The lesion in our patient extended more superiorly to involve the periventricular white matter. The aphasia lesions extended more inferiorly, involving more of the inferior part of the anterior limb of the internal capsule and of the putamen. The lack of this more inferior component may explain the absence of persistent aphasia in our patient.

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