Acquired Procedural Dyscalculia Associated to a Left Parietal Lesion in a Child*

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ABSTRACT

We report the case of an 11-year-old boy who developed an anarithmetia in association with a left temporo-parietal tumor. His oral and written language were normal as well as his ability to judge magnitudes, process numbers, read operation signs and retrieve number facts. He had a specific difficulty in performing the procedures of subtraction, especially when it involved borrowing. These skills had been mastered before the present illness.

This case shows that the components of calculation can be dissociated by brain lesions sustained during childhood, while arithmetic abilities are being acquired, thus reinforcing findings from developmental dyscalculias, that suggest a modular organisation of those skills during development.

CASE REPORT

J.E., an 11-year-old right-handed boy, was evaluated to characterize learning difficulties of recent onset.

J.E. was born after a full term normal pregnancy and an uneventful delivery. He is the single child of healthy, right-handed, unrelated parents. His mother is a primary school teacher and his father is a salesman. Both parents have completed secondary school (11 years of formal education) before beginning their specific professional education and training. There is no family history of developmental language disorders or learning disabilities. J.E.’s developmental milestones were normal – walking and producing his first intelligible words at 12 months of age.

When he was 4 years old he began suffering from epilepsy (generalized tonic-clonic seizures and absences) and language difficulties were noticed, consisting of a decrease in verbal out-
put, frequent pauses and difficulty retrieving names. His phrase length became progressively shorter, to the point of producing only isolated words. A left temporo-parietal tumor (an oligodendroglioma) was then diagnosed and partially removed by surgery. J.E. did quite well afterwards. He recovered from aphasia and his cognitive development seemed to progress normally. Seizures, which had been quite frequent before surgery (he had daily attacks for a few weeks), became very sporadic (no more than 3 attacks per year) while taking anticonvulsants.

J.E. entered primary school at the age of 6 years. Although there were complaints of poor attention, that led to his repeating a year, he reached the fourth grade. He was considered an average student, with classifications within the mean range, and arithmetic difficulties were never mentioned from school nor noticed by his mother, who used to help him in his homework. By the age of 10 years he was learning long multiplications and had mastered additions and subtractions, involving carrying and borrowing (according to his mother).

When J.E. was 10 years old there was a recurrence of epilepsy, with frequent complex partial seizures, and he worsened to the point of having attacks every day for a couple of weeks while anticonvulsants were adjusted. Attacks consisted of sudden disturbances in consciousness, interruption of ongoing activity, chewing and automatic hand movements. By that time his school achievement had deteriorated. He now displayed an arithmetic difficulty not present before. A cranial CAT Scan was performed showing an enlargement of the tumor, including a large cystic area (Fig. 1) involving the temporo-parietal confluence (underneath Wernicke’s area and the angular gyrus). The cyst had not been reported in previous imaging exams. Fits were controlled by the association of carbamazepine, phenytoin and vigabatrine.

Neuropsychological assessment was performed before the second surgery. He had been

Fig. 1. CT scan of J.E. showing a left temporo-parietal calcified tumour with a cystic area.
free of seizures for the preceding 6 months. The assessment took place in a single afternoon session because J.E. lived far away from our center, making it difficult to schedule a second exam. The whole session took about 2½–3 hours including a 30-minute interval for a snack. J.E. was a pleasant child who participated fully in the evaluation, with excellent attention and interest in the tests performed. His neurological examination was normal except for a right facial palsy. Testing for visual fields and sensation was normal.

Language assessment: Spontaneous speech was fluent with normal syntax and name retrieval. Object naming and object identification by name were easily performed and fully correct. He followed simple verbal commands and had a normal score (21.5/22) on a short version of the Token Test (De Renzi & Vignolo, 1962; Benton, 1969). Word, pseudoword and sentence repetition were normal (ELOLA battery) (Agostini et al., 1998), but his digit span was below the mean score for his age (digit span forward = 4).

J.E. performed well in tests for buccofacial and limb apraxia (both for transitive and intransitive gestures) on verbal command. There was no right/left disorientation. Although he did not recall finger names and did not identify fingers by name, he could match fingers visually and by tactile stimulation without errors.

Visuo-motor and visuo-perceptual skills: J.E.’s performance in the Visual Retention Test (form C by copy) (Benton et al., 1967) and in a test of Line Orientation (Benton, Hamsher, Varney, & Spreen, 1983) were average for age. On the Raven Coloured Matrices (Raven, Court & Raven, 1986) he scored at the 50th centile for his age.

WISC (Portuguese adaptation and standardization) (Marques, 1970): Verbal IQ (calculated after excluding the arithmetic subtest) was 89, Performance IQ was 80 and Full Scale IQ was 83.

Reading and Writing: J.E. could read aloud letters, words and sentences without difficulty and he answered correctly to questions about a written text. He had no difficulty copying words. Writing words to dictation was at the 10th percentile for his age and spontaneous writing (writing a letter to a friend) was syntactically correct and well structured but with occasional orthographic errors.

Calculation: On a screening test of written calculation (Ferro, 1990) J.E. scored below the 10th percentile for age. Furthermore, he performed certain operations, especially subtraction, in an atypical way, using the rules of multiplication. A more detailed evaluation of this skill was therefore undertaken, using an experimental calculation test battery, adapted from batteries designed according to the information processing approach (Temple, 1991; Macaruso, Harley, & McCloskey, 1992; Deloche et al., 1994). This approach consists in using specific tests to assess the different cognitive steps required to perform arithmetic operations (namely tests for number processing, counting, magnitude judgment, knowledge of arithmetic symbols, number fact retrieval and arithmetic procedures). J.E.’s performance on this battery was compared to five healthy boys of a local primary school with identical education (attending the 1st term of the 4th grade) (Table 1). Children in the control group were one-and-a-half years younger than J.E. (since J.E. had repeated one school grade) and were selected on the basis of their willingness to participate and having no history of learning disabilities or known neurological disease. A Raven test was also administered to check for, and exclude, a general cognitive impairment.

Number processing

Counting: J.E. counted out aloud in forward and inverse order from 1 to 25.

Number comprehension and magnitude judgements: J.E. was requested to point to the larger number of a pair, in a series of 10 pairs of numbers (5 pairs were printed in the symbolic (Arabic) form and 5 pairs in the orthographic (numeral) form). Numbers within the pair were of identical magnitude, varying from single digits to the tens of thousands. He made no errors in this task judging magnitudes correctly. Controls had an identical performance.
Table 1. Performance of Patient and Controls in Arithmetic.

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Note. Numbers in brackets represent the maximum score of that test.

Number production and transcoding between numerical forms: (a) transcoding from the symbolic (digital) to the verbal form: J.E. read aloud correctly 16 out of 17 numbers presented in the symbolic form (from a single digit to 7-digit numbers, including 1257010); (b) transcoding from the orthographic to the symbolic form: J.E. performed easily (14 out of 15 correct with a single syntactic error), a task requiring him to write in the symbolic form numbers presented in the verbal written form (e.g., six hundred and fifty thousand and one: 650001).

Controls obtained an identical score on the first task. Two of the controls made errors (both semantic and syntactic) in the second task.

Calculation Ability

Knowledge of arithmetic operation symbols: J.E. could easily name, identify by name (in a multiple choice task) and write by dictation all five arithmetic signs (+, −, ×, ÷, =), just as controls did.

Knowledge of arithmetical facts (retrieval of table facts): 44 simple arithmetic problems (12 additions, 12 subtractions, 12 multiplications and 8 divisions all involving single digits) were presented both orally (22 problems) and in the written form (22 problems) in random order. Responses were rapid and correct to all oral questions and all but two written questions (one
error in subtraction and one error in multiplication). One child in the control group also made one error in the written multiplication.

**Procedural knowledge:** Writing down an arithmetic operation: Several arithmetic problems were dictated to J.E. who was told to write them down but not to solve them. This task was designed to evaluate his ability to spatially organise an arithmetic operation (align columns and to place the symbols correctly) but without actually performing it. There were 3 additions, 3 multiplications, 3 subtractions and 3 divisions. Both J.E. and controls made no mistakes.

Written calculation with carrying and borrowing (Fig. 2): Addition – J.E. solved correctly all 11 problems presented (including addition of three parcels with three-digit numbers each), 6 of which required transport of terms. Controls produced no errors in this task; Subtraction (Fig. 2) – J.E. failed five out of seven subtraction problems, especially when they involved borrowing. He did not respect the column organisation, instead using the procedures as for multiplication. Example 1 (27 – 9): J.E. said “seven minus nine is zero, two minus nine is also zero”. However he was rather puzzled by the result and commented “but twenty-seven minus nine cannot be zero”, thus showing some dissociation between the knowledge of the quantity that should be the correct result and the operation procedures. The knowledge of table facts was correct. Example 2 (35 – 14): J.E. said “five minus four is one, three minus four is zero”. Controls performed all these operations correctly. Multiplication – J.E. solved three out of five simple problems (two digit numbers multiplied by a single digit and involving carrying). He refused to perform long multiplications (two or more digit numbers multiplied by two or more digits) because he had not mastered that operation at school. One of the controls also failed on these operations.

The screening test for written calculation was performed early in the evaluation; whereas this experimental battery was administered later. Tests of written calculation were performed firstly for addition, next for subtraction and finally for multiplication. The tests of table fact retrieval and of writing down an operation were the last to be performed during the session.

There was no reevaluation of this patient since he lived far away from our center. However, we know that the second surgery (with removal of about 50% of the tumor) was uneventful and was followed by cranial radiotherapy. Three and 4 years later he was contacted by telephone, at which stage he was well and had a fair control of epilepsy. There were no motor or speech defects. He progressed to the 8th grade of school, with special education support, and his mother’s

\[
\begin{align*}
36 + 14 & = 50 \\
516 + 93 & = 609 \\
654 + 458 & = 1112 \\
45 - 26 & = 19 \\
38 - 19 & = 19 \\
27 - 9 & = 18 \\
35 - 14 & = 21
\end{align*}
\]

Fig. 2. Written calculation of J.E. requiring transport and borrowing. Addition is normal. Procedural errors are present in subtraction especially when it requires borrowing: 45–26 “five minus six is zero, four minus two is two”; 35–14 “five minus four is one, three minus four is zero”.
help at home, but had difficulties with arithmetic (especially with subtraction and division) which he overcame by the use of a pocket calculator. His behavior however had changed. He was more impulsive, uninhibited and provocative, making it difficult to keep him at school. He had repeated two school grades.

DISCUSSION

This 11-year-old boy had an acquired acalculia selectively involving the procedures of subtraction and borrowing. This defect developed while arithmetic procedures were being acquired (long multiplication and division had not been mastered by that time).

Former classifications of calculation disorders (acalculias or dyscalculias) divided them into primary (when there was no other major cognitive defect) and secondary (due to language, visuo-spatial or other neuropsychological disorders). Hécaen (1961) classified them into: number alexia and agraphia (an inability to deal with numbers as linguistic entities, usually associated with aphasia), spatial acalculia (due to poor spatial organization of the arithmetic operations) and anarithmetia (which he considered the purest form). Later on, as a result of the information processing approach for the evaluation of calculation disorders (McCloskey et al., 1985; McCloskey, 1992; Deloche et al., 1994) other subtypes were considered. Acalculia was divided in two main variants, depending on the selective impairment of two independent cognitive systems: number processing disorders (involving the knowledge of numbers and transcoding between number systems) and calculation system disorders. The latter has been further dissected into multiple component failures: number fact disorders (difficulty to learn or retrieve table facts), procedural disorders (involving the knowledge or monitoring of the rules implied in different types of math operations) and alexia for arithmetical symbols. These disorders were characterized in adults with acquired brain lesions, i.e. after full acquisition and overlearning of calculation abilities, and it became well established that calculation is a multicomponential cognitive function, all components of which could be selectively impaired.

The developmental variants of these disorders were described during the last decade (Temple 1989,1991). On the other hand, the overall prevalence of developmental dyscalculia was estimated as 3.6–4.4% in epidemiological samples (as compared with a 3.7% prevalence rate for reading and spelling disorders) (Lewis et al., 1994; Von Aster, 1994). However, its study in children with acquired brain lesions has remained very limited.

In the literature of acquired cerebral lesions in childhood, acalculia is just mentioned as a frequent symptom of acquired aphasia (Alajouanine & Lhermithe, 1965; Hécaen, 1976; Cranberg, Filley, Hart, & Alexander, 1987). The close association between aphasia and acalculia suggests that the majority of those children had number processing defects (alexia/agraphia for numbers) rather than anarithmetia. Although two studies describe patients with acquired acalculia (Basso & Scarpa, 1990; Martins, Parreira, Albuquerque, & Ferro, 1999), their assessment was very restricted, consisting of a simple written arithmetic test, which is rather insufficient to characterize a calculation disorder. Thus, as far as we know there are no reports of acquired dissociation of math skills in children. This also means that it is not known if arithmetical knowledge is modular from the outset, or if the modular organization found in adults emerges from a more global (non-modular) approach to arithmetic.

J.E had normal language, reading, writing and visuo-spatial skills and an IQ within the low-to-normal range. His disorder of calculation involved the procedures of subtraction, sparing number processing, magnitude estimation and knowledge of table facts. His pattern of impairment is quite similar to those described in adults with anarithmetia (McCloskey, Caramazza & Basili, 1985; Caramazza & McCloskey, 1987) and in children with developmental procedural dyscalculia (Temple, 1991; Semenza, Miceli & Ginelli, 1997). Therefore, this case reinforces the idea of an innate modularity for the acquisition of arithmetic.
However, calculation is a complex cognitive task and multiple factors could explain the calculation impairment in this boy:

The first one concerns the differentiation between an acquired and a developmental disorder (or just a lack of exposure to math knowledge). There are three types of evidence favoring an acquired dyscalculia. Firstly, the information that no mathematical difficulties had been noticed before the present illness. His school classifications were within the average range and this information was corroborated by his mother, a school teacher, who used to help him with his homework. Calculation difficulty was one of the symptoms noticed during his clinical deterioration, which suggests a regression of previously acquired skills. A second notable symptom was J.E.’s behavior during the test. His surprise with the results of his own subtractions reinforces the fact that he had once been able to solve such math problems, and he implicitly knew the correct answer. This suggests that he had mastered that ability in the past. And the third type of evidence comes from his pattern of error. Compared to controls J.E. did not just perform below average but also qualitatively differently, which suggests an abnormal performance rather than a developmental lag.

On our control data (concerning the screening written arithmetic test) of 73 healthy children who completed the third grade, 91% performed correctly the subtraction part of the test. The errors encountered in the remaining 9% are quite different from those of J.E: table errors (77% of errors), confusion of arithmetic signs, specially with addition, performed just before subtraction (8%) and not performing the operation (15%) (unpublished data, Martins, Parreira, & Serafim, 1994).

Another possible explanation would be a form of perseveration. JE could just be perseverating the procedures of multiplication. However this is refuted by the fact that written multiplication was performed after written subtraction both on the screening and the experimental calculation battery.

A general, albeit mild, unspecific cognitive impairment or attentional difficulty, as is common in chronic epilepsy (Schoenfeld et al., 1999) and anticonvulsant therapy, or else ongoing subclinical seizures, could also interfere with his ability to solve math problems. However, in that case one would expect him to fail both at carrying and borrowing, at random, and not systematically at the procedures of subtraction (Lindsay, Tomazic, Levine & Accardo, 1999).

A fourth possibility was that his impairment was secondary to a short-term memory problem (expressed by his low digit span), although the latter does not necessarily interfere with calculation skills (Butterworth, Cipolotti & Warrington, 1996). Yet he performed well in other tasks requiring short-term memory, such as the Token Test. On the other hand, if that was the cause, one would expect it to affect predominantly mental calculation (Gathercole, 1999) rather than written calculation, as in this case.

A last explanation for his impairment is poor planning or monitoring of the subtraction procedures. This has been described as a cause of procedural dyscalculia (Temple, 1991). However in this patient it followed a systematic pattern, sparing addition, suggesting more a loss of knowledge of the specific algorithm of subtraction (Semenza, Miceli, & Ginelli, 1997).

Acalculia has traditionally been associated with lesions of the left parietal lobe (specially the angular gyrus), sometimes integrating the Gerstman syndrome (Grafman, Passafiume, Faglioni, & Boller, 1982), but it has been described with other lesions' localization (Ferro, 1990; Martins et al., 1999). According to some authors the angular gyrus contributes the spatial component of the algorithms for structuring and executing calculations, its lesion (as in this case) originating anarithmetia for complex written operations (Spiers, 1987). However, procedural dyscalculia has also been found in association with lesions of the frontal lobes (Luchelli & De Renzi, 1993; Temple, 1991) and disorders of executive functions. In our case, we deduce that arithmetic ability was partly subserved by the left parietal lobe, despite early onset of the tumor and previous local surgery. This reinforces the idea that acquisition/recovery of function after an early brain lesion depends more upon local reorganization (De Vos, Wyllie, Geckler,
Kotagal, & Comair, 1995) than function transfer to distant sites.

Several dissociations in calculation abilities have been described in children with developmental disorders: digit dyslexia, procedural dyscalculia and number fact dyscalculia (Temple, 1989, 1991; Semenza et al., 1997). Yet it has been recognized that developmental disorders have problems as models, for they may represent atypical forms of function acquisition. If these disorders selectively affect a few subsystems, they may induce, as a form of compensation, another strategy for learning. The present case, a boy who was acquiring arithmetic in an apparently normal way before the growth of the tumor, reinforces previous findings showing that calculation is acquired by independent modules that can be dissociated from each other during development up to adulthood. Failure of one system does not necessarily impair other modules that are being acquired at the same time.

REFERENCES


