Calculation impairment in neurodegenerative diseases

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Abstract

We examined oral calculation in patients with corticobasal degeneration (CBD; \( N = 17 \)), frontotemporal dementia (FTD; \( N = 17 \)), and Alzheimer’s disease (AD; \( N = 20 \)), as well as 17 healthy seniors matched for age and education. Our calculation model involves at least three components: numerosity, combinatorial processes, and executive resources such as working memory. We assessed addition, subtraction, multiplication, and division involving small numbers (small, single-digit answers) and large numbers (larger, single- and double-digit answers). We also assessed dot counting for small numbers (2–5) and large numbers (6–9), as well as a measure of working memory. All patient groups differed from healthy seniors in oral calculation. CBD (36% correct) and FTD (65% correct) demonstrated a significant overall impairment in oral calculation relative to AD (76% correct). CBD (66% correct) had more difficulty counting dots overall relative to AD (94% correct) and FTD (86% correct), consistent with our hypothesis that the calculation deficit in CBD is due in large part to a numerosity deficit. FTD had more difficulty relative to AD in their performance of reverse digit span, consistent with our hypothesis that FTD patients’ executive resource limitation contributes to their pattern of calculation impairment.

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1. Introduction

Mental calculation reflects our knowledge and ability to use numbers. Despite our daily use of numbers, the neural basis for calculation remains unclear. Several studies have begun to assess calculation and the collaboration of cerebral processes that it requires [1,2]. Much of the work concerned with calculation difficulties has come from occasional observations of single case studies [3–5] and rare reports of calculation performance in groups of patients, particularly those with lateralized disease due to stroke [6–8]. The present study investigates oral calculation performance comparatively in groups of patients with neurodegenerative diseases.

Our model of calculation involves three components: numerosity, or number meaning; combinatorial processes, or the various arithmetic operations we apply to numbers; and executive resources such as working memory that support complex calculation by holding in mind the results of intermediate computations. We hypothesize that groups of patients with neurodegenerative diseases are relatively impaired with calculation [12,17–20]. Moreover, as we note below, there is a reason to believe that different groups of demented patients will have deficits with components of this calculation model that are qualitatively different.

A sense of numerosity supports knowledge of small, single digits, and possibly combining small numbers with elementary operations such as addition via counting. Patients with impaired number knowledge thus may experience difficulty on all but the very simplest of calculations with small numbers. Operations such as division, by comparison, often involve more complex combinations of numbers that may also require retaining an intermediate solution in mind, particularly when a memorized set of number facts is not involved [1,9]. Executive limitations are likely to contribute difficulty in performing these more demanding calculations. Poor working memory may also limit the processes involved in any calculations with larger numbers, even for simpler calculations such as addition [10,11]. We examined these hypotheses in patients with neurodegenerative disease affecting these components of calculation.

Clinical descriptions of acaulcia have been noted in CBD [12], but there have been no formal investigations of number knowledge or calculation impairment in these...
patients. We expected CBD patients of which we are aware to have a profound impairment in calculation with all but the smallest numbers and the simplest operations due in large part to their limited number knowledge. We also assessed their number knowledge by analyzing their performance on a dot-counting task. We predicted significant difficulty on this task, consistent with their number impairment and difficulty in performing simple oral calculations.

Impairment on tasks requiring working memory is evident in FTD patients [13–15], but we are not aware of deficits in number knowledge in FTD. Indeed, one clinical report of a patient with semantic dementia, a subgroup of FTD, describes isolated preservation of number knowledge [16]. In this context, we expected that FTD patients, except those with semantic dementia, would have calculation difficulty with more demanding operations such as division, and would also be impaired for computations involving large numbers since these appear to be relatively dependent on working memory.

Perhaps the most common neurodegenerative condition is Alzheimer’s disease (AD). Acalculia has been demonstrated previously in AD [17–20], but the basis for this difficulty has been examined rarely [21]. AD appears to compromise executive functioning [22]. Impairment on tasks requiring working memory has been noted frequently in AD patients [23–25]. However, we are not aware of deficits involving number knowledge. Thus, we also expected some difficulty for AD patients with resource-demanding calculation problems and problems involving large numbers.

2. Methods

2.1. Subjects

We examined 54 patients with neurodegenerative diseases and 17 healthy seniors who were right-handed English speakers. These patients were diagnosed with Alzheimer’s disease (AD), frontotemporal dementia (FTD), and cortico-basal degeneration (CBD). All groups were matched for both age and education except AD patients who were significantly older than CBD patients. Demographic features are summarized in Table 1. All patients were identified in the outpatient clinic at the Department of Neurology in the University of Pennsylvania Medical Center. The clinical diagnosis was made by a board-certified neurologist with expertise in the diagnosis of dementing conditions. The basis for these clinical diagnoses was the National Institute of Neurologic and Communicative Diseases and Stroke–Alzheimer’s Disease and Related Disorders Association (NINCDS–ADRDA) [26] criteria for AD, and Lund-Manchester criteria [27] for FTD modified by McKhann et al. [28]. In order to account for the different behavioral disorders among the FTD patients, we divided this group into three subgroups: semantic dementia (SD), progressive non-fluent aphasia (PNFA), and a third group consisting of non-fluent FTD patients with primarily behavioral and executive limitations (BEHAV). This was based on consensus evaluations of semistructured interviews, detailed mental status evaluations, and clinical neurological assessments [29]. We are not aware of published consensus criteria for the clinical diagnosis of CBD although several experts in the area have recommended clinical features important in the diagnosis of CBD, as reviewed in Riley and Lang [30]. Based on a review of the literature concerned with clinical-pathological diagnosis in CBD [31–35], the criteria we have developed include cortical sensory deficit, extrapyramidal features such as asymmetric rigidity but little resting tremor, unilateral or asymmetrical alien hand, apraxia, visual perceptual-spatial difficulty, and anomia that are insidious in onset and gradual in progression. Other causes of dementia were excluded by history, physical exam, serum studies, and structural brain imaging. Structural and functional neuroimaging in all patients were consistent with the clinical diagnosis. The participants were not taking sedative medications at the time of assessment, although most of the patients were taking cholinergic-supplementing agents (e.g. rivastigmine) and some were taking serotonin-specific reuptake inhibitor antidepressants (e.g. sertraline and paroxetine). This study was approved by the IRB of the University of Pennsylvania, and all patients and responsible caregivers participated in the Informed Consent procedure.

Overall dementia severity was assessed with the Mini Mental State Examination (MMSE) [36], a general assessment of cognition that evaluates orientation, anterograde memory, language, executive functioning, and visual construction on a 30-point scale. CBD patients had a significantly lower MMSE score than AD patients ($t(35) = 3.04; p < 0.05$) and FTD patients ($t(32) = 2.55; p < 0.05$) although

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Means and standard deviations for age, years of education, MMSE, and disease duration in patient groups and healthy seniors</th>
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<tr>
<td></td>
<td>AD</td>
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<td>$N$</td>
<td>20</td>
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<tr>
<td>Age (year)$^a$</td>
<td>72.20 ± 8.53</td>
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<tr>
<td>Gender</td>
<td>10 M; 10 F</td>
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<tr>
<td>Education (year)$^b$</td>
<td>14.30 ± 3.18</td>
</tr>
<tr>
<td>MMSE (max = 30)</td>
<td>21.70 ± 4.35</td>
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<tr>
<td>Disease duration (months)</td>
<td>69.35 ± 35.20</td>
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</table>

$^a$ t tests showed that patient groups and healthy seniors did not differ at the $p < 0.05$ level for age or education except for AD and CBD patients who differ in age. According to Pearson’s correlations, age and education do not correlate with any patient groups’ oral calculation performance.

$^b$ MMSE—Mini Mental Status Exam.

$^c$ No correlation was found between disease duration and oral calculation performance.
FTD patients did not differ from AD patients in their MMSE scores. To assess oral calculation in a manner that minimizes the potential confound associated with differences in overall dementia severity, we used analyses of covariance (ANCO-VAs) in our group-wise comparisons, covarying for MMSE. In a recent study evaluating diagnostic criteria in FTD and AD patient groups that were equated on overall MMSE score, the authors found that the impairment on MMSE can be diagnostically useful [37]. However, the MMSE may not account for aspects of disease that contribute to overall severity in FTD and CBD, even though this test is generally thought to reflect the severity of cognitive impairment in AD. For example, it is limited in its assessment of executive functioning, and its simple memory and language tasks are relatively insensitive to the early stages of FTD [38]. Unfortunately, there are no well-validated brief measures of disease severity for FTD and CBD. It is beyond the scope of this study to determine whether the MMSE equally reflects overall disease severity across these patient groups. In this context, we supplemented our MMSE covariant by covarying the duration of the disease as well. AD patients \[t(32) = 2.75; p < 0.01\] had significantly longer disease duration than FTD patients, as summarized in Table 1, although CBD patients differed from neither FTD patients \[t(31) = 1.35; \text{ns}\] nor AD patients \[t(31) = 1.98; \text{ns}\]. In order to confirm the broad patterns of cognitive performance that are consistent with the clinical diagnosis in these patients, we also administered measures of anterograde memory, confrontation naming, and visuospatial constructional skills. Patterns of performance on these tasks were entirely consistent with the clinical diagnosis.1

2.2. Materials

A pencil and paper formatted task was presented to each subject as part of a larger protocol. This included measures aimed at assessing our calculation model including oral calculation, dot counting, and reverse digit span.

2.2.1. Oral calculation

For the oral calculation task, patients were presented with 32 calculation problems aurally, one at a time. Calculation problems consisted of eight addition (e.g. \(2 + 4 = \)), eight subtraction (e.g. \(3 - 1 = \)), eight multiplication (e.g. \(2 \times 3 = \)), and eight division (e.g. \(9 \div 3 = \)) problems. Four examples of each operation tested each subject’s ability to calculate with small numbers and orally produce a response (small, single-digit answers). We also tested each subject’s ability to calculate with large numbers and orally produce a response (larger, single- and double-digit answers) with four additional examples of each operation. Patients were given a maximum of 10 s for each problem, and failure to respond in the allotted time was scored as incorrect.

2.2.2. Dot-counting task

To assess numerosity, we presented 16 arrays of dots arranged side-by-side in two columns of eight. Each array contained large, black, filled circles, where half included a small number of dots (two to five) and half included a larger number of dots (six to nine). Half of each set of dots was arrayed in a regular pattern and half in an irregular pattern. These arrays were presented in a fixed, random order. Patients were asked to determine the number of dots in each array and we report patient accuracy.

2.2.3. Reverse digit span [39]

This is a brief assessment of working memory. For reverse digit span, we give each patient a sequence of digits beginning at a sequence length of two digits and gradually increasing up to seven digits, or until an error is made. Subjects are asked to immediately repeat the sequence in reverse order. We report the longest string of digits that can be repeated accurately in reverse order.

2.3. Procedures

The entire calculation protocol was administered in one session, requiring about 30 min to complete. The components of this protocol were administered in a fixed order, beginning with the reverse digit span procedure, followed by oral calculations and finishing with dot counting. The background procedures were obtained on average within 3 months of the calculation battery.

2.4. Statistical analysis

All statistical tests are designated significant at a \(p\) value less than 0.05. Nonparametric statistical tests were used to test the null hypothesis that differences in oral calculation and dot counting do not exist between neurodegenerative patients and healthy control subjects. We used nonparametric statistics for analyses involving control subjects because they produced so few errors in our calculation and dot-counting tasks. In order to assess qualitative differences in calculation performance between patient groups that assess our hypotheses and take into account the overall disease severity, we used parametric, multivariate analyses of covariance (MANCOVA), covarying for MMSE and disease duration, for all contrasts across patient groups.

3. Results

3.1. Oral calculations

Fig. 1 summarizes the mean (± S.D.) scores for overall oral calculation accuracy in patient groups. A Kruskal–Wallis analysis of variance (ANOVA) by ranks revealed that patient groups differ from healthy seniors in overall oral calculation \(\chi^2(3) = 28.92\). According to Mann–Whitney \(U\)
tests, each differed significantly from the healthy seniors at least at the $p < 0.05$ level of significance.

To assess differences in oral calculation between patient groups, we used a mixed-model repeated-measures analysis of covariance (MANCOVA) with a between-subject factor of group (3—AD, FTD, CBD) and within-subject factors of operation (4—addition, subtraction, multiplication, division) and number size (2—small, large), covarying for MMSE and duration of disease. We found a main effect for group ($F(2,45) = 4.92$) as well as a group $\times$ operation interaction effect ($F(6,135) = 2.19$). These findings are summarized in Table 2.

An ANCOVA covarying for MMSE and disease duration showed that CBD patients are more impaired in their overall oral calculation performance than AD patients and FTD patients ($F(1,46) = 4.57$). Within-group comparisons, using paired sample $t$ tests, showed that CBD patients are impaired in all calculation operations relative to their own performance on all other operations (addition: $t(16) = 4.00$; multiplication: $t(16) = 2.13$). These patients as a whole thus tended to have the greatest calculation difficulty with the operation making the greatest working memory demand. An analysis of FTD patients demonstrated differences in relative accuracy between subgroups, including SD, PNFA, and BEHAV patients. PNFA patients (% correct: $50.63 \pm 28.76$) were significantly less accurate in overall oral calculation performance than SD patients (% correct: $77.23 \pm 22.44$) ($F(1,8) = 9.24$). Neither SD patients nor PNFA patients differed from BEHAV patients (% correct: $63.13 \pm 28.93$).

An ANCOVA covarying for MMSE and disease duration showed that FTD patients are impaired in their overall oral calculation performance relative to AD patients ($F(1,30) = 5.69$). AD patients were less impaired in their performance with division relative to FTD patients ($F(1,30) = 6.96$). AD patients were impaired in division relative to their own performance with all other operations except multiplication (addition: $t(19) = 2.63$; subtraction: $t(19) = 3.46$). AD patients thus were modestly impaired overall, tending to only have mild difficulty with more demanding operations such as division and possibly multiplication.

### 3.2. Number knowledge

We performed between-group comparisons and within-group correlations of dot-counting performance to help establish the role of numerosity in the calculation performance of CBD, FTD, and AD patients. Fig. 2 summarizes the

<table>
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<tr>
<th>Table 2</th>
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<td><strong>Means (% correct) and standard deviations for calculation operations and reverse digit span in patient groups and healthy seniors</strong></td>
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<tr>
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<tr>
<td>Oral calculations*</td>
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<td>Addition</td>
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<td>Subtraction</td>
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<td>Division</td>
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<td>Executive processing</td>
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<td>Reverse digit span</td>
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*We performed an error analysis of incorrect responses to multiplication and division problems. This error analysis involved only multiplication and division to minimize ambiguities associated with interpreting the nature of the error. We examined table errors (e.g. solutions taken from cells adjacent to the true product, such as $6 \times 3 = 21$), operation errors (e.g. misinterpretation of the operation indicated by the sign, such as $6 \times 3 = 9$), and random (nontable) errors (e.g. solutions that appear to be unrelated to a table error or misinterpretation of an operation, such as $6 \times 3 = 14$). This examination of error types was derived from past studies [5,9]. Mann–Whitney $U$ tests demonstrated that all patient groups made more operation errors than healthy seniors. While Mann–Whitney $U$ tests showed that CBD patients ($U = 85$) make more random errors than healthy seniors, consistent with their impoverished number knowledge, FTD patients ($U = 68$) appear to make more table errors. We cannot definitely state that table (and operation) errors were not random in nature, but we assume that any of the table and operation errors are likely to include some random errors in proportion to their occurrence in each of the groups.
patients’ dot-counting accuracy. A Kruskal–Wallis ANOVA by ranks revealed that patient groups generally differ from healthy seniors in counting dots regardless of array size \( \chi^2(3) = 28.83 \). According to Mann–Whitney \( U \) tests, CBD patients \( U = 21.00 \) and FTD patients \( U = 53.50 \) differed from healthy seniors in their dot-counting accuracy while AD patients \( U = 119.00 \) did not. To assess differences in dot counting between patient groups, we performed a MANCOVA with a between-subject factor of group (3—AD, FTD, CBD) and a within-subject factor of array size \( (2—small \ and \ large \ numbers \ of \ dots) \) covarying for MMSE and disease duration. We found a significant main effect for group \( [F(2,45) = 3.28] \).

An ANCOVA covarying for MMSE and disease duration showed that the CBD patients are less accurate in counting dots overall compared to AD patients and FTD patients \( [F(1,46) = 4.50] \). FTD patients did not differ from AD patients \( [F(1,30) = 3.52] \). We also analyzed FTD subgroups. BEHAV patients \( [F(1,8) = 6.08] \) and PNFA patients \( [F(1,7) = 4.20] \) were more impaired in counting dots than SD patients. We also found that dot counting correlated with oral calculation in CBD \( [r = 0.51] \) and FTD patients \( [r = 0.51] \).

### 3.3. Executive resources

Table 2 summarizes the results of reverse digit span performance. An ANCOVA was used to evaluate group differences in reverse digit span (4—CBD, FTD, AD, WNL), covarying for MMSE and disease duration. We found a main effect for the group \( [F(3,61) = 3.44] \). \( T \) tests showed that all patients differ from healthy seniors in their reverse digit span performance. An ANCOVA covarying for MMSE and disease duration demonstrated that CBD patients do not have difficulty relative to AD patients \( [F(1,29) = 0.67] \) or FTD patients \( [F(1,29) = 2.41] \) in reverse digit span. FTD patients were more impaired than AD patients for reverse digit span \( [F(1,30) = 7.24] \). FTD subgroups did not differ on this task \( [F(2,12) = 1.68] \). According to Pearson’s correlations, reverse digit span correlated with the oral calculation performance in CBD \( [r = 0.65] \), FTD \( [r = 0.76] \), and AD \( [r = 0.54] \).

### 4. Discussion

Our analyses of patients with neurodegenerative diseases showed that they are impaired in oral calculation relative to healthy seniors. Moreover, in line with our expectations, we observed some qualitative differences between the oral calculation performance of patient groups due to relative impairments associated with number knowledge and executive resources.

CBD patients have the greatest overall calculation impairment. CBD patients demonstrated considerable difficulty with all calculation conditions except the simplest operation, addition. Indeed, they were relatively successful at addition only for calculations involving the smallest numbers. Our analyses also showed that only CBD patients are relatively impaired in the dot-counting task. These observations imply that CBD patients have a profound numerosity deficit that contributes to their oral calculation difficulty. Our findings also suggest that “subitizing” (enumerate a small group of four or fewer objects rapidly by a process such as deconstructing the arrays of objects into familiar patterns) small arrays of dots \( (1—4) \) and “counting” (an error prone and slower process of serially counting five or more objects) large arrays of dots \( (5—9) \) appear to rely on separate neural mechanisms, consistent with several previous studies [40–43]. However, it is beyond the scope of this study to definitively state that these processes are distinct [44]. The correlation between dot counting and calculation further suggests that limited number knowledge contributes to calculation difficulty in CBD.

CBD affects several cortical regions, but a review of the literature emphasizes core involvement of parietal cortex based on the frequent presence of clinical features such as spatial difficulty, cortical sensory loss, anomia, and apraxia [30,31,35,45,46]. Case studies with neuroanatomic correlation [5,47] and functional neuroimaging work in healthy adults [48,49] implicate parietal cortex in number knowledge. Functional imaging data and lesion studies in brain-damaged patients have suggested that bilateral defects in the region of the intraparietal sulcus play a central role in number processing [48,49]. We hypothesize that this distribution of disease in CBD contributes to a deficit in number knowledge and the profound calculation impairment seen in CBD.

It is possible to attribute difficulty with the calculation and dot-counting tasks in part to a deficit in visuospatial skills in CBD [12,33]. Our observations suggest that visuospatial difficulty cannot fully explain the calculation deficits in CBD. No correlation was found between visual construction and CBD patients’ oral calculation performance. The calculation task was administered aurally, minimizing errors due to spatial factors such as lining up written
numbers in a spatially inappropriate manner. Difficulty with spatial relations may contribute to their dot-counting impairment, particularly for large arrays. However, the patients were impaired for small arrays and as impaired with irregular arrays as the regular arrays that have a familiar configuration less dependent on a spatial analysis. In sum, it appears that a spatial deficit cannot fully explain dot-counting difficulty although additional work is needed to confirm this.

Some aspects of number knowledge have been hypothesized to depend on verbal mediation implying that aphasia can result in calculation difficulty [5,44]. Although some CBD patients have been reported to be aphasic [50–52], our CBD patients have only mild naming difficulty without gross aphasia or impaired comprehension. Moreover, several case studies dissociate language and calculation [7,53–56]. Patients with aphasia have frequently been shown to have preserved number knowledge and unimpaired calculation skills, and patients suffering from acalculia and a profound loss of number knowledge due to parietal disease have been reported to be not aphasic. These observations suggest that aphasia is unlikely to completely explain the acalculia that we observed in CBD.

A related possibility is that the CBD patients’ overall dementia severity may contribute to their calculation difficulty. Unfortunately, there are no well-validated brief measures of overall dementia severity that allow us to covary performance in comparisons of CBD patients with AD patients and FTD patients. It is unlikely that overall dementia severity can fully explain the differences in oral calculation that we observed and, indeed, correlations with factors commonly contributing to measures of overall dementia severity that we assessed independently—such as anterograde memory, confrontation naming, and visual-constructional performance—did not correlate with oral calculation performance. We also supplemented MMSE constructional performance—did not correlate with oral as anterograde memory, confrontation naming, and visual-dementia severity that we assessed independently—such factors commonly contributing to measures of overall calculation that we observed and, indeed, correlations with tia severity can fully explain the differences in oral calcu-

FTD patients are also impaired in their oral calculations. We demonstrated that their greatest impairment is on resource-demanding calculation operations such as division. We hypothesized that their impairment on these relatively difficult calculation operations is due to an executive limitation [13–15]. We found that FTD patients’ reverse digit span performance was impaired relative to healthy seniors and AD patients and this correlated with their oral calculation accuracy. Impairments in tasks requiring working memory have been noted in FTD patients [13–15]. We cannot completely rule out that their deficit may be due in part to degraded knowledge of the division operation itself. These patients did not show more operation errors than other patient groups. However, their production of many table errors suggests that they were implementing the appropriate operation but may have had difficulty holding intermediate operations in working memory so that the correct solution could be selected reliably from the table.

Functional neuroimaging studies show that complex calculation tasks increase activation in prefrontal areas that are known to contribute to working memory functions [43,58,59]. FTD patients have disease in this neuroanatomic distribution [60–62]. Other clinical [63] and functional neuroimaging work [58] has associated more complex calculations with prefrontal and inferior frontal cortices. In this context, we expected that FTD patients would have calculation difficulty with more resource-demanding operations.

FTD has been associated with progressive aphasia [28]. However, language difficulty is unlikely to account for their impaired calculation performance. This is because aphasia presumably would interfere equally with all calculation operations, but these patients were more impaired in division than in other operations. Other evidence dissociating language functioning and number processing comes from stroke patients [6–8]. SD patients have been reported to be significantly impaired in their knowledge of semantic facts involving numbers, such as the number of years in a millennium and the number of corners in a cube [61]. This kind of measure does not assess number knowledge per se, such as the meaning of the number “4”. Instead, our observations are consistent with another report [16] that found number knowledge to be relatively preserved in patients with SD, emphasizing dissociation between knowledge of semantic facts involving numbers and knowledge of number meaning per se.
AD patients were impaired in calculation relative to healthy seniors. Unlike Crutch and Warrington [64], however, we did not find that AD patients are the most impaired dementia group in their calculation performance. We attribute their impairment in part to a deficit of working memory. Several reports have described significant deficits in AD patients on measures of executive function [23–25]. This condition can compromise prefrontal brain regions [22] leading to difficulty with executive measures [30–32] as well as more demanding aspects of calculation. Thus, we also expected some difficulty for AD patients with resource-demanding calculation problems. Lafleche and Albert [23] indicate that AD patients’ impairment is unlikely to be a result of distractibility. Our results also support the claim that AD patients are impaired on tasks that required working memory relative to healthy seniors and this is correlated with their oral calculation accuracy. The results of dot repetition and counting suggest that AD patients do not have limited number knowledge.

AD has been associated with language difficulty [65]. However, this would not fully account for their selective difficulty with only some operations but not the others. Cummings et al. [65] found that despite language abnormalities, AD patients did not differ from controls in number repetition and counting.

In the present study, calculation impairment is evident in patients with certain neurodegenerative diseases relative to healthy seniors. Calculation difficulty appears to be most pronounced in CBD due to a severe deficit in number knowledge and possibly a limitation in executive resources, sparing their performance only in addition with small numbers. A pattern of impaired calculation involving the most resource-demanding computations such as division is evident in FTD. This appears to be due to an executive resource limitation. AD patients also appear to have a resource-based limitation in calculation. Different patterns of oral calculation difficulty in patients with neurodegenerative diseases are consistent with a model of calculation involving partially dissociable components of number knowledge and executive resources.

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