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Kim Uittenhove & Patrick Lemaire

Laboratoire de Psychologie Cognitive, Centre National de la Recherche Scientifique, and Aix-Marseille Université, Marseille, France

Institut Universitaire de France, Laboratoire de Psychologie Cognitive, Centre National de la Recherche Scientifique, and Aix-Marseille Université, Marseille, France

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Strategy sequential difficulty effects in Alzheimer patients: A study in arithmetic

Kim Uittenhove and Patrick Lemaire

1Laboratoire de Psychologie Cognitive, Centre National de la Recherche Scientifique, and Aix-Marseille Université, Marseille, France
2Institut Universitaire de France, Laboratoire de Psychologie Cognitive, Centre National de la Recherche Scientifique, and Aix-Marseille Université, Marseille, France

Objective: Consistent with Uittenhove and Lemaire (2012), we expected that strategy execution would be slower following execution of a difficult strategy than after an easy strategy (strategy sequential difficulty, SSD, effects). Moreover, we expected larger SSD effects in older adults than in young adults, and especially in Alzheimer’s disease (AD) patients, a population with marked cognitive impairments. Method: A total of 25 young and older (41 AD and 25 healthy) adults were asked to execute rounding strategies to solve arithmetic problems (e.g., solving 43 + 68 by rounding operands down or up, e.g., 40 + 70 = 110). We measured solution latencies and percentage errors with a strategy as a function of the difficulty of the just-executed strategy. Results: Solution latencies were significantly shorter following the easier rounding-down strategy than following the harder rounding-up strategy, $F(2, 156) = 35.8$. Moreover, this effect was significantly larger in AD patients, $F(1, 78) = 117.4$. Conclusions: We found comparable SSD effects in young and healthy older adults but dramatically increased SSD effects in AD patients. This has implications to further our understanding of strategic aspects underlying decreased cognitive functioning in AD patients.

Keywords: Alzheimer’s disease; Strategy sequential difficulty effects; Strategy execution; Perseveration; Arithmetic.

Strategy sequential difficulty effects (SSD effects) are the finding that when young adults execute strategies, performance is worse after a difficult strategy than following an easy strategy (Uittenhove & Lemaire, 2012). This suggests that strategies relying more on central resources (e.g., difficult or complicated strategies) increase duration of execution of the next strategy relative to less demanding strategies. Uittenhove and Lemaire proposed that difficult strategies temporarily consume central cognitive resources such as executive functions (e.g., inhibition) or working memory (see also Schneider & Anderson, 2010). Fewer of these resources would be available immediately after execution of a difficult strategy, which would slow down execution of the next strategy.

SSD effects challenge traditional views on strategy execution. Indeed, models of strategy execution and selection (Adaptive Strategy Choice Model (ASCM), Siegler & Shipley, 1995; ReCyCLe (RCCL), Lovett & Schunn, 1999; Strategy Selection Learning (SSL), Rieskamp & Otto, 2006; Strategy Choice And Discovery Simulation (SCADS)*, Siegler & Arraya, 2005) assume that strategies involving more and more complex procedures are executed less efficiently, independently of the strategy that was executed on the previous problem. SSD effects contest this by showing that strategy execution is also influenced by the procedures involved in the previously executed strategy.

The present study aimed at studying the evolution of SSD effects in normal and pathological
aging. Previous research has abundantly shown that strategy execution is altered in healthy and pathological aging (e.g., Arnaud, Lemaire, Allen, & Michel, 2008; Duverne & Lemaire, 2005; Gandini, Lemaire, & Michel, 2009; Lemaire & Arnaud, 2008; Mantovan, Delazer, Ermani, & Denes, 1999). For example, Lemaire and Arnaud (2008) found that healthy older adults executed procedural strategies to solve two-digit addition problems (e.g., 49 + 56) less efficiently than young adults. Regarding Alzheimer’s disease (AD) patients, Mantovan et al. (1999) looked at errors in written calculations of multidigit multiplications and found that they erred more than healthy older adults when executing complex written procedures. For example, when solving 56 × 32 on paper, AD patients would often only multiply the unit-digits (e.g., 6 × 2) and ten-digits (e.g., 50 × 30) and would not cross-multiply unit- and ten-digits (e.g., 3 × 30; see also Grafman, Kampen, Rosenberg, Salazar, & Boller, 1989).

Such age-related changes are often related to reductions in necessary processing resources in healthy and pathological aging (e.g., Duverne, Lemaire, & Vandierendonck, 2008; Taconnat, Clarys, Vanneste, Bouazzaoui, & Isingrini, 2007). These reductions in processing resources may also contribute to larger effects of previous strategy execution on subsequent strategies (i.e., SSD effects) in these populations.

Finding larger SSD effects in AD patients than in healthy older adults can contribute to variations in strategy execution in these populations. Much of the performance decrements in older adults and AD patients result from executing strategies less efficiently. However, SSD effects show that strategy execution efficiency is determined not only by the number and complexity of the procedures of the strategy in the course of execution, but also by the number and complexity of procedures involved in the previous strategy. Variations in SSD effects could thus add variation to strategy execution efficiency in healthy older adults and AD patients.

Finding larger SSD in AD patients would have additional important implications. It may be related to decreased flexibility (e.g., as tested with task switching) and increased perseveration (e.g., as seen in perseverative errors in the Wisconsin Card Sorting Task) in AD patients. Belleville, Bherer, Lepage, Chertkow, and Gauthier (2008) compared AD patients with healthy older adults and found that AD patients were impaired in the reconfiguration of actions (e.g., local switch costs). Furthermore, Cullen et al. (2005) described repetitive behaviors and perseverative errors in AD patients (e.g., AD patients may keep repeating the same question) and found that the degree of repetitiveness was related to executive dysfunction. In this paper, we argue that AD patients may have more and/or longer interference of previous difficult strategy execution with current strategy execution. Side effects could be a higher degree of strategy repetition or perseveration.

In this study, we tested AD patients and healthy older adults with the same computational estimation task as that of Uittenhove and Lemaire (2012) so as to test the prediction that SSD effects increase with age, especially in AD patients. We tested SSD effects by asking participants to provide estimates to two-digit arithmetic problems (e.g., 43 + 68) with one of the following strategies: mixed rounding (i.e., rounding the first operand down and the second operand up to the nearest decades; 40 + 70 = 110), rounding down (i.e., rounding both operands down to the nearest decades; 40 + 60 = 100), or rounding up (rounding both operands up to the nearest decades; 50 + 70 = 120). Previous research has shown that these strategies differ in difficulty (e.g., LeFevre, Greenham, & Waheed, 1993; Lemaire, Arnaud, & Lecacheur 2004). The rounding-down strategy is easiest because it does not require the extra step of incrementing operands and keeping them in working memory (WM). Both the rounding-up and mixed-rounding strategies are more difficult, because the rounding-up strategy requires incrementing and maintaining two operands in WM, and the mixed-rounding strategy requires a switch of operations (rounding the first operand down and the second one up). We predicted that SSD effects would be larger in healthy older adults and in AD patients. Compared to young adults, older healthy adults would be more impaired on the execution of the mixed-rounding strategy following a rounding-up strategy than would young adults, and this effect would be even larger in AD patients.

**METHOD**

**Participants**

Three groups of participants were selected according to their age and their health status: 25 healthy young adults (12 women), 25 healthy older adults (12 women), and 41 individuals diagnosed with probable AD (26 women). Probable AD patients were recruited from the Department of Geriatric Neurology, Sainte Marguerite Hospital (Marseille, France) and Saint Germain Daycentre (Paris, France). Diagnoses were based on extensive medical and psychiatric examinations and
have been confirmed with a wide range of psychometric and neuropsychological tests. The inclusion criteria of probable AD in the present study were based on the National Institute of Neurological and Communicative Disorders and Stroke–Alzheimer’s Disease and Related Disorders Association (NINCDS-ADRDA; McKhann et al., 1984) and the Diagnostic and Statistical Manual of Mental Disorders–Fourth Edition (DSM–IV; American Psychiatric Association, 1994) criteria.

We ensured that none of the healthy older adults was affected by any diseases that might affect cognition; they had a minimum score of 28 on the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975). We excluded 10 AD patients for failing to execute rounding strategies on the addition problems. The addition and the subtraction–multiplication subtests of the French Kit (French, Ekstrom, & Price, 1963) were used in order to assess participants’ arithmetic skills with an independent paper-and-pencil test. Number of correctly solved items was taken as an index of their arithmetic skills. Participants also completed a French version of the Mill Hill Vocabulary Scale (MHVS; Deltour, 1993, and Raven, Court, & Raven, 1986) so as to control for their verbal ability. Characteristics of the three groups are summarized in Table 1. The experimental procedures were approved by the local ethics committee (approval reference number: 2010-A00150-39), and all participants gave their written informed consent.

### Procedure

The stimuli were presented in a 72-point font on a 1,280 × 800-pixel screen. Participants were told that they were going to see addition problems to which they had to estimate the answer using one of three strategies. The rounding-down strategy was explained as rounding both operands down to the smaller decades (e.g., 43 + 24 = 40 + 20 = 60). The rounding-up strategy was described as rounding both operands up to the larger decades (e.g., 48 + 29 = 50 + 30 = 80). The mixed-rounding strategy was presented as rounding the first operand down to the smaller decade and the second operand up to the larger decade (e.g., 43 + 28 = 40 + 30 = 70). Participants were told that they should use the indicated strategy on each trial. Strategies were indicated by two arrows pointing in the direction in which the operands needed to be rounded. They were instructed to say the estimate of each problem out loud. Participants saw three blocks of 26 trials each. Each trial was made up of two problems, yielding a total of 156 problems per participant. On the first problem of each trial, participants were randomly cued to execute the rounding-down, rounding-up, or mixed-rounding strategy.

### Stimuli

Sets of two-digit addition problems (e.g., 32 + 68) were created. These sets included rounding-down problems, rounding-up problems, and mixed-rounding problems. Unit digits of both operands were smaller than 5 for rounding-down problems (e.g., 43 + 64) and larger than 5 for rounding-up problems (e.g., 47 + 68). Unit digit was smaller than 5 in the first operand and larger than 5 in the second operand for mixed-rounding problems (e.g., 43 + 69). Following previous findings in arithmetic (see Campbell, 2005, for overview), we controlled the following factors: (a) no operands contained a 0, 5, or repeated digit (e.g., 44), (b) no reverse orders of operands were used (e.g., 43 + 82 and 82 + 43), (c) the first operand was larger than the second in half the problems, (d) no operand would round to 0, 10, or 100, (e) the operands of a problem would never round to the same decade, (f) the problems had a comparable mean exact sum per item condition, (g) the conditions were matched for differences between correct sums and estimates, (h) the conditions had a comparable number of problems with carryover on the tens (50%), and (i) during the experiment, the estimated sums of two successive problems were never the same.

### Table 1

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Young adults (YA)</th>
<th>Healthy older adults (HOA)</th>
<th>Probable AD</th>
<th>F&lt;sub&gt;YA/HOA&lt;/sub&gt;</th>
<th>F&lt;sub&gt;HOA/AD&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>25</td>
<td>25</td>
<td>41</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Age (years): Mean (SD)</td>
<td>24 (2.43)</td>
<td>68 (5.15)</td>
<td>75 (3.51)</td>
<td>1,140.7***</td>
<td>24.8***</td>
</tr>
<tr>
<td>Mill Hill: Mean (SD)</td>
<td>26 (2.9)</td>
<td>28 (3.5)</td>
<td>24 (3)</td>
<td>3.9</td>
<td>16.2***</td>
</tr>
<tr>
<td>French Kit: Mean (SD)</td>
<td>53 (17.7)</td>
<td>82 (26.1)</td>
<td>54 (9.6)</td>
<td>27.2***</td>
<td>23.4***</td>
</tr>
<tr>
<td>MMSE</td>
<td>–</td>
<td>&gt;28</td>
<td>19.6 (2.1)</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

Note. AD = Alzheimer’s disease. MMSE = Mini-Mental State Examination.

**p < .001.
On the second problem, they had to execute the mixed-rounding strategy. Each problem matched the cued strategy: Rounding-down problems were cued to be solved by the rounding-down strategy, rounding-up problems by the rounding-up strategy, and mixed-rounding problems by the mixed-rounding strategy. All problems were separated by a 100-ms blank screen, followed by a 100-ms fixation cross, followed by another 100-ms blank screen. The trial procedure is displayed in Figure 1. The time until each response was measured by experimenter key-press, occurring as soon as possible after the response. To avoid experimenters’ expectations influencing the response time measurement, we used a double-blind procedure. Errors were recorded by having the experimenter write down the answers of the participants so errors could later be identified.

RESULTS

The first analysis was aimed at checking the relative difficulty of our strategies such that the rounding-down strategy yielded better estimates than rounding up, and whether relative strategy difficulty varied with groups. The second analysis aimed at testing SSD effects and how they differed between groups. Prior to analyses on solution latencies, values exceeding the mean + 2 standard deviations (4.5%) and all trials containing an error (9.4%) were removed. All reported effects are significant to at least $p < .05$.

Relative strategy difficulty

We conducted repeated measures analyses of variance (ANOVA) on participants’ mean solution times and percentage errors on the first problem with strategy as a within-participants variable and group as a between-participants variable (see Table 2).

TABLE 2

<table>
<thead>
<tr>
<th>Strategies</th>
<th>Young adults</th>
<th>Healthy older adults</th>
<th>AD patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rounding down</td>
<td>3,117 (3.1)</td>
<td>3,722 (6.3)</td>
<td>7,710 (5.2)</td>
</tr>
<tr>
<td>Rounding up</td>
<td>3,600 (10.5)</td>
<td>3,979 (7.7)</td>
<td>9,173 (7.9)</td>
</tr>
<tr>
<td>Mixed rounding</td>
<td>3,475 (6.4)</td>
<td>3,897 (5.7)</td>
<td>8,351 (5.6)</td>
</tr>
<tr>
<td>Rounding up – rounding down</td>
<td>483 (7.4)</td>
<td>255 (1.4)</td>
<td>1,463 (2.7)</td>
</tr>
</tbody>
</table>

Note: Solution latencies in ms. Percentages of errors in parentheses. AD = Alzheimer’s disease.

$F(1, 78) = 83.6, MSE = 1,092,000$, and the latter were not significantly slower than young adults (3,397 ms), $F < 1$. Solution latencies also varied with strategies, $F(2, 156) = 47.3, MSE = 228,640$. Planned comparisons showed that participants were slower when executing the mixed-rounding strategy (5,241 ms) than when executing the rounding-down strategy (4,850 ms), $F(1, 78) = 24.2, MSE = 253,383$. They were also significantly slower when executing the rounding-up strategy (5,584 ms) than when executing the mixed-rounding strategy, $F(1, 78) = 18.3, MSE = 257,698$.

Finally, variations in solution latencies with strategies (i.e., relative strategy difficulty) interacted with groups, $F(4, 156) = 13.3, MSE = 228,640$. Young and healthy older adults did not differ in relative strategy difficulty, $F < 1$; both groups executed the rounding-down strategy (3,420 ms) more quickly than the mixed-rounding strategy (3,686 ms), $F(1, 78) = 7, MSE = 253,383$, which they executed as quickly as the rounding-up strategy (3,789 ms), $F(1, 78) = 1, MSE = 257,698$. AD patients significantly differed from young and healthy older adults in relative strategy difficulty, $F(2, 156) = 25.8, MSE = 228,640$; they executed the rounding-down strategy (7,710 ms) a lot faster than the mixed-rounding strategy (8,351 ms), $F(1, 78) = 25.2, MSE = 253,383$, which they executed a lot faster than the rounding-up strategy (9,173 ms), $F(1, 78) = 40.6, MSE = 257,698.437$. To test whether this difference in relative difficulty between healthy older adults and AD patients
existed independently of longer solution latencies in AD patients, we contrasted z scores for the rounding-down and the rounding-up strategies. We found that the difference in relative difficulty between AD patients and healthy adults did not reach significance when analyzing z scores, $F < 1$.

Analyses of mean percentage errors showed no difference between groups, $F < 1$. We found a main effect of strategy, $F(2, 156) = 9.6$, $MSE = 32.4$. Planned comparisons showed that participants erred more when executing the rounding-up strategy (8.7%) than when executing the mixed-rounding strategy (5.9%), $F(1, 78) = 9$, $MSE = 34.6$ or when executing the rounding-down strategy (4.9%), $F(1, 78) = 15.6$, $MSE = 36.9$. Participants did not significantly err more with the mixed-rounding strategy than with the rounding-down strategy, $F(1, 78) = 1.6$, $MSE = 25.8$. Variations in accuracy with strategy was the same in all three groups, $F(4, 156) = 2.0$, $MSE = 32.4$.

### Strategy sequential difficulty effects

We conducted repeated measures ANOVAs on participants’ solution times and percentage errors on the second problem with the strategy on the first problem as a within-participants variable and group as a between-participants variable (see Table 3). Note that these second problems on which we conducted these analysis were all solved by the mixed-rounding strategy.

Solution latencies on the second problem differed between groups, $F(2, 78) = 60.2$, $MSE = 10,844,464$. Planned comparisons showed that AD patients (8,424 ms) were significantly slower than healthy older adults (3,827 ms), $F(1, 78) = 82.5$, $MSE = 10,432,200$, but the latter were not significantly slower than young adults (3,500 ms), $F < 1$. Solution latencies on the second problem also differed as a function of the strategy used on the first problem, $F(2, 156) = 35.8$, $MSE = 269,029$. Planned comparisons showed that participants were slower after executing the rounding-down strategy (5,183 ms) than after executing the mixed-rounding strategy (5,183 ms), $F(1, 78) = 32.7$, $MSE = 293,280$. Furthermore, they were slower after executing the mixed-rounding strategy than after the rounding-down strategy (4,943 ms), $F(1, 78) = 9.7$, $MSE = 293,431$.

Variations in solution latencies on the second problem with strategy (i.e., SSD effects) interacted with groups, $F(4, 156) = 17.1$, $MSE = 269,029$. Healthy older adults and young adults did not differ in SSD effects, $F < 1$; they executed mixed rounding more quickly after the rounding-down strategy (3,560 ms) than after the rounding-up strategy (3,789 ms), $F(1, 78) = 3.9$, $MSE = 334,283$, $p = .05$, with solution latencies after the mixed-rounding strategy (3,641 ms) not being different from the latter two solution latencies, $F S < 2.4$. AD patients significantly differed from young and healthy older adults in SSD effects, $F(2, 156) = 34$, $MSE = 269,029$; they executed mixed rounding 558 ms faster following rounding down than following mixed rounding, $F(1, 78) = 19.5$, $MSE = 247,818$, and 1,033 ms faster following mixed rounding than following rounding up, $F(1, 78) = 117.4$, $MSE = 334,283$. To test whether this difference in SSD effects between healthy adults and AD patients was independent from longer solution latencies in AD patients, we contrasted z scores for mixed rounding after the rounding-down and rounding-up strategies. We found that the differences in SSD effects between AD patients and healthy adults were still significant when analyzing z scores, $F(1, 78) = 4.3$, $MSE = 0.08$. Moreover, SSD effects expressed in fractions of solution latencies for each AD patient—that is, [(RT after rounding up) – (RT after rounding down)]/(RT after rounding down)—tended to correlate with AD patients’ scores on the MMSE, $r = −.35$, $p = .05$.

Mean percentage errors on the second problem did not differ with group, $F < 1$, or strategy used on the first problem, $F < 1$, and the interaction between these two factors was not significant, $F(4, 156) = 1.5$, $MSE = 24$.

### DISCUSSION

Young adults, healthy older adults, and AD patients presented the same patterns of relative strategy difficulty, with rounding down being associated to the shortest solution latencies, rounding up to the longest solution latencies, and mixed rounding in between. These differences were enhanced.

### Table 3

Mean solution latencies for the second problem as a function of the strategy that was executed on the first problem, for healthy young and older adults and Alzheimer patients

<table>
<thead>
<tr>
<th>Strategy executed on the first problem</th>
<th>Young adults</th>
<th>Healthy older adults</th>
<th>AD patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rounding down</td>
<td>3,370 (6.0)</td>
<td>3,751 (6.0)</td>
<td>7,708 (5.5)</td>
</tr>
<tr>
<td>Rounding up</td>
<td>3,647 (5.2)</td>
<td>3,931 (4.4)</td>
<td>9,299 (7.1)</td>
</tr>
<tr>
<td>Mixed rounding</td>
<td>3,482 (8.5)</td>
<td>3,800 (5.1)</td>
<td>8,266 (5.9)</td>
</tr>
<tr>
<td>Rounding down</td>
<td>277 (−0.8)</td>
<td>180 (−1.6)</td>
<td>1,591 (1.6)</td>
</tr>
</tbody>
</table>

Note. Solution latencies in ms. Percentages of errors in parentheses. AD = Alzheimer’s disease.
in AD patients. However, when controlling for AD patients’ longer solution latencies (i.e., processing speed) by analyzing z scores, AD patients relative strategy difficulty effects were the same as those of young and healthy older adults.

SSD effects were of comparable magnitude in healthy older and young adults. The lack of difference between healthy older and young adults could be due to compensation mechanisms in older adults. Healthy older adults obtained larger arithmetic scores at the independent arithmetic test. Their better skills could have helped them compensate for SSD effects. However, arithmetic scores did not correlate with SSD effects in young or healthy older adults (rs < .18). Another possibility is that the mechanisms underlying SSD effects were not sufficiently affected in healthy older adults, explaining comparable SSD effects in healthy older and young adults. Most interestingly, SSD effects were significantly and dramatically increased in AD patients. This increase in SSD effects was still observed when we controlled for AD patients’ longer solution latencies (i.e., general slowing).

How could SSD effects increase in AD patients? If, as proposed by Uittenhove and Lemaire (2012), SSD effects result from traces of previous difficult strategy executions in WM interfering with current strategy execution, two mechanisms may be responsible for increased SSD effects in AD patients. AD patients may have reduced functional WM capacities, and since difficult strategies may leave more traces in WM, this would explain why AD patients are relatively more impaired following difficult strategies than are young adults and healthy older adults. Alternatively, or in addition, AD patients could have deficits removing traces of a strategy from WM after executing it. The latter possibility may stem from less efficient executive WM components (e.g., central executive; Baddeley, Bressi, Della Sala, Logie, & Spinnler, 1991; Baddeley, Logie, Bressi, Della Sala, & Spinnler, 1986), or, adopting the theoretical framework from different streams of literature, from deficient inhibitory mechanisms (e.g., deletion inhibition; Hasher & Zacks, 1988). However, evidence supporting either claim is circumstantial. Future studies may test SSD effects, inhibition, and WM capacities in AD patients, to assess whether they are linked to SSD effects in AD patients.

Moreover, traces in WM of a previously executed strategy could be linked to diminished flexibility and perseverative errors in AD patients. Indeed, if WM is occupied with the content of a previous strategy, it can interfere with what AD patients do next, and they may persevere in executing this strategy. This may also be true for deficits in flexibility and perseverance in other domains (e.g., repeating the same question). Future research could test this hypothesis with a correlation between SSD effects and perseverative errors in AD.

Increased SSD effects in Alzheimer patients question the practice of using sequential problem-solving tests for assessing cognitive functioning in this population. SSD effects during sequential problem solving in this group may lead to underestimation of true problem-solving capacities because they interfere with strategy execution. Hence, neuropsychological tests should allow Alzheimer patients sufficient time to recover between problems to more accurately estimate their functioning. Neuropsychologists should also consider that Alzheimer patients may use inadequate strategies because of SSD effects associated to more resource-demanding strategies.

Lastly, future research may investigate whether SSD effects are a reliable hallmark for the diagnosis of AD, as has been the case for more general arithmetic impairment (Deloche et al., 1995; Grafman et al., 1989; Mantovan et al., 1999). Deloche et al. (1995) found that calculation performance of patients with beginning AD correlated with MMSE scores but not with memory. SSD effects could indicate difficulties in restoring of WM capacities, which may precede difficulties with calculation or procedural strategies. Similar to Deloche et al., we found that SSD effects in Alzheimer patients tended to correlate with their scores in the MMSE, indicating that SSD effects in Alzheimer are related to the degree of more general cognitive dysfunctioning.

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