Changes in neuropsychological functioning following temporal lobectomy in patients with temporal lobe epilepsy

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Purpose: *This study was conducted to evaluate the changes in neuropsychological functioning in patients with temporal lobe epilepsy (TLE) after temporal lobe resection.*
Methods: *Fifty-four TLE patients were evaluated before and after surgery using comprehensive neuropsychological tests to assess general intelligence, executive functioning, language, verbal and visual memory, working memory, visuo-spatial ability, attention and motor function.*
Results: *The patients with left TLE showed no impairment of neuropsychological functioning after surgery, with the exception of auditory immediate memory. Furthermore, they showed significant improvement in performance IQ, executive function, working memory, visual memory, attention and psychomotor speed. The patients with right TLE did not show any significant impairment in post-operative neuropsychological functioning. They showed improvements in intellectual and executive functions, language, visual memory, visuo-spatial ability, attention and motor function post-operatively. The patients with hippocampal sclerosis showed greater post-operative improvements than the patients without hippocampal sclerosis regardless of the side. Patients with better pre-operative neuropsychological function had a higher chance of successfully discontinuing all seizure medications after surgery.*
Discussion: *The results of this study suggest that temporal lobectomy does not harm the neuropsychological functioning of patients with intractable TLE and that it improves cognitive functions of the contralateral hemisphere.* [Neurol Res 2009; **31**: 692–701]

Keywords: Executive function; hippocampal sclerosis; memory; temporal resection; TLE

INTRODUCTION

Owing to rapid developments in neurosurgical techniques, surgical treatment for medically refractory epilepsy is now being performed more frequently than ever before, and these developments have also improved the safety and efficacy of surgery for medically refractory epilepsy. The neuropsychological changes that occur after temporal lobe resection in patients with medically intractable temporal lobe epilepsy (TLE) have been widely investigated. Since declines in memory and language capabilities have been regarded as the most salient consequences of temporal lobectomy (TL), the majority of studies concerning TLE have been focused on memory and language functions.

Fewer studies have examined changes in neuropsychological functions other than memory and language in TLE patients after TL. Previous studies suggested that executive function improved after TL, and enhancement of cognitive functions was also observed in the side opposite to the surgery[1,2]. According to a recent study on the executive performance in mesial TLE[3], patients with better pre-operative executive abilities showed more post-operative deterioration in executive functioning, whereas those with poorer pre-operative sorting ability showed greater improvements in executive functioning after mesial temporal resection.

The purpose of the present study was to examine the possible changes in neuropsychological functioning, including intellectual function, executive function, language, verbal, visual and working memory, visuo-spatial ability, attention and motor function, in terms of lateralization of seizure foci, hippocampal sclerosis and medication following temporal lobe resection in TLE patients. In the present study, it was predicted that material-specific memory and verbal abilities would decrease after TL, especially in left TLE patients, while other neuropsychological functions, such as executive functions and motor functions, would improve after TL because patients would experience the release or

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recovery of extratemporal functions when they become seizure-free[4,5].

METHODS

Participants

Patients were consecutively recruited from the epilepsy clinic at the Department of Neurosurgery, Seoul National University Hospital. They consisted of 54 TLE patients aged 16–51 years who underwent temporal lobe resection for medically intractable epilepsy. They were selected for surgery based on comprehensive pre-operative tests, including history and neurological examination, seizure semiology, long-term video EEG monitoring, magnetoencephalography, magnetic resonance imaging and/or positron emission tomography, interictal and ictal single-photon emission computed tomography and intracarotid amytal test (Wada test). All patients had a clearly defined seizure focus limited to the unilateral temporal region. They were divided into left TLE (L-TLE) and right TLE (R-TLE) groups based on the results of comprehensive pre-operative tests, which showed that 30 patients had left temporal lobe epileptogenic foci and 24 had right temporal lobe foci. There were no significant differences between the L-TLE and R-TLE groups in terms of age, gender, handedness and IQ score, but there was a statistically significant difference in the mean education level between the two groups. A summary of the demographic and medical information for each group is presented in *Table 1*. The exclusion criteria included (1) multiple seizure foci documented on previous EEG studies, (2) concurrent neuropsychiatric disorders such as Tourette's disorder, obsessive–compulsive disorder and schizophrenia and (3) full-scale IQ<70.

Standard two-thirds anterior TL including the hippocampus was performed in 14 patients, selective amygdalohippocampectomy (SAH) was performed in 23 patients and temporolateral lesionectomy was performed in 17 patients. All surgeries were performed by the same neurosurgeon (C.C.K.). The patients were considered to be seizure-free if they did not experience any seizures during the 1-year follow-up period after surgery. The Institutional Review Board at Seoul National University Hospital approved the current study protocol (no. H-0507-511-153), and informed consent was obtained from all patients before the study was conducted.

Neuropsychological test battery

Neuropsychological tests were administered to each patient with TLE within 1 month before surgery. The patients were then reassessed by the same neuropsychological tests at the 1-year follow-up examination [interval (month), mean=11.11, SD=6.52]. The neuropsychological test battery included various standardized tests commonly used to evaluate general intellectual functioning, executive functioning, language, memory, visuo-spatial ability, attention and motor function.

General intelligence

The Korean version of the Wechsler Adult Intelligence Scale-Revised (K-WAIS-R) was used to evaluate intellectual functioning[6]. Verbal IQ (VIQ), performance IQ (PIQ), full scale IQ (FSIQ) and 11 subscale scores were calculated based on the Korean age norms.

Executive function

The Wisconsin Card Sorting Test[7] (WCST), Trail Making Test Part B[8] (TMT-B), Controlled Word Fluency Test[9], Figural Fluency Test[10] and Stroop Test[11] were used to assess several domains of executive function, including response inhibition, cognitive flexibility, fluency and goal setting.

Table 1: Demographic variables of all patients

	Left (n=30)	Right (n=24)	Group difference
Male/female	11/19	11/13	NS*
Handedness (right/left/ambidextrous)	28/3/2	21/1/2	NS*
Language dominance (left/right/missing)	21/5/4	19/1/4	NS*
Age at surgery (years)	30.07 ± 8.61	30.08 ± 8.73	NS†
Age at onset of epilepsy (years)	15.23 ± 7.78	16.21 ± 8.33	NS†
Duration of illness (years)	14.87 ± 8.14	13.88 ± 10.63	NS†
Hippocampal sclerosis (%)	23 (77)	16 (67)	NS*
Number anticonvulsants, pre-operative	2.17 ± .95	2.58 ± 1.21	S†
Number anticonvulsants, post-operative	1.30 ± 1.32	1.33 ± 1.44	NS†
Medication-free after surgery (%)	12 (40)	10 (42)	NS*
Seizure-free after surgery (%)	25 (83)	21 (88)	NS*
Education (years)	12.20 ± 2.30	13.50 ± 2.17	S†
Intelligence (full scale IQ)	89.67 ± 11.27	95.25 ± 12.18	NS†

The cells contain the number of patients for gender, seizure-free after surgery, medication-free after surgery and hippocampal sclerosis (percent in parentheses) and group means and SD for the other variables.
NS, not significant (p>0.05); S, significant (p<0.05).
*χ^2 Test.
†t-test.

Language

Language abilities were assessed using the Vocabulary subtest of the K-WAIS-R, the Korean version of the Boston Naming Test[12] (K-BNT) and the Korean version of the Western Aphasia Battery[13] (K-WAB), which included seven subsets: spontaneous speech, comprehension, repetition, naming, reading, writing and sequential command.

Memory function

Verbal memory was assessed using the Korean version of the Rey Auditory Verbal Learning Test[14] (RAVLT) and the Wechsler Memory Scale-III[15] (WMS-III). The Immediate and Delayed Recall scores of the RAVLT and the Auditory Immediate and Delayed Recall scores of the WMS-III were used in the analysis. Visual memory was assessed using the Immediate and Delayed Recall scores of the Rey–Osterrieth Complex Figure Test[14] (ROCF) and the Visual Immediate and Delayed recall scores of the WMS-III. The Arithmetic subtest of the K-WAIS-R, the Letter–Number Sequencing test of the WMS-III and the computerized Auditory and Visual Span backward tasks[16] were used to assess working memory.

Visuo-spatial ability

Visuo-spatial ability was measured using the Block Design subtest of the K-WAIS-R, and the copy condition of the ROCF in which subjects copy a complex geometric figure composed of 18 separate elements. Visual constructional ability was assessed using the 36-point itemized scoring system of the ROCF[14].

Attention

The Trail Making Test Part A[8] (TMT-A), the Continuous Performance Test[17] (CPT) and the Auditory and Visual Span forward tasks[16] were used to assess attention span, sustained attention (vigilance), selective attention and divided attention.

Motor function

Grip strength, motor skills, manual dexterity and fine-motor coordination of the dominant and non-dominant hands were measured with the hand dynamometer[18] and the grooved pegboard[19], respectively.

Statistical methods

Data were analysed using SPSS software, version 12.0. Comparisons of the demographic data between the L-TLE and R-TLE groups were conducted using the *t*-test and χ^2 test. Comparisons of neuropsychological functions pre- and post-surgery in each group were performed using the paired *t*-test. Repeated measures analysis of variance was performed in order to examine the interaction effect of group by surgery.

RESULTS

Left TLE

Statistically significant differences in the pre- and post-operative means of the neuropsychological variables assessed in the L-TLE patients are presented in *Table 2*. Owing to the large number of neuropsychological tests included in this study, the results of all variables are presented in Appendix 1. No impairment of various neuropsychological functions was found in the L-TLE

Table 2: Pre-operative and post-operative comparisons of the neuropsychological test scores in the L-TLE group

	Pre-operative	Post-operative	*t*
Intellectual functioning			
K-WAIS-R PIQ	93.90 (11.54)	98.47 (10.82)	−4.30‡
Executive function			
WCST Total Errors	33.87 (24.25)	25.67 (18.16)	2.57*
Trail Making Test Part B (seconds)	89.83 (64.45)	74.53 (58.79)	2.50*
Verbal memory			
WMS-III Auditory Immediate	14.04 (5.27)	11.58 (4.88)	2.16*
Visual memory			
ROCF Immediate Recall	19.05 (6.33)	21.62 (5.62)	−2.06*
Working memory			
K-WAIS-R Arithmetic	8.37 (2.47)	9.27 (2.74)	−3.66†
Auditory Span backward	4.13 (1.31)	4.57 (1.38)	−2.28*
Visuo-spatial ability			
K-WAIS-R Block Design	9.60 (2.04)	10.27 (2.13)	−2.66*
Attention			
CPT Number of Correct	114.43 (7.84)	117.00 (6.12)	−2.10*
Auditory Span forward	5.20 (1.45)	6.23 (1.83)	−4.11‡
Motor function			
Grooved pegboard dominant hand (seconds)	76.72 (20.19)	69.24 (16.12)	3.20†

Values are expressed as mean (SD).
K-WAIS-R, Korean-Wechsler Adult Intelligence Scale-Revised; WCST, Wisconsin Card Sorting Test; WMS-III, Wechsler Memory Scale-III; ROCF, Rey–Osterrieth Complex Figures Test; CPT, Continuous Performance Test.
*$p<0.05$, †$p<0.01$, ‡$p<0.001$.

patients after surgery. Furthermore, significant improvements in PIQ, executive function, visual memory, working memory, visuo-spatial ability, attention and psychomotor speed, which were mediated by the right hemisphere, were observed post-operatively ($p<0.05$). However, the Auditory Immediate Memory score of the WMS-III decreased significantly after left TL ($p<0.05$).

Right TLE

The means and standard deviations of all variables assessed before and after surgery in patients with R-TLE are presented in Appendix 2, and the statistically significant variables are presented in *Table 3*. As it was previously reported, no impairments were found in any of the neuropsychological functions, including executive function, language, verbal and visual memory, working memory, visuo-spatial ability, attention and motor function, in the R-TLE patients after surgery. Even though the Letter–Number Sequencing score of the WMS-III, which is known to assess working memory, decreased after surgery, the scores of Auditory and Visual Span backward tasks, which are sensitive measures of working memory, were at the average level for their age norm and did not change at all after surgery. The R-TLE patients showed remarkable improvement in executive functioning. The number of Total and Perseverative Errors on the WCST, which are associated with right dorsolateral prefrontal dysfunction, markedly decreased after surgery. The R-TLE patients also showed significant improvements in intelligence, language, visual memory, visuo-spatial ability, attention and motor function ($p<0.05$).

Comparisons of neuropsychological functioning in patients with L-TLE and R-TLE before and after surgery

Repeated measures analysis of variance was performed in order to examine the interaction effect of group by surgery. Significant interaction effects between group (L-TLE versus R-TLE) and surgery (pre versus post) were only found for the Boston Naming Test, WMS-III Auditory Immediate Recall and WMS-III Auditory Delayed Recall ($F=9.75$, $p<0.01$; $F=5.44$, $p<0.05$; $F=4.58$, $p<0.05$, respectively). The Boston Naming Test scores of the R-TLE patients improved significantly after surgery, while those of the L-TLE patients were slightly decreased. The L-TLE patients performed significantly worse on the Auditory Immediate Recall test of the WMS-III after surgery, while the R-TLE patients scored better, but this improvement was not statistically significant. The scores of the R-TLE patients on the WMS-III Auditory Delayed recall test slightly improved, while those of the L-TLE patients were slightly decreased.

In order to examine the auditory immediate memory function and learning ability of the patients in each TLE group in detail, we plotted the pre- and post-operative

Table 3: Pre-operative and post-operative comparisons of the neuropsychological tests scores in the R-TLE group

	Pre-operative	Post-operative	*t*
Intellectual functioning			
K-WAIS-R VIQ	94.00 (13.81)	97.92 (13.04)	−2.73*
K-WAIS-R PIQ	97.42 (10.39)	104.17 (10.45)	−5.00‡
K-WAIS-R FSIQ	95.25 (12.18)	100.54 (10.81)	−4.32‡
Executive function			
WCST Total Errors	43.17 (22.11)	30.17 (27.30)	2.72*
WCST Perseverative Errors	24.43 (19.06)	16.96 (18.38)	3.26†
Verbal Fluency	22.71 (10.56)	27.04 (11.88)	−2.56*
Stroop Test (seconds)	26.50 (12.60)	22.46 (6.50)	2.08*
Language			
Boston Naming Test (max.=60)	46.79 (6.97)	49.50 (6.01)	−3.30†
K-WAB Reading	92.79 (7.57)	95.96 (4.92)	−2.25*
Visual memory			
ROCF Immediate Recall	18.29 (7.81)	21.00 (6.91)	−2.14*
Working memory			
K-WAIS-R Arithmetic	8.96 (2.88)	9.83 (2.88)	−2.56*
WMS-III Letter–Number Sequencing	9.23 (2.84)	8.18 (2.75)	2.41*
Visuo-spatial ability			
K-WAIS-R Block Design	10.17 (2.50)	11.04 (2.69)	−2.64*
Attention			
CPT Reaction Times (seconds)	0.98 (0.14)	0.91 (0.14)	2.73*
Motor function			
Grooved pegboard dominant hand (seconds)	77.48 (17.91)	68.65 (11.12)	2.57*
Grooved pegboard non-dominant hand (seconds)	84.32 (21.97)	75.00 (12.38)	2.41*

Values are expressed as mean (SD).
K-WAIS-R, Korean-Wechsler Adult Intelligence Scale-Revised; WCST, Wisconsin Card Sorting Test; K-WAB, Korean version of Western Aphasia Battery; ROCF, Rey–Osterrieth Complex Figures Test; WMS-III, Wechsler Memory Scale-III; CPT, Continuous Performance Test.
*$p<0.05$, †$p<0.01$, ‡$p<0.001$.

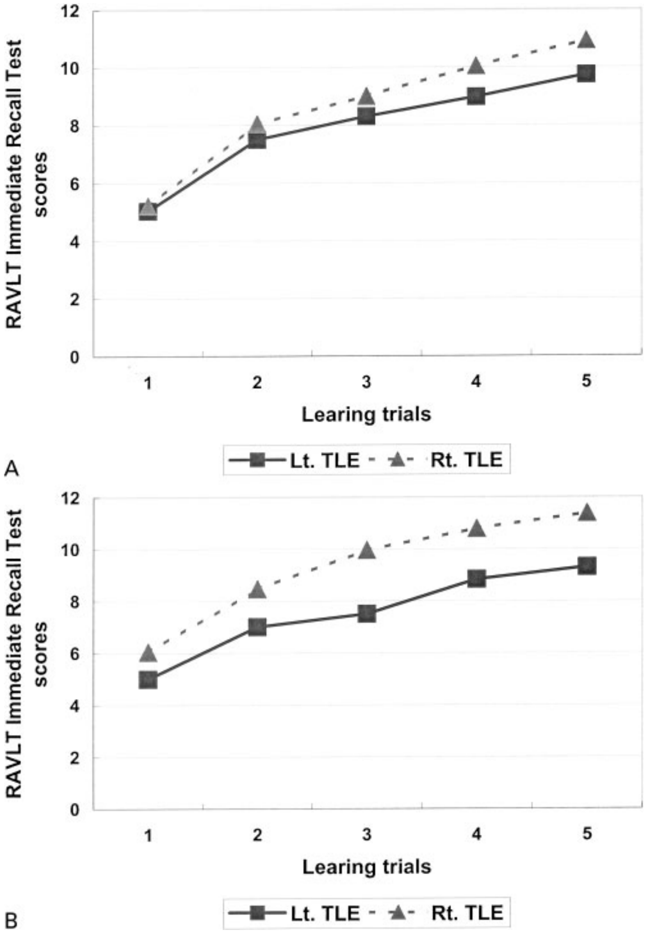

Figure 1: Comparison of the RAVLT Immediate Recall test scores between the L-TLE and R-TLE groups: (**A**) pre-operative; (**B**) post-operative

means of five trials of the RAVLT Auditory Immediate Recall test for each group (*Figure 1A,B*). The test scores demonstrated that even though the L-TLE patients performed worse than the R-TLE patients on the Auditory Immediate Recall test after surgery (F=10.23, p<0.01), both groups clearly showed a similar learning effect over trials, implying that they retained their verbal learning abilities despite undergoing TL.

Comparison of post-operative outcomes between patients with and without hippocampal sclerosis

In comparison with the patients without hippocampal sclerosis (n=15), the TLE patients with hippocampal sclerosis (n=39) showed greater improvements in VIQ, PIQ, the Vocabulary subtest of the K-WAIS-R, the Trail Making Test Part B, the Letter–Number Sequencing subtest of the WMS-III and the WAB Reading subtest after surgery (F=6.36, p<0.05; F=4.06, p<0.05; F=11.51, p<0.01; F=4.74, p<0.05; F=10.37, p<0.01; F=7.25, p<0.05, respectively).

Comparison of neuropsychological function between patients with and without medication after surgery

Thirty-two patients (59%) were on medication, and 22 patients (41%) were drug-free at 1 year after the operation (*Table 4*). A significant interaction effect between medication (on medication versus medication-free) and surgery (pre versus post) was found only on the Visual Span backward task. The drug-free patients showed much more improvement in visual working memory after surgery than the patients on medication. All of the other variables showed only significant main effects of medication, implying that the patients who discontinued all seizure medications after surgery showed better neuropsychological functioning before and after surgery.

DISCUSSION

We examined the changes in neuropsychological functions, including intellectual function, executive function, language, memory, visuo-spatial ability, attention and motor function, following TL in TLE patients, especially in terms of seizure foci, hippocampal sclerosis and medication. The L-TLE and R-TLE patients group had no differences in handedness and language dominance. No declines in neuropsychological functioning were found in any of the TLE patients after surgery, with the exception of auditory immediate memory in the L-TLE patients. As expected, a decline in material-specific memory was observed depending on the laterality of the lesion. The L-TLE patients showed decreases in auditory immediate memory after surgery, whereas the R-TLE patients showed no decline in verbal

Table 4: Pre-operative and post-operative comparisons of neuropsychological function between patients with and without medication

	On medication (n=32)		Medication-free (n=22)		F		
	Pre-operative	Post-operative	Pre-operative	Post-operative	Medication	Surgery	Medication × Surgery
K-WAIS-R Vocabulary	8.19 (1.89)	8.00 (2.03)	9.55 (2.72)	9.45 (1.77)	6.76*	0.42	0.05
Visual Span backward	5.28 (1.33)	5.12 (1.43)	4.90 (1.22)	5.43 (1.25)	0.92	1.42	4.87*
RAVLT Delayed Recall	6.41 (2.95)	6.72 (2.76)	8.32 (3.23)	8.27 (3.60)	4.86*	0.15	0.27
Stroop Test	29.09 (12.49)	26.87 (15.80)	22.24 (5.14)	20.52 (6.38)	5.13*	1.71	0.03
Verbal Fluency	19.19 (8.15)	22.72 (10.77)	26.41 (13.31)	29.18 (11.62)	6.59*	5.23*	0.08

Values are expressed as mean (SD).
K-WAIS-R, Korean-Wechsler Adult Intelligence Scale-Revised; RAVLT, Rey Auditory Verbal Learning Test.
*p<0.05.

or visual memory, and these findings are in agreement with those of previous studies[5,20,21]. However, the L-TLE patients clearly showed a similar learning effect over trials on the RAVLT Immediate Recall test when compared with the R-TLE group, suggesting that they retained their verbal learning abilities despite undergoing left TL.

Consistent with the functional reserve model of memory change[20,21], the L-TLE patients showed significant improvements in visual immediate memory after surgery. Although the R-TLE patients tended to show improvements in verbal memory, these improvements were not statistically significant.

We also found that hippocampal sclerosis (HS) was positively correlated with improvements in VIQ, PIQ and Vocabulary score of the K-WAIS-R, the Trail Making Test Part B scores, the Letter–Number Sequencing subtest of the WMS-III and the WAB Reading subtest after surgery. This finding is consistent with the results demonstrating that patients with HS showed more improvements than the patients without HS[22,23]. These results suggest that patients with HS might develop a compensatory mechanism for their hippocampal deficits before surgery.

The risk of cognitive decline after surgery depends on the site of resection. Previous studies have consistently shown that verbal memory is likely to decrease following resection of the language-dominant left temporal lobe[24–26]. Alpherts *et al.*[24] found that L-TLE patients showed an ongoing decline in the acquisition and consolidation of verbal memory for up to 2 years after surgery, while R-TLE patients initially showed a slight improvement in verbal memory, which vanished 2 years after surgery. However, the main limitation of that study was that they only examined the post-operative changes in general intelligence, memory, language and visual–motor functions and did not examine the changes in executive functioning after surgery.

Surprisingly, we found improvements in the other neuropsychological functions, such as executive function and working memory, which is in agreement with the previous findings that release or recovery of extratemporal functions can be observed as patients become seizure-free[4,5]. It is interesting to note that the WCST scores of the R-TLE improved considerably after surgery. Improvement of WCST score after epilepsy surgery is not an uncommon finding, and it can be attributed to successful seizure control[27]. These results have also been described by the 'nociferous cortex hypothesis', which states that freedom from seizure may lead to the release of previously suppressed capacities or functions for compensation[28]. Even though no significant difference in the ratio of seizure-free patients after surgery was found between the L-TLE and R-TLE groups, there were more drug-free patients in the R-TLE group after surgery. Therefore, the R-TLE patients might experience a greater release of extratemporal functions due to successful seizure control after surgery, especially in the right dorsolateral frontal lobe. However, these results may be attributable to the difference between the L-TLE and R-TLE groups in performance on the WCST at the pre-operative assessment. Since the R-TLE patients had more errors on the WCST before surgery than the L-TLE patients, which was also reported in a previous study[29], they showed a greater reduction in the number of errors on the WCST after surgery than the L-TLE patients. However, since the numbers of Total and Perseveration Errors on the WCST in the L-TLE patients were within the normal range before the operation, they could not be further reduced, and it is not surprising that they remained about the same after surgery.

The L-TLE patients showed significant improvements in auditory attention span and visuo-spatial ability, and both the L- and R-TLE patients showed significant improvements in motor function after surgery. Following the same mechanism involved in the improvement of prefrontal lobe function, the post-operative reduction of interictal neural noise in the extratemporal regions may also bring about improvements in attention, visuo-spatial ability and motor function. Wachi *et al.*[30] reported that TLE patients had improved on the VIQ, PIQ and FSIQ of the WAIS-R, the WMS verbal and delayed paired associate memory tests and the Raven Colored Progressive Matrices at both 1 month and 1 year after surgery, suggesting that post-operative neuropsychological improvements are influenced by the reduction in seizure frequency after surgery.

The improvements in cognitive functioning after surgery observed in this study may be attributed to good surgical outcomes. Successful removal of the epileptogenic tissue could reduce the amount of unusual electrical activity and thereby preserve the function of the surrounding tissues[31,32]. Many studies have suggested that AEDs could directly alter cognitive functioning[33,34]. In our study, 22 TLE patients (41%) stopped taking AEDs after surgery, which may have led to the improvement of their performance on neuropsychological assessments. Rausch *et al.*[26] reported that all patients were taking antiepileptic drugs at the 1-year follow-up. However, in our study, only 59% of the patients were taking antiepileptic drugs at the 1-year follow-up and 41% were drug-free after surgery. We found that the patients who were medication-free after surgery had higher levels of intellectual and neuropsychological functioning before and after surgery. It suggests that better pre-operative functions, such as higher IQ, memory and executive functions, predicts a better surgical outcome, that is, a higher chance of successfully discontinuing all seizure medications after surgery. Another possibility is that the patients who were medication-free after surgery might have less severe seizure and, therefore, less impaired before surgery. However, there were no significant differences in the duration of illness and frequency of seizure between the medication and medication-free groups.

In the present study, 85.2% of the patients were seizure-free after surgery, which is similar to the 80% seizure-free rate reported in previous studies[35,36]. Although there were significant differences in neuropsychological performance between the TLE patients on medication and those who were medication-free, we could not examine the post-operative neuropsychological functions in terms of seizure-free outcome because 46 of the TLE patients (85%) were seizure-free 1 year after the surgery, and only eight patients continued to experience seizures.

A limitation of the present study is that the number of TLE patients who were subjected to a 1-year follow-up assessment was relatively small, especially in the right TLE group, and the 1-year neuropsychological follow-up in the present study was not sufficient to examine the long-term prognosis of surgical treatment of intractable epilepsy. A previous study observed improvements within the first year after surgery[4]. Surgery-induced verbal memory deficits following left TL were found to be stable for 13 years after surgery[26]. However, our study found that even though L-TLE patients showed a decrease in auditory immediate memory after surgery, both the L-TLE and R-TLE patients who underwent TL, which included the hippocampus, retained their ability to learn, as demonstrated by the five trials of Rey Auditory Verbal Learning Test. Therefore, we also compared the post-operative neuropsychological functions of the patients who underwent TL including the hippocampus, with those of the patients who underwent SAH in order to examine whether the lateral temporal cortex plays an important role in maintaining the ability to learn. The results showed that there was no significant difference in neuropsychological performance in terms of the type of surgery performed (TL versus SAH) in the R-TLE patients, while the L-TLE patients who underwent SAH did not show significant learning effect over trials in the Auditory Immediate Recall test. Helmstaedter *et al.*[37] suggested that the reason that the outcome of SAH is not better than that of TL is because SAH causes more frontal lobe injury, which is referred to as collateral damage. Thus, a long-term neuropsychological follow-up study with a large sample of patients should be carried out in order to examine the cognitive sequelae of surgery for epilepsy in terms of the type of surgery and lateralization.

A third limitation of this study is that practice effects may have influenced the observed improvement of neuropsychological functioning, especially PIQ of K-WAIS-R and WCST scores after surgery. To identify these effects, we briefly retested four participants performed pre-operative test without surgery, and the result showed only FSIQ of the K-WAIS-R and Perseverative Errors in WCST to be slightly improved. Other tests, especially the tests used to assess verbal and memory functions and attention were less likely to be influenced by the practice effect. Therefore, the improvements in the TLE patients after surgery observed in this study may be regarded as the results supporting the safety and effectiveness of epileptic surgery.

In conclusion, the present study suggests that TL does not harm the neuropsychological functioning of patients with TLE and that TL improves cognitive functioning by preventing the propagation of epileptic discharge to other brain areas and by giving advantage to previously suppressed capacities and functions in extratemporal areas, so called ‘releasing effect’.

APPENDIX 1

Table 5: Neuropsychological test results of the patients in the L-TLE group

	Pre-operative	Post-operative	*t*
Intellectual functioning			
K-WAIS-R VIQ	88.00 (11.87)	90.23 (10.76)	−1.58
K-WAIS-R PIQ	93.90 (11.54)	98.47 (10.82)	−4.30‡
K-WAIS-R FSIQ	89.67 (11.27)	92.17 (13.16)	−1.54
Executive function			
WCST Total Errors	33.87 (24.25)	25.67 (18.16)	2.57*
WCST Perseverative Errors	18.67 (17.03)	13.43 (11.46)	1.95
WCST Categories Completed	5.10 (1.61)	5.83 (2.31)	−1.52
Trail Making Test Part B (seconds)	89.83 (64.45)	74.53 (58.79)	2.50*
Verbal Fluency	21.67 (11.57)	24.00 (11.15)	−1.16
Figural Fluency	37.90 (12.40)	41.60 (14.78)	−1.62
Stroop Test (seconds)	26.28 (9.08)	25.93 (16.83)	0.16
Language			
K-WAIS-R Vocabulary	8.13 (2.05)	8.10 (1.97)	0.11
Boston Naming Test (max.=60)	42.34 (10.64)	40.55 (12.00)	1.60
K-WAB Spontaneous Speech	19.15 (1.31)	19.38 (1.27)	−1.92
K-WAB Comprehension	189.57 (12.22)	190.47 (13.74)	−0.61
K-WAB Repetition	96.90 (7.64)	96.67 (6.77)	0.26
K-WAB Naming	89.76 (6.13)	89.86 (7.82)	−0.08
K-WAB Reading	89.23 (11.19)	91.17 (9.73)	−1.03
K-WAB Writing	92.63 (14.37)	93.13 (15.62)	−0.35
K-WAB Sequential Commands	59.70 (0.65)	59.67 (1.37)	0.14
Verbal memory			
RAVLT Immediate Recall (total)	39.63 (10.24)	37.73 (13.36)	1.07
RAVLT Long-Delay Free Recall	6.27 (3.28)	6.33 (2.88)	−0.13
WMS-III Auditory Immediate	14.04 (5.27)	11.58 (4.88)	2.16*
WMS-III Auditory Delayed	14.04 (5.65)	12.04 (5.96)	1.58
Visual memory			
ROCF Immediate Recall	19.05 (6.33)	21.62 (5.62)	−2.06*
ROCF Delayed Recall	18.93 (5.58)	21.43 (5.75)	−1.98
WMS-III Visual Immediate	14.04 (4.88)	17.92 (11.41)	−1.73
WMS-III Visual Delayed	14.00 (5.10)	15.04 (4.14)	−0.93
Working memory			
K-WAIS-R Arithmetic	8.37 (2.47)	9.27 (2.74)	−3.66†
WMS-III Letter–Number Sequencing	8.23 (2.73)	8.23 (3.00)	0.00
Auditory Span backward	4.13 (1.31)	4.57 (1.38)	−2.28*
Visual Span backward	4.93 (1.16)	5.28 (1.31)	−1.72
Visuo-spatial ability			
K-WAIS-R Block Design	9.60 (2.04)	10.27 (2.13)	−2.66*
ROCF Copy score	31.97 (5.80)	33.57 (2.21)	−1.41
Attention			
Trail Making Test Part A (seconds)	37.82 (14.06)	39.05 (23.19)	−0.33
CPT Number of Correct	114.43 (7.84)	117.00 (6.12)	−2.10*
CPT Number of Incorrect	6.03 (5.67)	7.63 (16.62)	−0.50
CPT Reaction Times (seconds)	1.01 (0.14)	1.32 (1.82)	−0.93
Auditory Span forward	5.20 (1.45)	6.23 (1.83)	−4.11‡
Visual Span forward	5.03 (2.04)	5.59 (1.45)	−1.49
Motor function			
Grooved pegboard dominant hand (seconds)	76.72 (20.19)	69.24 (16.12)	3.20†
Grooved pegboard non-dominant hand (seconds)	77.55 (13.08)	76.35 (14.50)	0.50
Dynamometer dominant hand	27.71 (11.78)	28.48 (11.21)	−1.09
Dynamometer non-dominant hand	26.25 (11.97)	26.60 (11.36)	−0.50

Values are expressed as mean (SD).
K-WAIS-R, Korean-Wechsler Adult Intelligence Scale-Revised; WCST, Wisconsin Card Sorting Test; K-WAB, Korean version of Western Aphasia Battery; RAVLT, Rey Auditory Verbal Learning Test; WMS-III, Wechsler Memory Scale-III; ROCF, Rey–Osterrieth Complex Figures Test; CPT, Continuous Performance Test.
*$p<0.05$, †$p<0.01$, ‡$p<0.001$.

APPENDIX 2

Table 6: Neuropsychological test results of the patients in the R-TLE group

	Pre-operative	Post-operative	*t*
Intellectual functioning			
K-WAIS-R VIQ	94.00 (13.81)	97.92 (13.04)	−2.73*
K-WAIS-R PIQ	97.42 (10.39)	104.17 (10.45)	−5.00‡
K-WAIS-R FSIQ	95.25 (12.18)	100.54 (10.81)	−4.32‡
Executive function			
WCST Total Errors	43.17 (22.11)	30.17 (27.30)	2.72*
WCST Perseverative Errors	24.43 (19.06)	16.96 (18.38)	3.26†
WCST Categories Completed	4.52 (1.86)	4.96 (1.89)	−1.27
Trail Making Test Part B (seconds)	75.17 (40.38)	68.54 (47.06)	0.81
Verbal Fluency	22.71 (10.56)	27.04 (11.88)	−2.56*
Figural Fluency	41.33 (16.01)	43.58 (20.05)	−0.59
Stroop Test	26.50 (12.60)	22.46 (6.50)	2.08*
Language			
K-WAIS-R Vocabulary	9.50 (2.50)	9.21 (2.00)	1.07
Boston Naming Test (max=60)	46.79 (6.97)	49.50 (6.01)	−3.30†
K-WAB Spontaneous Speech	19.75 (0.61)	19.58 (1.47)	0.50
K-WAB Comprehension	185.29 (24.92)	192.17 (9.85)	−1.76
K-WAB Repetition	98.25 (2.13)	98.92 (1.95)	−1.33
K-WAB Naming	93.29 (4.98)	94.04 (5.10)	−0.88
K-WAB Reading	92.79 (7.57)	95.96 (4.92)	−2.25*
K-WAB Writing	97.83 (3.16)	98.77 (2.05)	−1.42
K-WAB Sequential Commands	59.79 (0.59)	59.54 (1.35)	0.95
Verbal memory			
RAVLT Immediate Recall (total)	42.04 (10.89)	45.42 (11.98)	−1.21
RAVLT Long-Delay Free Recall	8.33 (2.70)	8.63 (3.16)	−0.71
WMS-III Auditory Immediate	16.14 (6.74)	17.18 (6.36)	−1.13
WMS-III Auditory Delayed	16.91 (5.37)	18.41 (6.23)	−1.56
Visual memory			
ROCF Immediate Recall	18.29 (7.81)	21.00 (6.91)	−2.14*
ROCF Delayed Recall	17.44 (6.73)	19.58 (7.72)	−1.73
WMS-III Visual Immediate	13.55 (4.28)	14.32 (5.84)	−0.89
WMS-III Visual Delayed	11.86 (4.19)	15.45 (12.40)	−1.33
Working memory			
K-WAIS-R Arithmetic	8.96 (2.88)	9.83 (2.88)	−2.56*
WMS-III Letter–Number Sequencing	9.23 (2.84)	8.18 (2.75)	2.41*
Auditory Span backward	4.29 (1.23)	4.38 (1.35)	−0.40
Visual Span backward	5.38 (1.41)	5.21 (1.44)	0.70
Visuo-spatial ability			
K-WAIS-R Block Design	10.17 (2.50)	11.04 (2.69)	−2.64*
ROCF Copy score	32.70 (3.40)	33.33 (2.09)	−0.86
Attention			
Trail Making Test Part A (seconds)	34.36 (13.71)	33.84 (13.42)	0.17
CPT Number of Correct	113.79 (7.89)	116.58 (6.73)	−1.35
CPT Number of Incorrect	6.58 (5.10)	4.58 (4.46)	1.72
CPT Reaction Times (seconds)	0.98 (0.14)	0.91 (0.14)	2.73*
Auditory Span forward	6.17 (1.52)	6.50 (1.10)	−1.28
Visual Span forward	5.42 (1.38)	5.67 (1.34)	−0.90
Motor function			
Grooved pegboard dominant hand (seconds)	77.48 (17.91)	68.65 (11.12)	2.57*
Grooved pegboard non-dominant hand (seconds)	84.32 (21.97)	75.00 (12.38)	2.41*
Dynamometer dominant hand	30.88 (13.94)	32.00 (13.74)	−1.36
Dynamometer non-dominant hand	28.98 (12.91)	28.46 (13.84)	0.32

Values are expressed as mean (SD).
K-WAIS-R, Korean-Wechsler Adult Intelligence Scale-Revised; WCST, Wisconsin Card Sorting Test; K-WAB, Korean version of Western Aphasia Battery; RAVLT, Rey Auditory Verbal Learning Test; WMS-III, Wechsler Memory Scale-III; ROCF, Rey–Osterrieth Complex Figures Test; CPT, Continuous Performance Test.
*$p<0.05$, †$p<0.01$, ‡$p<0.001$.

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