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Research report

The role of the left anterior temporal lobe in language processing revisited: Evidence from an individual with ATL resection

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ABSTRACT

Various hypotheses about the role of the anterior temporal lobe (ATL) in language processing have been proposed. One hypothesis is that it binds the semantic/conceptual properties of words, functioning as a hub for linking modality-specific conceptual properties of objects. This hypothesis predicts that damage to ATL would give rise to impaired conceptual knowledge of all categories. A related school of hypotheses assumes that the left ATL is critical for lexical retrieval, with different sub-regions potentially important for different categories of items. We examined these hypotheses by studying a case of surgical resection of left ATL due to a low-grade glioma (LGG). Thorough language assessments performed four months after the operation revealed the following profile: the patient showed intact conceptual knowledge for all categories of items tested using both accuracy and response latency measures; he suffered from name retrieval deficits for proper names (people and place names) and artifacts (including tools), but showed no name retrieval difficulties for animate things. This pattern of results challenges both target hypotheses about the role of ATL in language processing tested here.

1. Introduction

The neuroanatomical basis for language processing has been studied using a wide range of paradigms, including lesion–function mappings in brain-damaged patients and functional brain–imaging studies on normal subjects and patients. While it is a current consensus that language processing involves a large network of anatomical regions mostly in the left hemisphere, including, but not restricted to the classical Broca's and Wernicke's areas (e.g., Damasio et al., 2004; Foundas, 2001; Spitsyna et al., 2006), specific hypotheses about brain-function relationships differ greatly. One example, which is the target issue of this article, is the role of the anterior temporal lobe (ATL) in language processing.

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Here we consider two influential hypotheses about the role of ATL in language processing that were mainly motivated by neuropsychological evidence. One view is that ATL is the binding site of the semantic/conceptual[1] properties of words and objects (e.g., Patterson et al., 2007; Rogers et al., 2004; Rogers et al., 2006), and damage to this area will result in the loss of conceptual knowledge. Another hypothesis is that ATL in the dominant hemisphere is crucially involved in lexical retrieval (e.g., Damasio et al., 1996, 2004; Drane et al., 2008; Grabowski et al., 2001; Tranel, 2006, 2009). Below we briefly present these contrasting theories and relevant empirical findings.

The conceptual hub hypothesis was motivated by studies of a neurodegenerative disease – semantic dementia (SD) (see Patterson et al., 2007 for a review; Davies et al., 2005; Warrington, 1975). Patients suffering from SD usually show asymmetric, focal atrophy of the antero-lateral temporal lobe and a progressive loss of semantic knowledge about words and objects, as revealed by poor performance on neuropsychological tasks that require access to conceptual knowledge (e.g., word–picture matching, picture–drawing from memory, picture naming or object sound naming). These patients tend to retain knowledge of the common and typical features of objects but lose knowledge about more fine-grained features of those objects. For instance, patients typically draw similar images for all animals, i.e., having a head, two ears and four legs, omitting distinctive features such as the hump for camels. Some anatomy–function correlation studies have further suggested that the extent of atrophy in anterior temporal regions correlates with semantic impairment severity in SD patients (e.g., Mummery et al., 1999; Mummery et al., 2000; but see Martin, 2007 for alternative interpretations) and with meaningful cross-modal feature integration abilities (Taylor et al., 2009). These profiles were the strong motivation for Patterson et al. (2007) to propose that 1) there are amodal, abstract conceptual hubs that bind modality-specific properties which are grounded in the sensory–motor system (see also Caramazza and Mahon, 2006; Mahon and Caramazza, 2009) and 2) such amodal, abstract, item-specific conceptual ‘‘hubs’’ reside in bilateral ATL. We will refer to this theory as the ATL-conceptual hub theory. According to this theory, pathological changes of bilateral ATL will disrupt conceptual knowledge, affecting all kinds/modalities of semantic features of a concept. Evidence in accord with this theory has also been reported from other neurological groups including herpes simplex virus encephalitis (HSVE) and Alzheimer’s disease and from neuroimaging studies (e.g., Binder et al., 2009; Lambon Ralph et al., 2007; Noppeney et al., 2007; see Patterson et al., 2007 for a review). Two recent studies (Lambon Ralph et al., 2009; Pobric et al., 2007) using repetitive transcranial magnetic stimulation (rTMS) over the temporal pole region in either left ATL or right ATL alone showed that temporary disruption of neural processes in these unilateral ATL region produced a selective slowing on tasks that involve semantic processing (e.g., word synonymy judgment) but not for non-semantic tasks (digit judgment). This result demonstrates that unilateral disruption alone is sufficient to induce semantic impairment. It is at least strong enough to affect response latencies, if not accuracies.

The other hypothesis of ATL’s function in language processing is that it is involved in the intermediate stage between conceptual knowledge and word forms (e.g., phonological patterns for naming) (Damasio et al., 1996, 2004; Rudrauf et al., 2008). Damasio et al. (1996) studied the relationship between lesion site in a group of 127 patients with brain damage (106 with stroke, others with HSVE or temporal lobectomy) and their performance on picture naming tasks. They analyzed the naming responses to only those items the patients could identify and, presumably, access the corresponding conceptual knowledge. The naming performance on these items was therefore hypothesized to reflect the ‘‘lexical retrieval’’, i.e., the intermediate stage between conceptual representation and words’ phonological forms. One significant finding was that while patients showed a variety of categorical effects in their naming performance, such as disproportionate deficit for people, animals, or tools, there was no single case in their sample who showed deficits for both people and tools, leaving animals intact, and this pattern was not due to chance (Fisher exact probability test, $p = .0001$). The authors proposed that the left temporal pole, the left inferior temporal (IT) lobe, and the posterolateral inferior temporal lobe are important in name retrieval for people, animals, and tools, respectively. Because the temporal pole and the posterior IT regions are distant and do not overlap cortically or subcortically, it is virtually impossible for a single lesion to affect the retrieval of both people and tool names while leaving the animal items unaffected. Converging evidence for such a distribution of the three conceptual categories was provided by a positron emission tomography (PET) activation experiment where normal subjects named pictures of these categories of objects. The authors proposed that the existence of such category-specific intermediate regions for word retrieval is driven by the distribution of conceptual knowledge of the different categories. Subsequent studies (Damasio et al., 2004; Rudrauf et al., 2008) by the same group, using improved methods for the analysis of behavior–lesion mapping data, have come to similar conclusions in terms of the role of ATL in naming. Nonetheless, the categorical distinctions were less crisp in the most recent study (Rudrauf et al., 2008): left anterior inferior temporal region lesions were found to be associated with naming deficits for all categories and left lateral posterior IT lesions with naming deficits for both animals and tools. Recognition deficits of faces were associated with right temporal lobe lesions, and deficits of tool recognition were associated with left posterior lateral IT lesions. Thus, unlike the original proposal by this group (Damasio et al., 1996) their most recent proposal would predict a naming impairment for all categories following left ATL lesion. Either way, the results by this group of researchers suggest that left ATL is involved in aspects of language processing that are beyond the conceptual level, involving an intermediate stage between conceptual knowledge and word forms.

Patients who underwent left ATL lobectomy as treatment for temporal lobe epilepsy (TLE) usually exhibit good semantic knowledge but selective difficulty for naming people (and other proper name entities) (e.g., Fukatsu et al., 1999;

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[1] These two terms are interchangeable in the paper without any implied distinctions.

Tsukiura, et al., 2002; Glosser et al., 2003; but see Giovagnoli et al., 2005; Wilkins and Moscovitch, 1978). These deficits are typically attributed to *word retrieval* processing failures rather than to damage to conceptual knowledge about people (e.g., occupations). Naming impairments for other categories have also been reported. Drane et al. (2008) showed that category-specific deficits for naming famous faces and animals were shown by patients with dominant ATL seizure onset/resection, in line with the proposal of Damasio et al. about the function of ATL. Tippett et al. (1996), on the other hand, reported a set of patients with left ATL resection who were disproportionately impaired at naming non-living things compared to living things.

Such studies on patients with ATL resections for either TLE or glioma provide direct evidence against the ATL-hub hypothesis, but their theoretical implications have been challenged on the basis of brain plasticity. Proponents of the ATL-conceptual hub hypothesis (Crinion et al., 2003; Jefferies and Lambon Ralph, 2006) have argued that long-standing epilepsy might lead to functional reorganization of the brain given that recent imaging studies showed significant alteration in white matter connectivity and neurotransmitter function in TLE patients (e.g., Powell et al., 2007; Hammers et al., 2003). Similarly, functional reorganization might also happen in patients with LGG (see Desmurget et al., 2007 for a review). For instance, Duffau et al. (2002a, 2002b, 2003) showed that LGGs invading Broca's and other speech areas do not always induce obvious language deficits, and surgical resections that involve these areas often do not lead to long-term functional impairment. Using PET and rTMS techniques Thiel et al. (2001, 2005) observed that patients with LGGs invading left language areas show varying degrees of right-hemisphere language involvement.

However, it would be premature to simply dismiss the relevance of research on patients with ATL resection in this context. After all, SD is a progressive neurodegenerative disease that unfolds gradually over a period of time, in principle allowing time for some plasticity (but see Welbourne and Lambon Ralph, 2007). Even for stroke patients, plasticity could take place at acute stages (Saur et al., 2006; Winhuisen et al., 2005). It might be possible that patients with LGG (and TLE) are subject to plasticity to an extent greater than are other patient types (e.g., SD and stroke). Nevertheless, given that many patients with ATL resection do suffer from some kind of cognitive deficits after the surgery (e.g., proper name retrieval, Drane et al., 2008), it is clear that not all such patients go through full reorganization; the extent and mechanisms of functional reorganization after various types of damage are open issues. Therefore in order to test the theories of the function of ATL it is important to examine a variety of brain disorders and to seek convergent evidence for or against the theories, taking into consideration neuropathological differences. Moreover, in the current context, even without the plasticity issue, existing data from patients with TLE and LGG are not strong enough to challenge the ATL-hub theory as these patients are rarely studied in-depth on semantic processing. Given that their lesions are usually unilateral, they might have subtle semantic impairments that are only apparent with extensive evaluation of performance accuracy and/or response latencies. This is especially pertinent to any evaluation of the ATL-hub theory since this theory assumes that concepts have bilateral ATL hubs and, therefore, unilateral lesions might lead to very mild impairment that may only be rendered visible with sensitive measures such as processing speed (see above, Lambon Ralph et al., 2009; Pobric et al., 2007).

In this paper, we investigate the conceptual and lexical theories of the role of ATL by studying an individual who suffered from a LGG and underwent surgical resection of the left ATL. We carried out extensive language and conceptual processing assessments using both accuracy and response latency measures. He showed the following profile: 1) normal conceptual knowledge about all categories of items tested, including people, animals, tools and other living and non-living things; 2) impaired naming for proper names and non-living artifacts with relatively spared naming of living items; 3) response latencies comparable to matched controls on both semantic and non-semantic comprehension tasks; naming latencies were slower than controls on the tool/inanimate items and were comparable to controls on animal/living items. Such a profile challenges both of the target hypotheses.

2. Case background

When we started testing, ZSK was a 28 year-old, right-handed man with high school education. He worked as a salesperson for kitchen utensils. When admitted to Beijing Tiantan Hospital in April 2007, he reported that one month before he had had a seizure for about 3 min and experienced dizziness post seizure with no hemiplegia. He had no previous history of seizure or epilepsy. Another seizure occurred one week later. He was diagnosed as suffering from a LGG that located at the posterior region of the left middle and superior temporal lobe (Fig. 1a). His results on the pre-operative neuropsychological evaluation were normal: mini mental state examination (MMSE, Folstein et al., 1975); western aphasia battery (WAB, Kertesz, 1982, Chinese adaptation, Gao et al., 1993): spontaneous speech, 10; auditory comprehension, 10; repetition, 9.9; naming, 10. He underwent tumor resection surgery in April 2007. Intraoperative ultrasonography scaning was used to mark the anatomical borders of the glioma, and direct electrical cerebral stimulation was used to mark the functional border. While undergoing surgery with local anesthesia he was asked to repeat words and to name pictures (50 line drawings of common objects presented in repeated cycles). The patient was never informed of when the brain was stimulated. The stimulation method followed the one described in Duffau et al. (2000) with slightly modified parameters: A bipolar probe with tips spaced at 5 mm delivered a biphasic current (pulse frequency of 50 Hz, single pulse phase duration of 1 msec, amplitude from 2 to 8 mA, OSIRIS cortical stimulator). Mapping was first performed in the fronto-temporal cortical level to identify speech areas. No positive responses to language functions were observed within the tumor and the resection regions. The resection started from the posterior border of the tumor and moved forward all the way encompassing the temporal pole (Fig. 1b). To demonstrate the resection regions more explicitly, we manually transformed the 3D image of ZSK's post-surgery magnetic resonance imaging (MRI) to a standard space (Talairach and Tournoux, 1988) by using the Analysis of functional neuroimages (AFNI) software package

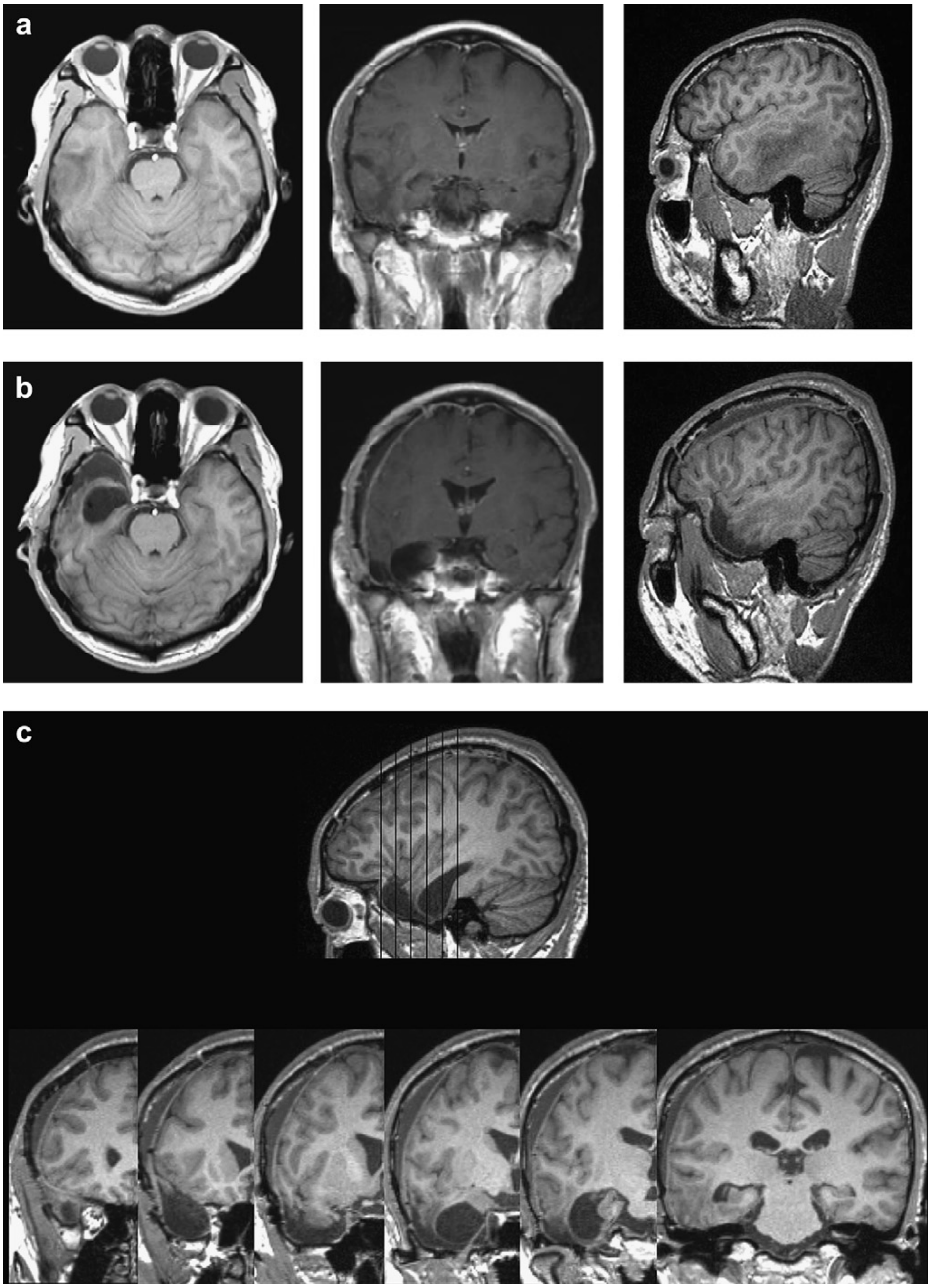

Fig. 1 – MRI scans of ZSK. a) Pre-operation scans. b) Scans at the time of our neuropsychological testing (four months post operation). c) Standardized post-operative MRI in Talairach and Tournoux system. Six coronal slices are presented to depict the extent of the lesion.

(http://afni.nimh.nih.gov/afni/, Fig. 1c). The inferolateral margin of the resection cavity extended to the collateral sulcus, leaving the hippocampus and amygdala intact. The inferoposterior margin bordered the anterior fusiform gyrus. The posterior region of left superior temporal gyrus was anatomically preserved. The tumor was about 5 cm × 2.5 cm in size and the histological examination revealed it to be an oligodendroglioma (World Health Organization Grade II). The immediate post-operative MRI scan showed that the glioma removal was subtotal (grade III, Simpson's classification). The patient was released two weeks after the operation and resumed normal life and work.

About four months post operation, we tested him on the BNU CNLab language screener (Bi and Han, unpublished) and observed mild impairment in speaking and picture naming. His spontaneous speech was fluent and relatively normal, as illustrated by the following response when asked to describe the cookie-theft picture (Goodglass and Kaplan, 1983):

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“小男孩儿跑上去拿那个面包吧. 我就随便瞎说了, 完全不对. 给底下的小姑娘吃，站到那个圆凳上. 那个是阿姨吧. 阿姨在擦盘子. 这边在流水，没有关上水管. 外面的风景不错…”. (Roughly translated as: ‘‘A boy goes up to get that bread. I will just say whatever I think, completely wrong … to give to the girl down here to eat. Standing on the stool. That is an auntie. Aunt is drying dishes. It’s flowing here, has not turned off the tap. Good view outside…’’). However, he complained about experiencing occasional word finding difficulty, especially for familiar people’s names and the kitchen utensils he sells. He explained how he bypassed such difficulties by calling people ‘‘brother’’ or ‘‘sister’’ and using the pictures in the product brochure.

He was perfect in an oral repetition tasks with words and non-words (40/40), an auditory lexical discrimination task in which the ‘‘no’’ trial pairs differed by one vowel, one consonant, or one tone (40/40), and an auditory word lexical decision task where non-words were constructed by combining two random syllables (19/20). He was also able to correctly read aloud both words (45/45) and pseudo-words (15/15), which were composed of two random characters/morphemes (e.g., tea-pen). His picture naming ability, however, showed mild impairment (objects: 27/34; actions: 33/34).

We then carried out the following sets of experiments to examine his conceptual knowledge and his naming abilities across the relevant categories. The first set examined conceptual knowledge, including off-line tasks probing various modalities of information (Experiment 1a) and an on-line comprehension task (Experiment 1b); the second set examined off-line naming (Experiment 2a) and on-line naming of various categories of objects (Experiment 2b). The inclusion of Experiment 1b and 2b was to further evaluate whether ZSK has subtle semantic impairments that are not reflected by performance (accuracy) in off-line tasks (see Lambon Ralph et al., 2009; Pobric et al., 2007). Experiments 1a and 2a were completed in 9 two-hour sessions during August and November in 2007 and Experiments 1b and 2b were conducted in September 2008 (naming) and May 2009 (comprehension). For tasks that needed more than one session (e.g., picture–word verification tasks), a Latin-square method was used to counterbalance the experimental trials. Repetition of the same items across different tasks in each session was avoided. The patient’s performance remained stable during these testing sessions. Controls’ performance was collected by administering the tests to groups of healthy participants and scoring their responses following the identical criteria to those used with ZSK.

3. Experiment 1: conceptual knowledge assessments

3.1. *Experiment 1a: off-line conceptual tasks*

3.1.1. *Method*

The following tasks were employed to reveal ZSK’s conceptual knowledge for common objects, people and places. See Tables 1 and 3 for the control subjects’ information and performance.

3.1.1.1. Word–picture matching. 1) *Word–picture matching task with 64-item semantic battery* (*N* = 64, Bozeat et al., 2000). In each trial, a spoken word was presented along with ten pictures of objects from the same category (e.g., animals, tools, and fruits/vegetables, etc.), and ZSK was asked to match the word to the correct picture; 2) *Word–picture matching task from BNU CNlab* (*N* = 50). The patient was asked to match a spoken word (including names of common objects and actions) to one of two pictures. In about 1/3 of the trials of the task, the foils were semantically related to the target; in 1/3 they were phonologically and/or orthographically related, and in 1/3 they were visually related.

Table 1 – The correct percentages of ZSK and the control groups on the conceptual assessments.

Conceptual tasks	ZSK	Controls[a]		*p* value (ZSK *vs* controls)
		Mean	SD (range)	
Auditory word–picture matching				
64-item semantic battery (Bozeat et al., 2000)	95%	97%[1]	.026 (94–100%)	.48
BNU CNLab word-matching (*N* = 50)	100%			
Auditory sentence–picture matching (*N* = 20)	100%			
Visual picture–word verification (*N* = 162)	97%	94%[2]	.036 (86–98%)	.43
Visual face–name verification (*N* = 30)	100%	84%[2]	.143 (60–100%)	.30
Visual place–name verification (*N* = 24)	79%	87%[2]	.102 (63–100%)	.46
Associative match				
Task 12 in BORB (*N* = 30)	97%	92%[3]	.042 (87–100%)	.28
Picture version of PPT (*N* = 52)	79%	85%[4]	.048 (77–92%)	.27
Word version of PPT (*N* = 52)	92%	93%[4]	.030 (87–98%)	.87
Visual synonym judgment (*N* = 84)	88%	92%[5]	.045 (83–98%)	.42
Attribute judgment (*N* = 322)	97%	95%[6]	.025 (89–98%)	.45
Animate (*N* = 143)	94%	95%[6]	.034 (86–99%)	.78
Inanimate (*N* = 179)	99%	95%[6]	.022 (91–98%)	.10
Visual attribute (*N* = 196)	95%	93%[6]	.029 (87–97%)	.52
Non-visual attribute (*N* = 126)	99%	97%[6]	.025 (92–100%)	.45

a The control data were collected from several groups of normal participants, corresponding to the labels in the table: 1. 10 college students (mean age: 23); 2. 15 college students (mean age: 23); 3. 10 college students (mean age: 22); 4. 11 college students (mean age: 23); 5. 10 college students (mean age: 24); 6. 15 college students (mean age: 24).

Table 2 – The correct percentages of ZSK and controls (a same group of 10 BNU students for all naming tasks; mean age = 24) on the picture naming tasks.

Picture naming tasks	ZSK	Controls ($N = 10$)		p value (ZSK *vs* controls)
		Mean	SD (range)	
Snodgrass picture naming ($N = 232$)	81%	96%	.030 (91–99%)	.00
Animal ($N = 32$)	97%	98%	.034 (91–100%)	.76
Tool ($N = 40$)	80%	97%	.033 (93–100%)	.00
Living ($N = 72$)	90%	96%	.041 (88–100%)	.20
Non-living ($N = 160$)	78%	97%	.028 (92–99%)	.00
Proper item naming ($N = 54$)	28%	87%	.103 (67–98%)	.00
Face naming ($N = 30$)	33%	88%	.106 (70–100%)	.00
Place naming ($N = 24$)	21%	87%	.158 (58–100%)	.00
Subset ($N = 35$; 18 faces; 17 places)	34%	96%	.047 (91–100%)	.00

3.1.1.2. Sentence–picture matching ($N = 20$). The patient matched one spoken sentence to two pictures, in which the foils were constructed by reversing the object and subject or replacing one word by morphological or semantic neighbors.

3.1.1.3. Picture–word verification ($N = 162$). In this task a picture was presented along with a written word, and ZSK was required to say "yes" or "no" to indicate whether the word corresponded to the picture. Each target picture was paired with three words administered in three separate blocks, including the target, a semantically related foil, and a phonologically/orthographically related foil. A target was scored correct only if it was correctly identified in all three trials – i.e., the subject correctly accepted the target picture and rejected the two foils. It is arguably more sensitive than other matching tasks because the subject cannot make the decision based on the rejection of foils (Breese and Hillis, 2004). The pictures were selected from the set in Snodgrass and Vanderwart (1980) and covered a wide range of categories.

3.1.1.4. Face–name verification ($N = 30$). The design was the same as that of picture–word verification, except that the target pictures here were people's photographs that were used in the "famous face naming" task described below. The paired words were their names. In two separate blocks, each picture was paired with either a correct name or a name denoting a person sharing the same occupation and gender as the target. By using this type of foil we intended to maximize the sensitivity of the verification task.

3.1.1.5. Place–name verification ($N = 24$). The same design as the above test was used and here the target pictures were photographs of famous sites and places (see "place naming" task described below). The paired words were their names. In two separate blocks, each picture was paired with either a correct name or a name denoting a place that was as similar to the target as possible, such as both being foreign or visually alike.

3.1.1.6. Associative match. *1) Pyramid and Palm trees Test (PPT,* $N = 52$, Howard and Patterson, 1992). Both the picture version and the word version of this task were administered. In the picture version, a target picture (e.g., pyramid) was presented along with two related pictures (e.g., palm tree and pine tree). The subject needed to judge which of the two pictures was

Table 3 – The performance of ZSK and controls on the on-line tasks.

	ZSK		Controls ($N = 5$)			RT (t value) (ZSK *vs* controls)	RT (p value) (ZSK *vs* controls)
	RT (msec)	Error rate %	Mean RT (msec) (range)	SD	Error rate % (range)		
Experiment 1b (comprehension)							
Semantic ($N = 79$)	2241	3%	1906 (1446–2579)	463	6% (1–18%)	.661	.545
Non-semantic ($N = 79$)	1510	1%	1676 (1155–2468)	505	6% (1–13%)	−.300	.779
Experiment 2b (picture naming)							
Living ($N = 30$)	1220	3%	1183 (880–1378)	196	5% (0–10%)	.172	.872
Animal ($N = 6$)	1127	0%	1027 (734–1216)	181	7% (0–17%)	.504	.641
Bird ($N = 6$)	1339	0%	1448 (856–1841)	398	3% (0–17%)	−.250	.815
Insect ($N = 6$)	1992	17%	1295 (864–1569)	261	4% (0–17%)	2.438	.071
Fruit ($N = 6$)	898	0%	1139 (1084–1247)	68	7% (0–17%)	−3.235	.032
Vegetable ($N = 6$)	1003	0%	995 (835–1188)	138	0% (0%)	.053	.960
Non-living ($N = 30$)	1444	3%	1126 (993–1256)	133	3% (0–10%)	2.183	.094
Appliance ($N = 6$)	1329	0%	1044 (869–1241)	168	0% (0%)	1.549	.196
Clothing ($N = 6$)	1358	0%	1180 (943–1137)	160	3% (0–17%)	1.016	.367
Food ($N = 6$)	1486	0%	1141 (1054–1352)	123	3% (0–17%)	2.560	.063
Tool ($N = 6$)	1769	0%	1303 (1188–1422)	103	7% (0–33%)	4.130	.014
Vehicle ($N = 6$)	1240	17%	984 (684–1185)	188	0% (0%)	1.243	.282
Total ($N = 60$)	1327	3%	1153 (906 –1307)	163	4% (0–7%)	.975	.385

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more closely related to the target picture. In the word version, all things were identical except that words were presented instead of pictures. *2) Task 12 in* Birmingham object recognition battery (BORB, $N = 30$, Riddoch and Humphreys, 1993). This task is similar to the picture version of PPT.

3.1.1.7. SYNONYM JUDGMENT ($N = 84$). This was a Chinese adaptation of the synonym triplets test (Breedin et al., 1994), where three words were presented in each trial, and the subject needed to select the one word that was semantically most distant from the other two (odd-one-out, e.g., lake, brook, stream). The test included 26 trials of abstract items (13 nouns and 13 verbs), 26 of concrete items (all nouns), 16 noun trials and 16 verb trials.

3.1.1.8. ATTRIBUTE JUDGMENT ($N = 322$). This task was a Chinese adaptation of the Central Attributes judgment test in Caramazza and Shelton (1998), which was designed to examine whether a patient is impaired at conceptual knowledge of objects. The task included true and false statements about objects, e.g., ‘‘a rooster has a short curly tail’’ and subjects were asked to judge whether the statement was correct. The statements tapped into both visual and non-visual properties of animate and inanimate objects and they were matched on difficulty levels (see details in Bi et al., 2007).

3.1.2. *Results*

ZSK’s performance and the performance of control groups are listed in Table 1, along with the statistical comparison results of ZSK’s performance against the control groups. We used the program that accompanies the paper by Crawford and Garthwaite (2002), which tests whether an individual’s score is significantly different from a control or normative sample. ZSK was within normal range in all of these conceptual tasks, independently of whether pictorial or linguistic stimuli were used.

3.2. *Experiment 1b: on-line conceptual tasks*

While we did not detect any semantic impairment in ZSK’s performance in Experiment 1a, proponents of ATL-hub theory might argue that bilateral ATL is crucial for conceptual knowledge, and because ZSK had a unilateral ATL resection, his semantic impairment is too subtle to be detected in the tasks we administered. Based on the results in Pobric et al. (2007) and Lambon Ralph et al. (2009), where rTMS stimulation to the left temporal pole affected semantic processing reaction times (RT) in normal subjects, it may be reasoned that left ATL resection will lead to the slowing of responses rather than to errors. Therefore we carried out on-line experiments with ZSK and control subjects to test whether indeed ZSK’s semantic impairment is manifested in a RT task.

3.2.1. *Method*

3.2.1.1. PARTICIPANTS. Five native speakers of Mandarin Chinese with no history of neurological injury matched to ZSK on age and education level were included in the control group (mean age: 26, all male with high school education).

3.2.1.2. MATERIAL, DESIGN AND PROCEDURE. Following the rationale in Pobric et al. (2007), we selected a word associative matching task as the semantic task and a digit judgment task as the non-semantic task. The word associative matching task is similar to PPT (see Experiment 1a). The participants saw a target word and two other words in each trial; they were asked to choose the word that was more semantically related to the target. In the digit judgment task, the participants were asked to choose one out of two digits (e.g., 11, 19) that was closer to a target digit (13). There were 79 target–response triplets in the word associative matching task (41 were taken from PPT) and 79 in the digit judgment task. The digits used in the digit judgment task were all two-digit numbers.

In each trial of both tasks a fixation point (‘‘+’’) was presented for 500 msec, followed by the three stimuli with the target on top and the two alternatives below. The triplets stayed on the screen for 4 sec or until the participant pressed the key. The intertrial interval was 1 sec. The DMDX program (Forster and Forster, 2003) was used to present the stimuli and record response latencies. The whole experiment lasted about 15 min.

3.2.2. *Results*

RT of incorrect responses were excluded from further analysis. In total there were only three RT values that were three standard deviations away from a subject’s mean; these values were replaced with the cutoffs (mean plus/minus three standard deviations). ZSK and controls’ performances on the on-line semantic (word associative matching) and non-semantic (digit judgment) tasks are shown in Table 3. The t and p values were derived using the method proposed by Crawford and Garthwaite (2002) to detect a significant deficit in comparison to controls’ performance. ZSK’s accuracy was not lower than controls on either task. His response latencies were not significantly different from the control group either. Further analyses using the Revised Standardized Difference Test (RSDT) (Crawford and Garthwaite, 2005; see below for explanation) showed that there was no dissociation between ZSK’s performance on the semantic and the non-semantic tasks [$t(4) = .822$, $p = .457$]. In other words, ZSK was not different from controls on the semantic task relative to the non-semantic task.

4. Experiment 2: picture naming across categories

4.1. *Experiment 2a: off-line picture naming tasks*

4.1.1. *Methods*

To examine whether ZSK’s naming performance was affected by semantic category as predicted by Damasio et al. (1996, 2004), we administered a naming task with pictures of common objects and proper name entities (people and places). For common objects we used the Snodgrass and Vanderwart (1980) pictures (Chinese adaptation, Shu et al., 1989), which includes line drawings of common objects from a wide range of categories, e.g., four-legged animals, vehicles,

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musical instruments, kitchen utensils, body parts, birds, insects, etc. For pictures of people, we used a ‘‘Chinese famous face database’’ (Liu, unpublished). For place items, we selected 24 places that are well known to Chinese people, such as the Summer Palace and the Fuji Mountain.

4.1.2. *Results and discussion*

ZSK’s first complete responses were considered and were scored as correct if the response was identical to the designated target or was an acceptable alternative to the target. Table 2 displays his naming accuracy broken down by item category (see below for detailed categorization criteria within common objects).

On the Snodgrass and Vanderwart (1980) pictures, he made the following errors: 1) fourteen semantic errors (e.g., 吉他, guitar, /ji2 ta/ → 钢琴,, piano, /gang1 qin2/); 2) three phonological errors (a word or a non-word that is phonologically related to the target; e.g., 电熨斗, iron, /dian4 yun4 dou3/ →/dian4 lou4 dou3/); 3) two mixed errors, where the response was both semantically and phonologically related to the target (e.g., 白菜, cabbage, /bai2 cai4/ → 芹菜, celery, /qin2 cai4/); 4) seventeen circumlocution errors (descriptions of the target picture; e.g., 摇椅, rocking chair, /yao2 yi3/ → 椅子,前后摇晃的, chair, rocks back and forth); 5) six visually related errors (e.g., 鼓, drum, /gu3/→ 桶, bucket, /tong3/); 6) one ‘‘don’t know’’ response. On people and place items, his only error types were circumlocutions (37/39) and don’t knows (2/39).

His responses further suggested that he had relatively good knowledge about the items that he failed to name. Especially for the items in the people and place categories for which his naming performance was rather poor, he often provided detailed descriptions demonstrating correct recognition of these items. For example he correctly described one person as Chinese and the champion of the 110 m hurdles. For the 20 people he failed to name, he voluntarily provided the profession of 19 of them and they were all correct. He had only one ‘‘don’t know’’ response for people and one for place; this number of errors was actually fewer than most controls. We gave his descriptions of the people he failed to name to four naïve subjects with the instruction that they were to guess who the person was. Subjects correctly identified 12 of the 19 items from the descriptions. Of the 19 place items he failed to name, his descriptions for seven items were precise enough to allow the four naïve subjects to guess their names correctly. What little vagueness there was in his descriptions was usually due to the fact that the descriptions involve other proper names that he had difficulty retrieving (e.g., the names of songs sung by a singer) rather than from picture recognition failure.

To test for any potential category-specific effects in his naming performance, we conducted the following types of category comparisons. First, following the classification in Damasio et al. (1996), we compared animals, tools, and people’s names; second, given the hypothesis that the temporal pole is central to proper name processing in general (Damasio et al., 2004), we compared animals, tools, and proper names (combining people and places); finally, because in the recent literature the animal/tool distinction parallels the living/non-living distinction in many aspects including feature type composition or evolutionary relevance, we also considered the living/non-living distinction along with proper name categories. The naming accuracies according to all these classifications are shown in Table 2.

We carried out the RSDT to detect dissociations between tasks, using the software released with the article by Crawford and Garthwaite (2005), which took into consideration the correlation within normal controls across the different tasks. The RSDT method evaluates whether a patient shows either of the following two types of dissociations on two tasks: Classical dissociations, where a patient is impaired by comparison to normal controls on Task A, but is within the normal range on Task B; and strong dissociations, where a patient is impaired on both Tasks A and B, but is relatively more impaired on Task A. The control group’s performance variances were rather different across categories, with proper item naming yielding larger variance than other object categories, which might influence the outcome of the statistical analyses. Therefore we selected a subset of items by discarding items that were not named consistently by controls. The mean and variance of the remaining proper name items were comparable with those of other categories (see Table 2) and we carried out the statistical analyses of ZSK’s performance across categories on this subset. Furthermore, given that multiple comparisons were conducted (e.g., animals *vs* tools *vs* proper names), p values adjusted using Bonferroni method are reported.

4.1.2.1. Animals versus tools versus people. We found that ZSK was significantly more severely impaired on tools and faces than on animals, meeting the criteria of classical dissociation defined by Crawford and Garthwaite (2005): Animal versus tool: $t(9) = 4.601$, $p < .003$; animal versus people: $t(9) = 8.188$, $p < .001$. His performance on animal items was not different from the control group. ZSK’s impairment for people naming was also more severe than tool naming, meeting the criteria of strong dissociation [tool *vs* people: $t(9) = 6.350$, $p < .001$].

4.1.2.2. Animals versus tools versus proper names (people + places). We followed the procedure in the previous section except that we now also included the place name items in the proper name category. The results are as follows: animal versus proper: $t(9) = 8.097$, $p < .001$; tool versus proper: $t(9) = 6.915$; $p < .001$.

4.1.2.3. Living versus non-living versus proper names. We followed the procedure in the previous section. The living items included animals, birds, insects, vegetable, fruits, and plants. The non-living items included body parts, musical instruments, tools, furniture, kitchen utensils, vehicles, clothing, commodities and other things. The results are as follows: living versus non-living: $t(9) = 5.542$, $p < .002$, meeting the criteria for classical dissociation; living versus proper: $t(9) = 7.892$, $p < .001$, classical dissociation; non-living versus proper: $t(9) = 6.859$, $p < .001$, strong dissociation.

4.1.2.4. Overall regression analyses. We further carried out multiple logistic regression analyses for all items in the Snodgrass and Vanderwart (1980) set to confirm the living/non-living and animal/tool differences within the common

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name set. The advantage of regression analyses is that we can partial out potential contaminating variables such as word frequency and reveal any "real" categorical effect. In the regression analyses, the dependent variable was ZSK's response scores (1 for correct and 0 for incorrect). Independent variables included living/non-living categorization (1 for living and 0 for non-living), target word frequency (log value), age of acquisition (AoA), number of syllables, visual complexity of the target picture, naming agreement, and familiarity. The values of word frequency were taken from Yu et al. (1998) and of all other independent variables were from Shu et al. (1989). All the effects of independent variables are random effects in the regression model except for the living/non-living categorization, which is a fixed effect. Using the Forward/logistic regression method we found that significant predictors included the living/non-living category ($p = .005$), AoA ($p = .012$), visual complexity ($p = .007$), and frequency ($p = .029$). Using a step-by-step method, we first entered all other variables except the living/non-living categorization and then entered this variable. Its contribution was still significant ($p = .002$). We also tested the animal/tool categorical distinction in the same way by changing the coding method for categories into the following: 1 for animals, 2 for tools, and 3 for others. This categorical distinction was also a significant predictor of ZSK's naming performance (step-by-step method: $p = .001$). In other words, the living/non-living or animal/tool categorical membership significantly predicted ZSK's naming performance on top of other nuisance variables.

4.2. *Experiment 2b: an on-line naming task*

4.2.1. *Method*

4.2.1.1. PARTICIPANTS. The same group of control subjects as in Experiment 1b participated in the study.

4.2.1.2. MATERIAL. We only included objects (living and non-living) in this experiment because ZSK's naming deficit for proper names was too severe (see Experiment 2a) to generate meaningful RT data. From the corpus of Snodgrass and Vanderwart's (1980) pictures, six black and white line drawings were selected from each of five living categories (four-legged animals, birds, bugs, fruits, vegetables) and five non-living categories (tools, furniture, appliances, vehicles and clothing) as experimental stimuli. An additional 18 pictures from other categories were chosen for practice, warm-up, and filler trials. ZSK had successfully named these items in the off-line task in Experiment 2a. The presentation order of this whole list of 78 pictures was pseudo-randomized such that the testing started with six warm-up trials. In each trial, subjects had no time limit to name the picture, and the pictures only disappeared after the experimenter manually pressed the space bar upon hearing the subject's complete response. The next trial started 1 sec later. The experimental apparatus was identical to that of Experiment 1b.

4.2.2. *Results and discussion*

The same data analysis procedure as Experiment 1b was used and there were three outliers that were replaced by the cutoffs. The error rates and RTs of ZSK and controls across all categories are presented in Table 3. For the overall RT, ZSK was not significantly slower than the controls. Importantly, he showed a categorical pattern here that parallels that observed in Experiment 2a: while his naming latencies were marginally significantly slower than the controls on non-living categories, his RTs of items belonging to living categories did not differ significantly from the control distribution. Further RSDT analyses showed that the difference between the non-living versus living picture naming was significantly dissociated [$t(4) = 5.35$, $p = .006$]. Worth noting was that the pattern is rather consistent across various subordinate categories within the living and non-living domains (see Table 3).

Such normal naming latencies for living items further consolidates our findings in Experiment 1 that ZSK's ability to process conceptual knowledge was not different from controls. His difficulty in naming non-living objects and proper name entities in terms of error rates (Experiment 2a) and RTs (Experiment 2b) was best attributed to a post-semantic lexical retrieval process. Given that ZSK was perfect in tasks such as reading and repetition, indicating intact phonological output lexical representations and peripheral phonological encoding, the categorical deficits should lie in the process of retrieving the lexical node (or lemma) for oral production (e.g., Caramazza, 1997; Caramazza and Hillis, 1990; Dell, 1986; Levelt et al., 1999), which might be relayed through the convergent zones (e.g., Damasio, 1989; Damasio et al., 1996, 2004). There are several ways in which a post-semantic lexical retrieval deficit might yield a category-specific effect in naming. One is that the convergent zones that relay distributed conceptual information to lexical nodes are organized by semantic category; another is that the (output) lexicon itself is organized by semantic categories. Finally, if the semantic system is organized by semantic categories and given that the lexical retrieval/access process originates from the semantic system, then impairment in lexical retrieval may present with a categorical effect.

5. General discussion

We report the performance of a patient (ZSK) who underwent surgical removal of part of the left ATL (temporal pole and neighboring ventral regions) for a slow-growing glioma. ZSK showed the following post-surgery cognitive profile: he did not show any impairment relative to controls in conceptual tasks (both offline and online) across various types of semantic categories but exhibited a semantic category effect in word naming, with the most severe difficulties on proper names (people and place), less severe impairment on non-living items, and intact naming of animate (living) things. Therefore, the cognitive origin of his deficit would seem to lie at the lexical retrieval stage of production for certain categories (non-living and proper entities), rather than at the conceptual processing stage.

Part of ZSK's profile – the lack of visible semantic deficit and severe difficulties in naming unique entities – is consistent with many other similar cases with left ATL resection in the literature (e.g., Fukatsu et al., 1999; Tsukiura, et al., 2002; Glosser et al., 2003). More severe impairment with tool (non-living) compared to living things naming, on the other hand, is rarely reported (Tippett et al., 1996).

The lack of (visible) semantic impairment in our patient following left ATL resection is predicted by Damasio et al.'s theory but not by the ATL-hub theory. The ATL-conceptual hub theory holds that the bilateral ATL serves to bind the modality-specific features associated with a given concept. It has been argued that damage to left ATL alone would induce subtle semantic disruptions that can only be detected using sensitive measures (e.g., Jefferies and Lambon Ralph, 2006). However, while rTMS stimulation to the left temporal pole has been shown to slow down semantic processing in normal subjects (Pobric et al., 2007; see also Lambon Ralph et al., 2009), ZSK did not perform differently from controls even when assessed with sensitive measures such as RT measures. Not only was his performance comparable to controls in semantic comprehension tests – both in terms of accuracy and response latencies – but he was also not significantly slower than the controls in speeded picture naming for living items. Worth noting here is that our extensive comprehension tests required access to item-specific, fine-grained semantic features that distinguish among semantic neighbors. Thus, we found no evidence of even subtle semantic impairment in our patient contrary to what we would expect from the ATL-hub theory (e.g., Jefferies and Lambon Ralph, 2006). Nonetheless, the lack of semantic impairment in our patient could be accommodated by the ATL-hub theory if we were to assume that the conceptual hubs in the two hemispheres are each capable of supporting full semantic processing. This modification (or other variants, such as arguing that the left hub is less important than the right hub for conceptual processing) awaits further articulation and direct empirical evaluation.

The particular pattern of categorical effects in ZSK's naming, i.e., deficit with proper entities and artifacts and not with animals, is not readily explained by either target theory. The naming deficit for proper name items as a consequence of left temporal lobe resection is in accord with the findings by Damasio et al. (1996, 2004) (Grabowski et al., 2001; Tranel, 2006; see Tranel, 2009 for a review), the ATL-hub theory (e.g., Patterson et al., 2007), and various other researchers (e.g., Fukatsu et al., 1999; Simmons et al., in press; Tsukiura et al., 2002; Glosser et al., 2003). Researchers have debated whether the selective impairment for proper names arises because unique and common entities are represented/processed as distinct categories or because proper name processing places greater processing demands (e.g., level of specificity) on a shared system (e.g., Miceli et al., 2000; Patterson et al., 2007; Semenza, 2006; Semenza and Zettin, 1988, 1989). Our results do not speak to this issue. However, the association between the naming deficits for proper names and artifacts, in the context of spared ability to name animate items, in our current case is inconsistent with the theory proposed by Damasio et al. (1996, 2004). The earlier formulation of the theory suggested that the categories of proper names, animals, and tools are distributed along the temporal lobe in an orderly manner from temporal pole to the posterior regions. The more recent version of this theory emphasizes the importance of the left ATL region in naming items from all concrete categories. The pattern of category-specific naming deficit reported here does not fit either account.

How might these differences with the target theories be explained? There are several issues to consider. The first is the role of brain plasticity and reorganization. There is strong evidence that long-standing epilepsy and slow-growing tumors lead to functional reorganization of the brain (Thiel et al., 2005) and it is possible that there has been a gradual shift of function in our patient during the growth of the tumor. In addition, there is the possibility of recovery of function post surgery (Plaza et al., 2009). Yucus and Tranel (2007) reported that seizure onset might even predict proper name naming ability after TLE, consistent with the notion that patients with early seizure onset might have greater chance for functional reorganization of the brain, which would protect them from developing a naming deficit following left temporal pole resection. Their study not only confirmed the functional relevance of the temporal pole in proper item naming, but also provided support for functional reorganization in patients with long-standing epilepsy. The same argument might apply to patients with LGG (Duffau et al., 2002a, 2002b, 2003; see also Campanella et al., 2009), including our case ZSK. Nonetheless, the pattern seen here is not easily explained by functional reorganization. Under the ATL-conceptual hub hypothesis, it is not obvious why functional reorganization in the temporal lobe protected ZSK from a conceptual deficit but not a naming deficit for only tools/artifacts and proper name items. It might be argued that there was considerable but incomplete plasticity-related recovery and thus the resection gave rise to a limited semantic impairment. The name retrieval deficit of proper names when compared to common names might be explained by assuming that proper names demand greater degree of specificity and would be most easily affected by any mild semantic impairment. However, such an account fails to explain the observed preservation of naming ability for animate items relative to artifacts, *unless* it is further assumed that the semantic system hubbed at ATL is organized by animate/inanimate categories and a partial recovery would somehow benefit one category more than the other. To explain ZSK's profile in the framework of Damasio et al. (1996, 2004) with functional reorganization, one would have to assume that the regions normally associated with animate things and artifacts are somehow switched around by functional reorganization. Besides, it is not obvious why TLE patients, who are also subject to reorganization, would have a similar categorical distribution (e.g., Drane et al., 2008) with those observed in other patient groups and PET experiments (e.g., Damasio et al., 1996).

Another possible explanation of the current results in the context of the category-specific organization proposed by Damasio, Tranel et al., is that there are individual differences in the distribution of semantic categories along the temporal lobe. Damasio et al.'s proposal is based on studies with large patient groups and captures strong tendencies regarding the functional–anatomical organization of the human brain. Thus, our case does not undermine but rather, tempers the value of the generalizations that follow from those findings.

Finally, it is possible that there are complicated subdivisions within ATL that serve different functions. For instance, it has been shown that medial ATL is related to processing animate items (Brambati et al., 2006; Gainotti, 2000; Noppeney et al., 2007)

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and left ATL is more important in processing concrete entities, while right ATL may be more important for abstract entities (e.g., Papagno et al., 2009; but see Pobric et al., 2009). A recent functional MRI (fMRI) study (Simmons et al., in press) reported that anterolateral regions of the superior temporal gyri and temporal poles are more activated when subjects learned person facts, relative to buildings or tools. Furthermore, at least two reports (Cappa et al., 1998; Tippett et al., 1996) described more severe naming deficit for non-living things than for animals due to left ATL lesions. The diversity of functional consequences following ATL lesion might result from the disruption of different subcomponents of ATL. A related possibility is that surgery damaged subcortical structures that connect the posterolateral inferior temporal lobe (the artifact region) and other relevant regions that are crucial for naming. More generally, we suspect that there has been insufficient attention paid to the possibility that many of the deficits we observe result from damage to structures that play primarily a connective role (Geschwind, 1965). So, it could turn out that the role of parts of the ATL and its underlying white matter is less to bind conceptual information than to connect areas in the frontal and posterior temporal areas where such information might be represented. If such were the case, then seemingly discordant patterns of performance such as ZSK's may reflect different forms of disconnection from stable representational areas in the frontal and posterior temporal lobes.

To conclude, we presented a case showing a novel profile of semantic category effects in naming after left ATL resection, which is not readily explained by current hypotheses about the role of the ATL in language and conceptual processing. This finding invites further studies that take into consideration the anatomical and functional complexity within ATL, possible individual differences, and the course of functional reorganization following ATL resection.

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