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Determinants of lexical access in pure-anomic recovery: a longitudinal study*

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Abstract: Many studies involving lexical access in picture-naming tasks have been undertaken at a point in time, mainly focusing on age of acquisition (AoA). To identify the real determinates of lexical access in recovery and their traces in the brain, we carried out a longitudinal study on a Chinese pure anomic patient using multiple logistic regression analysis. We found that AoA played an important role in early recovery but not in total recovery, whereas familiarity was significant in the whole process. From a new dynamic point of view, our results indicate that AoA and familiarity are the main determinants of lexical access in anomia recovery. We suggest that the changing effects of AoA during recovery may be related to the pathologic process; AoA and familiarity should be taken into account in constructing materials to assess and treat anomic patients.

Key words: Object naming, Age of acquisition, Anomia, Therapy
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INTRODUCTION

An individual's mental lexicon is a language's inventory of lexemes, the minimum units of vocabulary. As a major topic in the field of cognitive neuroscience, lexical access is about retrieving words in the lexicon. To date, many naming studies in different languages have shown that cognitive variables affecting concept or word properties play important roles in cognitive processes in normal subjects. Furthermore, they have separated these variables and related them to particular cognitive processes. First, visual complexity and image agreement, associated with picture properties, probably affect picture recognition. Second, concept familiarity and imageability (or image variability) probably affect activation latencies of concept and semantic representation. Third, name agreement, frequency, and age of acquisition (AoA) probably affect the stages of lexical access. Finally, phonological factors such as the numbers of phonemes and syllables are thought to affect phonological encoding (Alario *et al*., 2004). Among all the variables, AoA has attracted a great deal of attention in picture-naming tasks.

Using experiments focusing on AoA and especially its mechanism, some researchers have attempted to dig into the core of lexical access. Besides the accumulative frequency hypothesis (Lewis *et al*., 2001), researchers proposed two classical hypotheses to interpret AoA effects: the arbitrary mapping hypothesis (Ellis and Lambon Ralph, 2000) and the semantic hypothesis (Brysbaert *et al*., 2000). (1) The accumulative frequency hypothesis claims that AoA is an outcome variable of frequency. (2) The arbitrary mapping hypothesis states that AoA effects appear to be larger in tasks including arbitrary mappings of visual information in their naming (e.g., object naming) than in tasks including predictable correlated mappings (e.g., rapid word naming in alphabetic scripts). The researchers constructed neural network models that showed that early acquired words are also

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processed more rapidly because they are acquired earlier, when a brain network has maximum plasticity. That is, the semantic parts of later acquired words are built on those of earlier words, which gives early acquired items a more central and better connected place in the network. Thus, earlier acquired words are processed more easily. (3) The semantic hypothesis proposes that late acquired words are processed more slowly because they are less central in the semantic network. Based mostly on behavior experiments, the three mainstream hypotheses have some drawbacks and contradictions among them, and consequently they need to be further investigated.

Functional magnetic resonance imaging (fMRI) was only recently applied to studies of AoA. In fMRI experiments on healthy subjects, Ellis *et al*.(2006) found traces of AoA in the brain: greater activation occurred in the left occipital poles (the posterior part of BA 18) and the left temporal poles (the anterior part of BA 38) when subjects named early-than-late objects; while greater activation occurred in the left middle occipital and fusiform gyri (conjunct areas between BA 37 and BA 19) when subjects named late-than-early objects. Nevertheless, activation does not always mean excitability. For example, reorganization could cause a smaller activation, as measured with fMRI, but a higher excitability of the areas, as measured with transcranial magnetic stimulation (TMS) and as shown by some behavior data (Michel, 2006). Thus, the areas of activation revealed by fMRI still need further investigation.

Aphasic studies, especially rare pure anomic cases with specific lexical-retrieving problems, may provide convincing evidence for the locations of AoA in the brain and its mechanism. Pure anomic patients do not have semantic and phonological problems as they understand the meaning of pictures and can pronounce words perfectly, but they most certainly have lexical-access problems (Kay and Ellis, 1987), and a previous study showed that AoA is the main determinant of lexical access in anomic cases (Cuetos *et al*., 2005). Because the cerebral damage areas of pure anomic patients clearly are confined to particular areas, especially conjunct areas between BA 37 and BA 19, studies of recovery may reveal the relationship between the special cerebral areas and AoA effects.

Longitudinal studies on pure anomic patients are rare and the mechanisms of aphasic recovery are at present unclear, so we designed an overt naming task and tested a rare Chinese anomic case 11 d, 22 d, and over 12 months post-onset to explore the real determinates of lexical access and their traces in the brain. In the end, we drew recovery graphs affected by AoA and carried out multiple logistic regression analysis (forward: LR) using SPSS.

CASE REPORT

Case history

We reported a 76-year-old right-handed Mandarin-speaking man, a retired worker in an iron factory, with a 2-year primary education at age 19. He suffered from a left ischemic stroke and was admitted to the First Affiliated Hospital of Zhejiang University in China. We started to examine him 11 d after his admittance, when his general physical condition was stable. We used the Aphasia Battery of Chinese (ABC) (Gao and Benson, 1990) to test him 11 d, 22 d, and over 12 months post-onset, and found that: first, his spontaneous speech was fluent, his understanding and repetition were unimpaired. Second, his reading and writing were impaired 11 d post-onset but recovered quickly to a normal level in the last examination. Third, he had serious oral naming problems, especially lexical-retrieving problems, during the whole year. When he failed to name, he tried to provide some descriptions of the pictures to prove that he knew the meaning but just could not find the word. Furthermore, his memory was almost normal (Wechsler memory scale, WMS) and he had no buccofacial or limb apraxia, no difficulty in copying 3D drawings, and no visual agnosia or neglect.

MRI data

MRI images (Fig.1) showed that: (1) the ischemic areas included parts of the left temporo-occipital cortex, especially the left conjunct areas between BA 37 and BA 19. (2) The left temporal poles were unimpaired. (3) Left visual-word-forms areas (VWFA) and left occipital poles were unimpaired (Figs.1b and 1c: almost normal signals), but were affected by edema (Fig.1a: high signals). This suggests that edema on the edge of the ischemic areas, such as parts of the occipital poles and the VWFA, diminished in the early recovery phase, while the middle ischemic areas suffered irreversible cerebral infarction.

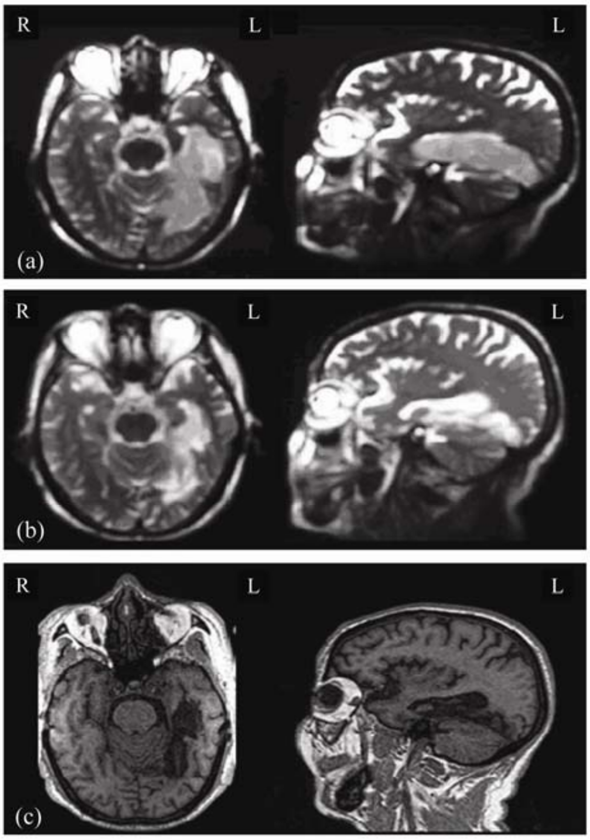

Fig.1 MRI images (a) 4 d and (b) 130 d post-onset, and (c) fMRI-3D images over 12 months post-onset

MATERIALS AND METHODS

We used the pictures in the paper of Cycowicz *et al*.(1997) to test the patient 11 d, 22 d, and over 12 months after the stroke. Image agreement, concept familiarity, image complexity, AoA, word frequency, and cumulative frequency came from the norms based on healthy Chinese subjects (Weekes *et al*., 2007). Image variability came from Alario and Ferrand (1999). The value of name agreement came from the norms of Hao *et al*.(2003). Every picture was presented randomly and clearly to the patient with an experimental instruction "What is it?", and he cooperated well. All the responses were recorded in detail.

Because parts of Snodgrass's pictures are included in the Chinese norms (Hao *et al*., 2003; Weekes *et al*., 2007), and because the difficulty of the tasks (the value of name agreement) may affect the naming response (Laganaro *et al*., 2006), we selected the pictures included in both the Chinese norms (Weekes *et al*., 2007) and in our tasks, and sorted them from the one with the maximum of name agreement variable to the one with the minimum, and chose the top 120 pictures for the analysis (Laganaro *et al*., 2006). At each stage, those pictures the patient could not name were coded 0, while others were coded 1. The living materials contained animal, bird, insect, vegetable, fruit, and plant, while the non-living materials included body part, music, tool, furniture, kitchen, vehicle, clothing, commodity, etc. Living materials were scored 0, while the non-living ones were scored 1. All of them were treated as dummy variables in SPSS.

RESULTS

Recovery graph of AoA effects

The patient could not name any picture 11 d after the stroke. He could name 28 pictures from the 120 pictures 22 d after the stroke, and 64 pictures 12 months after the stroke, including all the pictures that he could name 22 d after stroke.

We divided the 120 items into three groups, a high AoA group (5.58~9.14), a middle AoA group (4.28~5.54), and a low AoA group (2.15~4.21), and we graphed the AoA effects (Fig.2). Most of the items that the patient could name in the early-phase were the early acquired items (χ^2=12.391, P=0.02), and eventually he could name almost the same amount of items among the three groups (χ^2=2.076, P=0.354).

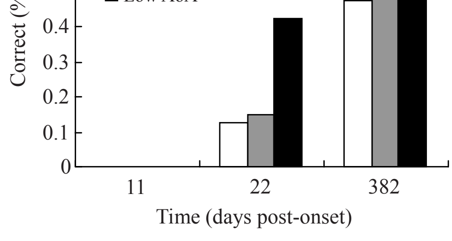

Fig.2 The patient's naming scores (correct) of the three AoA groups from 11 d to 12 months post-onset

Logistic regression results

We firstly carried out simple logistic regression analysis using SPSS with correct naming as dependent discrete variables and the nine cognitive variables as independent variables. The nine cognitive variables were: image agreement (IA), concept familiarity (F), image complexity (IC), image variability (IV), age of acquisition (AoA), word frequency (WF, log transform), cumulative frequency (CF, log transform), word length (WL, chosen as the variable of phonological factors), and category (CA). We considered those pictures that the patient correctly named 22 d after his stroke as 'early recovered,' and those that he correctly named over 12 months post-onset as 'total recovered,' based on the fact that he could not name any of these pictures 11 d after his stroke. Results are shown in Table 1.

Table 1 Logistic regression analysis of the effects of the nine cognitive variables on the naming scores

Cognitive variable	Coefficient		Wald (χ^2)	
	Early recovered	Total recovered	Early recovered	Total recovered
AoA	-0.961^{**}	−0.146	10.060	−0.191
F	1.077^{*}	2.062^{**}	4.628	−10.577
CA	-1.745^{*}	−1.540	4.023	−2.643
WF	−6.271	−5.163	3.005	−1.302
WL	−1.230	−0.118	2.962	−0.032
CF	4.580	−4.621	1.702	−1.065
IA	−0.420	−0.455	1.105	−1.010
IC	0.365	-1.070^{*}	0.963	−5.535
IV	0.154	−0.302	0.111	−0.347

AoA: age of acquisition; F: concept familiarity; CA: category; WF: word frequency (log transform); WL: word length; CF: cumulative frequency (log transform); IA: image agreement; IC: image complexity; IV: image variability. *Correlations significant at the P=0.05 level; **Correlations significant at the P=0.01 level

Using simple logistics analysis of the early recovery group, AoA was significant at $P<0.01$ ($P=0.002$), familiarity was significant at $P<0.05$ ($P=0.031$) and category was significant at $P<0.05$ ($P=0.045$). AoA, familiarity and category were entered in the multiple logistic regression analysis (forward: LR) as independent variables, and familiarity and AoA were the only independent significant predictors in the multiple regression analysis.

In simple logistics analysis of the total recovery, AoA was not significant at $P<0.05$ ($P=0.662$), familiarity was significant at $P<0.01$ ($P=0.001$). Image complexity was significant at $P<0.05$ ($P=0.019$). Familiarity and image complexity were entered in the multiple logistic regression analysis (forward: LR) as independent variables, and familiarity was the only independent significant predictor in the multiple regression analysis.

DISCUSSION

Our work found that AoA and familiarity, rather than frequency, were related to the early recovery phase and only familiarity was related to the total recovery phase, even when the effects of all the other variables were taken into account. In the early recovery phase, most of the retrieved items were those acquired early in life, and thus AoA effects were significant. Then, retrieval of most of the late acquired items began to recover and retrieval of a small part of the early acquired items continued to recover. Twelve months post-onset, the patient could name almost the same amount of late acquired items as that of early acquired ones, which made AoA effects non-significant in the total recovery.

Firstly, our results provide some new dynamic supplements to studies on AoA and lexical access. Previous studies sometimes found that AoA was significantly related to naming success even when the effects of all other variables were taken into account, and suggested that early acquired items are more resistant to damage (Nickels and Howard, 1995; Cuetos *et al.*, 2005). Sometimes, they found that AoA did not relate to the naming success of aphasic patients (Nickels and Howard, 1995; Laganaro *et al.*, 2006). Because their research was carried out at a point of time, we suggested that studies on AoA should begin at an earlier phase, from a dynamic point of view. If one studies AoA at a certain time when retrieval of most of the late acquired items of the patients has recovered, one may conclude wrongly that AoA effects do not exist, when AoA effects do exist initially but disappear later.

Secondly, our results support Ellis *et al.*(2006)'s hypothesis in 2006 about the relationship between the left occipital poles and early acquired items in the brain. The fact that retrieval of most of the early acquired items began in the early phase of recovery is associated with the fact that the left temporal and occipital poles were unimpaired. Let us look at the pathological process of the acute stage of the recovery. At first, shortly after a stroke, a depression of the entire network corresponding to diaschisis may occur, and central hemorrhagic lesions may cause edemas and consequently induce the lowering of cerebral blood fluid as well as dysfunction of the peripheral brain areas. The left occipital poles were affected by edema at the time when the patient could rarely name a picture. Afterwards, edema diminished, hemorrhagic lesions were reabsorbed, neurotransmitters were restored, and the function of peripheral brain areas, including the affected poles, recovered at a time when the patient could name some pictures, especially the early acquired items.

What causes the relationship between these two facts? What are the functions of these cerebral areas? Ellis *et al*.(2006) suggested that early rather than late acquired items are associated with the left occipital and temporal poles. The left occipital poles are visual areas that store the basic visual memory and are sensitive to familiarity, while the left temporal poles reflect the more detailed visual and semantic representations of early acquired items and achieve binding between representations (Rogers *et al*., 2004a; 2004b). Hodges *et al*.(1994; 1995) found that damage to these areas may cause fragmentation and breakdown of semantic knowledge, shown by deficits in naming and other lexical-semantic processes. There are many supporting studies based on Alzheimer disease including Davies *et al*.(2005) and Thompson *et al*.(2003). Based on all these facts, we suggest that the left temporal poles may stimulate the recovery of the early acquired items together with the left occipital poles, and thus damage to these areas may cause difficulty in object recognition, and consequently result in a slow and wrong naming response. Thus, the patient in our study with unaffected temporal poles could not name any pictures at first because his left occipital poles affected by edema may affect the retrieval of visual information. Later, the recovering functions of the left temporal poles and the left occipital poles help the visual information to activate lexical access, and thus help the patient to name the early acquired items.

On the other hand, late acquired items did not recover significantly in the early stage, which doubtless was related to the impaired area. In the experiments of Ellis *et al*.(2006), conjunct areas between BA 37 and BA 19 simultaneously showed significantly greater activation for late rather than for early acquired items. Ellis *et al*.(2006) suggested that the areas connected late acquired items with the early acquired items. So we hypothesized that because only small parts of the conjunct areas remained unimpaired, only a very small number of late acquired items were retrievable in the early stage of recovery. At the late stage of recovery, researchers observed two primary phenomena: (1) the right hemisphere areas homologous to left lesions may take over or substitute for the lost functions; (2) neural tissues in left perilesional regions may be recruited and can subsume functions of damaged areas (Thompson and den Ouden, 2008). Thus, retrieval of the late acquired items starts to recover quickly. Because recovery is a process including a fast and short early phase and a slow and long late phase, the recovery of retrieval of early acquired items inevitably slows down after the faster recovery phase at the time when most of the late acquired items are retrieved, and thus AoA effects disappear. Nevertheless, we need further studies including fMRI experiments on the patient to get solid evidence to validate our hypothesis.

Thirdly, parts of our results support the viewpoint of the arbitrary mapping hypothesis and the semantic hypothesis on account of the existence of AoA effects in the earlier stage. However, our results do not support the hypothesis of cumulative frequency. Neither word frequency nor cumulative frequency was significant in our experiment, since both are based mostly on written materials and may not be relevant to picture naming tasks. More and more evidence supports the view that words that are acquired early in life are processed faster and recover earlier than later acquired words, even when other factors such as frequency are controlled (Bonin *et al.*, 2001; Stadthagen-Gonzalez *et al*., 2004). Moreover, Belke *et al*.(2005) claimed that there are two AoA effects, of which one is frequency-independent. The basic difference is that the frequency-independent effect involves the process of mapping concepts onto lemmas, particularly in the lexical-retrieve stage, which obviously is found in object naming.

Fourthly, multiple regression analysis showed that familiarity was significant throughout our experiment. If one is more familiar with the items, the items are stored firmer in the brain, and are more resistant to damage, so it is likely that familiarity may play an important role in the process of recovery. Moreover, familiarity is considered by some to be object frequency (Gernsbacher, 1984), which correlates highly with AoA (Brown and Watson, 1987). However, Nickels and Howard (1995) observed a double dissociation: one patient showed significant AoA effects but no familiarity effects and another showed the reverse pattern. They suggested that AoA and familiarity may influence different processes of word production. Alario *et al*.(2004) suggested that concept familiarity affects latencies of the activation of the concept and semantic representation, while AoA affects the stages of lexical access. However, there is no doubt about the important role of familiarity in recovery, and our results suggest that AoA is not an outcome variable of familiarity: AoA and familiarity may influence different stages of recovery but both of them are determiners in lexical access.

Finally, our results suggest that AoA and familiarity should be taken into account in constructing materials to assess and treat anomic patients. Up to now, word frequency has been the common variable used in assessment and therapy. However, these data prove that the real variables that must be manipulated are AoA and familiarity, which are the determining factors in lexical access. Oral production tests of anomic cases should select item-naming difficulty as a function of AoA and familiarity rather than a function of frequency. Meanwhile, we should select stimuli sequenced as a function of AoA and familiarity to facilitate rehabilitation programs for anomic disorders.

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