Brain & Language 119 (2011) 110–118

Contents lists available at ScienceDirect

Brain & Language

journal homepage: www.elsevier.com/locate/b&l

# Motor knowledge is one dimension for concept organization: Further evidence from a Chinese semantic dementia case

Nan Lin [a,1], Qihao Guo [b,1], Zaizhu Han [a], Yanchao Bi [a,*]

[a] State Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University, China
[b] Department of Neurology and Institute of Neurology, Huashan Hospital, State Key Laboratory of Medical Neurobiology, Shanghai Medical College, Fudan University, Shanghai, China

a r t i c l e i n f o

*Article history:*
Accepted 8 July 2010
Available online 10 August 2010

*Keywords:*
Motor knowledge
Concepts
Grammatical dissociation
Semantic category-specific deficit
Semantic features
Semantic dementia

a b s t r a c t

Neuropsychological and neuroimaging studies have indicated that motor knowledge is one potential dimension along which concepts are organized. Here we present further direct evidence for the effects of motor knowledge in accounting for categorical patterns across object domains (living vs. nonliving) and grammatical domains (nouns vs. verbs), as well as the integrity of other modality-specific knowledge (e.g., visual). We present a Chinese case, XRK, who suffered from semantic dementia with left temporal lobe atrophy. In naming and comprehension tasks, he performed better at nonliving items than at living items, and better at verbs than at nouns. Critically, multiple regression method revealed that these two categorical effects could be both accounted for by the charade rating, a continuous measurement of the significance of motor knowledge for a concept or a semantic feature. Furthermore, charade rating also predicted his performances on the generation frequency of semantic features of various modalities. These findings consolidate the significance of motor knowledge in conceptual organization and further highlights the interactions between different types of semantic knowledge.



## 1. I d c

One type of critical findings that advanced our understanding of the semantic system is that brain-damage may impair different categories of knowledge disproportionately, such as living things vs. nonliving things (Warrington & McCarthy, 1983; Warrington & Shallice, 1984; see Capitani, Laiacona, Mahon and Caramazza (2003), for a review), or objects/nouns vs. actions/verbs (Laiacona & Caramazza, 2004; Miceli, Silveri, Nocentini, & Caramazza, 1988; see Shapiro and Caramazza (2003), for a review). One influential notion motivated by such observations assumes that semantic memory is (at least partially) distributed in subsystems corresponding to different modality-specific types of knowledge (e.g., visual, motor, tactile, function, etc., Bird, Howard, & Franklin, 2000; Cree & Mcrae, 2003; Martin, Ungerleider, & Haxby, 2000; Vigliocco, Vinson, Lewis, & Garrett, 2004; Warrington & Shallice, 1984). Furthermore, the significance of a certain knowledge type varies across different semantic/grammatical categories of concepts. Therefore, selective impairment or preservation of certain types of knowledge may lead to categorical effects.

In this article, we present evidence for the significance of one specific modality of semantic feature (knowledge) – motor knowledge – in the representation of concepts and other semantic features. The importance of motor knowledge in the representation of object concepts, especially manipulable objects, has been reported in both neuropsychological and brain imaging research. Warrington and McCarthy (1987) reported a case Y.O.T., who was significantly more impaired in the comprehension of small manipulable objects (e.g., fork, shoe) than large artifacts (e.g., ship, house), living things and foods. The authors attributed this dissociation to the difference between the weights of motor (i.e., action derived) knowledge in these classes of objects. Complimentary to this pattern, later studies reported the association between better performance on manipulable objects than non-manipulable ones and the preservation of motor knowledge (Magnie, Ferreira, Giusiano, & Poncet, 1999; Sirigu, Duhamel, & Poncet, 1991). In a group study, Buxbaum and Saffran (2002) showed that apraxic patients were more impaired with tools than with animals and with manipulation knowledge than with function knowledge. The non-apraxic patients exhibited the opposite pattern. These results indicated the greater significance of motor knowledge for tool concepts than for other non-manipulable objects (e.g., animals and large artifacts).

The association between tool concepts and motor knowledge is further observed on the anatomical level. Patients showing tool-specific impairment tended to have lesions encompassing brain regions associated with motor and visual-motion processing, such as the left fronto-parietal and posterior middle temporal regions

* Corresponding author. Address: State Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University, Beijing 100875, PR China. Fax: +86 10 5880 2911.
*E-mail address:* ybi@bnu.edu.cn (Y. Bi).
[1] These authors contributed equally to this work and should be considered co-first authors.

0093-934X/$ - see front matter © 2010 Elsevier Inc. All rights reserved.
doi:10.1016/j.bandl.2010.07.001

(Gainotti, 2000; Tranel, Damasio, & Damasio, 1997; Tranel, Kemmerer, Adolphs, Damasio, & Damasio, 2003). Similarly, functional brain imaging studies showed that processing tool items tended to induce greater activations in these regions relative to other objects (e.g., animals) (Chao, Haxby, & Martin, 1999; Martin, Wiggs, Ungerleider, & Haxby, 1996).

The significance of motor knowledge has also been assumed for the conceptual representation of actions (verbs) (Warrington & McCarthy, 1987). Both lesion studies and functional brain imaging studies have reported that brain regions associated with action/verb processing included the left fronto-parietal and posterior middle temporal regions (Gainotti, Silveri, Daniele, & Giustolisi, 1995; Martin, Haxby, Lalonde, Wiggs, & Ungerleider, 1995; Perani et al., 1999; Tettamanti et al., 2005; Tranel et al., 2003), similar to the brain regions involved in tool processing as described above. Indeed, some authors have proposed that the noun/verb differences might be reduced to the weighting differences of motoric knowledge (Arévalo et al., 2007; Saccuman et al., 2006), or of distribution differences of various feature types including motoric ones (Vigliocco et al., 2004; Vigliocco et al., 2006; but see Bedny, Caramazza, Grossman, Pascual-Leone and Saxe (2008)). For instance, in an fMRI study Saccuman and colleagues (2006) manipulated the grammatical categories (nouns or verbs) and the motoric characteristics (involves hand or not), and found significant effects of motoric fashion but no effect of grammatical class.

The importance of motor knowledge for objects were quantified by Magnie and colleagues (2003) using a manipulability index. They asked healthy subjects to rate how easily an object could evoke actions that unambiguously allow its recognition (labeled "charade rating" here).[2] Indeed, they found that artifacts and living things differed systematically on the charade rating. The charade rating was used to account for semantic category-specific object naming performance of a case (AD; Wolk, Coslett, & Glosser, 2005). AD showed significant advantage in naming nonliving things than naming living things. However, the patient's naming performance was also a function of Magnie's charade rating for the item set, leading the authors to conclude that the categorical effect could be reduced to a motor-knowledge effect. Interestingly, although AD's performances on naming objects (nouns) did not differ significantly from naming actions (verbs), he named human actions, for which charade ratings are presumably high, significantly more accurately than nonhuman actions (26/29 vs. 11/19). This trend implied the potential role of charade rating in predicting some patients' performance for both nouns and verbs. Nevertheless, the charade ratings for actions were not available, leaving it open whether the charade effect functions across nouns and verbs similarly.

The role of charade rating in the relationship between motor knowledge and other modalities of knowledge has also been implicated in a recent fMRI study (Mahon et al., 2007). The authors contrasted stimulus-specific repetition suppression (RS) effects for animals and three types of artifacts that differed by charade ratings: tools, arbitrarily manipulable objects, and non-manipulable ones. They observed that viewing tool pictures, whose charade ratings were the highest, elicited the strongest RS effect in the ventral visual-form processing regions (medial fusiform gyrus), along with dorsal regions processing motor and motion information (left inferior parietal lobule and left middle temporal gyrus). Functional connectivity was also found between areas showing RS for tools on the ventral and the dorsal streams. While such results can be explained by tool-specific processing circuits, as suggested by the authors, they may also reflect the potential modulation of motor knowledge, measured by charade rating, on the visual-form modality.

To summarize briefly, previous reports using various approaches demonstrated the effect of motor knowledge weightings in explaining the object recognition or naming performance patterns. It remains open whether the motor knowledge significance (charade rating) predicts performances of actions (verbs) in the same manner, or even those of modality-specific semantic features, as suggested by the results in Mahon et al. (2007). These two issues are of central interest here. In this article, we reported a Chinese patient suffering from left temporal lobe atrophy, who showed disproportionate semantic impairments for nouns (objects) relative to verbs (actions) and for living things relative to nonliving things within nouns. To anticipate, both his semantic- and grammatical-category-specific deficits could be interpreted by a continuous effect of charade ratings. Furthermore, such charade rating played a similar role in predicting his performances with semantic features of various modalities.

## 2. Ca e bac ▾ d

XRK is a 68-year-old, right-handed Chinese man with a college education. He worked as a college professor and then a restaurant manager. He came to the neurological clinic in 2007, showing anomic and emotional symptoms, and reported that since 2005 he had started to notice deterioration in naming familiar people, followed by fruits, vegetables, and then animals. An MRI performed in March 2007 revealed remarkable atrophy in both the lateral and medial aspects of the whole left temporal lobe, with narrowed gyri and widened sulci in the left inferior, middle, and superior temporal regions, including fusiform gyrus and hippocampus (see Fig. 1, panels A and B). A SPECT (see Fig. 1, panel C) and a MRA performed at the same time did not reveal any visible abnormalities. No symptoms of amnesia or spatial disorientation were observed by XRK or his family. His performances on various clinical neuropsychological evaluations, including MMSE (Folstein, Folstein, & McHugh, 1975), WMS-RC (Gong, 1989), Rey–Osterrieth complex figure test (ROCF; Guo, Lv, & Hong, 2000) and the Performance Subsets of WAIS-RC (Gong, 1982) were all within the normal range. However, he showed impairment on the Verbal Subsets of WAIS-RC (XRK: 81; cut-off: >84), along with various language and semantic tests. He was clinically diagnosed as semantic dementia (SD).

A set of language assessments conducted in 2007 revealed several aspects of XRK's language and/or semantic deficits. He performed poorly on two sets of naming tests: Huashan naming test (HNT; developed by Guo; including pictures of common objects of various living and nonliving categories): 32/100 correct; naming test in Aphasia Battery of Chinese (ABC; Gao & Benson, 1990): 13/20. He made frequent semantic errors (e.g., "lemon" → "banana"; "saw" → "scissors"; "teapot" → "teacup"; "injector" → "liquid medicine"). He was severely impaired in category fluency (XRK: 10 for animals, fruits, and vegetables; normal range: >30). He also had reading difficulty (62/100) and showed surface dyslexic symptoms by erroneously reading the phonetic radical of target characters (e.g., "空", /kong1/[3] for 

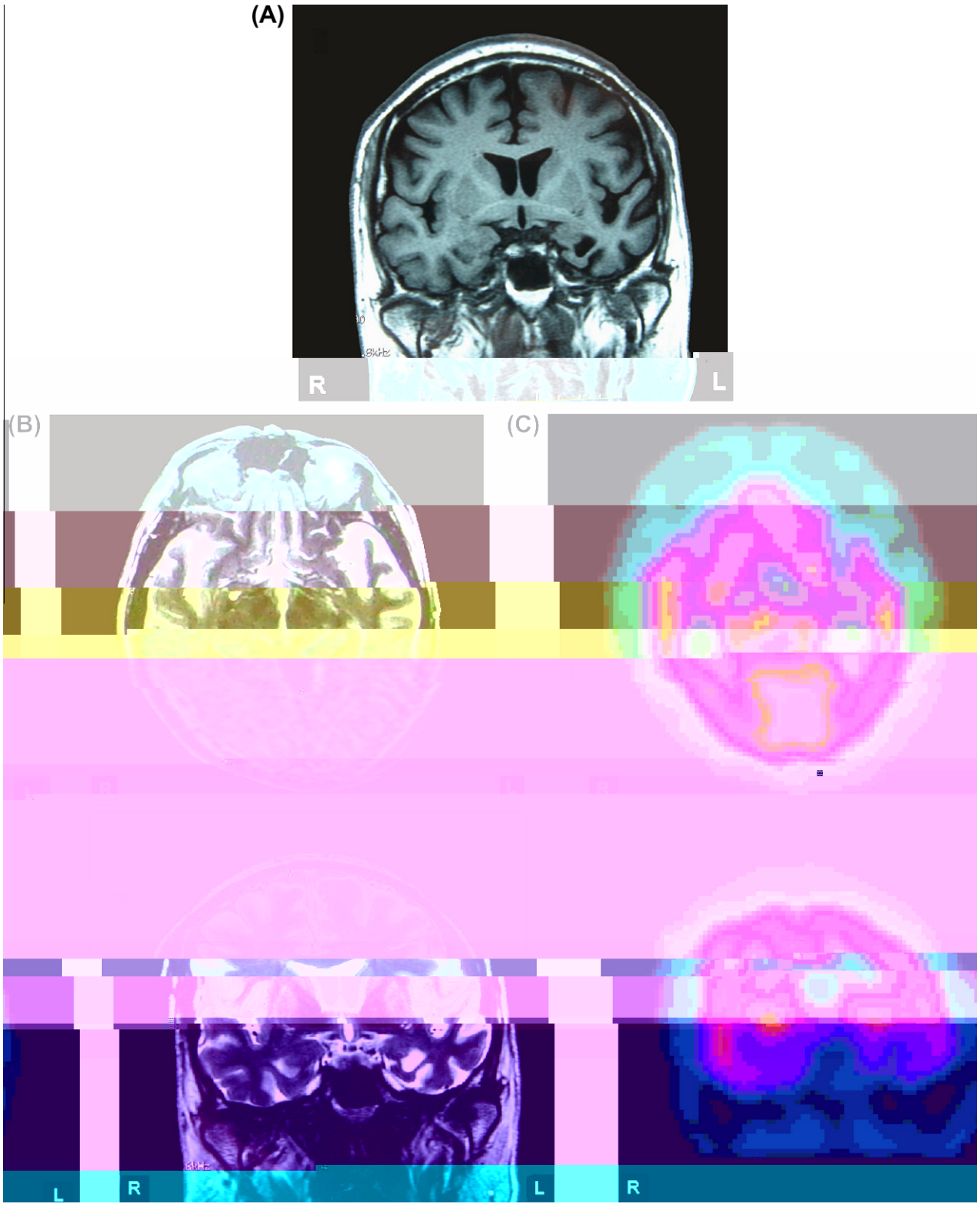


**Fig. 1.** (A) A T1-weighted fluid attenuated inversion recovery (FLAIR) MRI image of XRK. (B) T2-weighted fast-spin echo (FSE) MRI images of XRK. (C) SPECT images of XRK.

relevant action, can explain XRK's dissociations in object and action naming. One motivation to do this analysis is the observation that he tended to describe the related manipulations and motions in picture-naming tests as described above. Furthermore, XRK's atrophy was most apparent in the left temporal regions, leaving parietal and frontal regions relatively intact. Given that motor-related knowledge is assumed to be processed by the parietal and frontal regions (Gainotti et al., 1995; Pulvermüller, 2005; Tranel et al., 2003), the potential motor-knowledge advantage might be able to explain the categorical dissociations we observed earlier. Note that we did not carry out similar analyses on the non-naming tasks because in those tasks usually multiple items are involved (e.g., picture associative matching) and it is difficult to estimate the effective index for the motor knowledge relevance.

**Tab e 1**
Tests of XRK's living–nonliving and noun–verb dissociations.

| Tests | XRK | | | Controls | | | *p* value (C&G) |
|---|---|---|---|---|---|---|---|
| | Percentage (correct/all) | | *p* value ($\chi^2$) | Mean percentage (SD) | | *N* | |
| *Living–nonliving dissociation* | | | | | | | |
| | Living | Nonliving | | Living | Nonliving | | |
| Snodgrass picture naming | 18% (13/73) | 45% (71/159) | <.001 | 96% (3.0%) | 97% (3.1%) | 9 | <.001 |
| Mahon picture naming | 20% (4/20) | 28% (17/60) | n.s. | – | – | – | – |
| Object decision | 79% (41/52) | 92% (35/38) | 0.09 | 95% (3.9%) | 94% (4.5%) | 15 | <.05 |
| Attribute judgement | 79% (130/164) | 89% (140/158) | <.05 | 95% (2.9%) | 95% (2.5%) | 15 | <.01 |
| *Noun–verb dissociation* | | | | | | | |
| | Noun | Verb | | Noun | Verb | | |
| Object/action picture naming I | 46% (22/48) | 74% (25/34) | <.05 | 90% (6.0%) | 91% (5.6%) | 16 | <.01 |
| Object/action picture naming II | 25% (15/59) | 55% (32/58) | <.01 | – | – | – | – |
| Picture–word verification | 74% (119/162) | 85% (41/48) | 0.09 | 95% (3.0%) | 93% (3.2%) | 14 | <.05 |
| Picture associative matching | 60% (31/52) | 62% (32/52) | n.s. | 81% (5.0%) | 83% (8.9%) | 6 | n.s. |
| Word associative matching | 54% (28/52) | 83% (43/52) | <.01 | – | – | – | – |

*Note*: "*P* value (C&G)": statistical results derived from the program developed by Crawford and Garthwaite (2005); "n.s.": no significance; "–": not be tested.

*3.2.1. Charade effect and living–nonliving dissociation*

To elucidate whether XRK's living/nonliving dissociation in object naming could be accounted for by the charade effect, we carried out a binary logistic regression analysis on his performance on the Snodgrass picture-naming test. The dependent variable was XRK's score for each item ("1" for correct, "0' for incorrect). Two critical predictors were the charade rating (Magnie et al., 2003) and semantic domain (living/nonliving), as we were most interested in whether the charade rating can fully explain the effect of semantic domain on XRK's performances. We further included several predictors to partial out potentially confounding variables (see Funnell and Sheridan (1992), Magnie et al. (2003) and Stewart, Parkin and Hunkin (1992)): word frequency (Sun, Huang, Sun, Li, & Xing, 1997), familiarity and visual complexity (Shu et al., 1989). No pair-wise correlation of predictors was higher than .70, ruling out the potential multicollinearity problems following the rule generally adopted for regression studies (Baayen, Feldman, & Schreuder, 2006).

We developed the following two types of regression models. In the first set of regression models, we included the nuisance predictors and the "semantic domain" predictor, but not the charade-rating predictor. In the second model set, we additionally included the charade-rating predictor. The critical question is whether any significant effect of semantic domain in the first model set would still survive after the inclusion of charade rating in the second model set. Specifically, in both sets of models, we used two types of entering methods to consolidate the unique contributions of each predictor: simultaneous entering and two-step hierarchical methods. In the simultaneous entering method, all predictors were simultaneously introduced into regression model. In the two-step hierarchical method, separate models were developed for each predictor (e.g., semantic domain), such that all other predictors (word frequency, familiarity, visual complexity, etc.) were entered in the first step, and then the predictor of interest (semantic domain) entered in the second step. In this way, the unique contribution of the predictor in the second step was illustrated. The results from these regression methods are shown in Table 2. As can be seen under the "regression without charade rating" heading, besides word frequency and familiarity, semantic domain had significantly predictive power in XRK's naming performance, using both the simultaneous entering method and the hierarchical method. Critically, when charade rating was included as a predictor, semantic domain no longer had significant effect. The naming performance was significantly predicted by charade rating, word frequency and familiarity.

To examine whether the charade effect was mainly driven by items in one particular domain, we further carried out analyses within the two semantic domains (living and nonliving) separately. Charade effect was significant within the living domain (*p*s < .005 for both entering methods) and was marginally significant for the nonliving items (*p*s < .1 for both entering methods), indicating that charade rating was a significant predictor of naming performance for all items.

*3.2.2. Charade effect and noun–verb dissociation*

We used the logistic regression methods identical to the ones used in Section 3.2.1 here to examine the effects of grammatical class (noun/verb) and charade rating in XRK's picture naming performance. To maximize the item number, we included all 511 items from the four picture naming tasks (Snodgrass picture naming; Mahon picture naming; Object/action picture naming II & I). The dependent variable was still XRK's score for each item ("1" for correct, "0" for incorrect). The predictors for this session were charade rating, grammatical class, word frequency (Sun et al., 1997), and familiarity. Visual complexity was not included in this session because the rating was not available for many items and that it did not yield any effect in the regression analyses above.

Because the charade rating in the literature (Magnie et al., 2003; Mahon et al., 2007) were exclusively for nouns, we collected our own ratings for the nouns and verbs in the current analyses. We presented target words and adopted the instructions from Mahon et al. (2007), which were applicable for both nouns and verbs: "Suppose you were playing charades, such that one person had to identify a word based on how another person mimed various actions that might be associated with its meaning. You are asked to rate, for the following words, how difficult it would be to play that game with these items (1 = very difficult/impossible; 7 = very easy)". Sixteen naive undergraduate subjects were asked conduct the rating on a 7-point scale. Another sixteen subjects participated in the familiarity rating for the whole item set, presented with target words and instructions adopted from Shu et al. (1989). Our rating results were well correlated with those of previous studies (Charade rating: $R_{\text{current-Magnie}} = .60$, $R_{\text{current-Mahon}} = .71$; familiarity rating: $R_{\text{current-Shu}} = .67$).

The regression results are displayed in Table 2. No pair-wise correlation of predictors was higher than .70. The regression results without the charade rating as a predictor showed that grammatical class, in addition to word frequency and familiarity, significantly predicted XRK's naming performance. Critically, the second analysis showed that once charade rating was included in the regression model, it replaced grammatical class as a significant predictor for XRK's performance.

We also carried out logistic regression analysis for nouns and verbs separately, using word frequency, familiarity, and charade

rating as predictors. Charade rating was a significant predictor for

Our results consolidate the significance of motor knowledge in concept representation, and are consistent with previous observations of the correlation between motor knowledge (measured by object use ability) and conceptual tasks in semantic dementia cases (Bozeat, Lambon-Ralph, Patterson, & Hodges, 2002; Hodges, Bozeat, Lambon-Ralph, Patterson, & Spatt, 2000). Our results indicated that this correlation might (at least partly) be due to the predictability of motor knowledge for conceptual tasks, as opposed to what was proposed by the authors, who argued that the object use ability was determined by the general conceptual knowledge. Note that the current results do not speak to whether motor knowledge is necessary for some concepts such as tools. Indeed, ample neuropsychological evidence has shown that object recognition and naming can be achieved without corresponding motor knowledge (for a review see Mahon and Caramazza (2007)). Rather, we believe that motor knowledge (or any modality) supports the retrieval of the corresponding concepts, other types of knowledge, and the object/action name retrieval.

Our results are in line with a wide range of theories assuming modality-specific organization of conceptual knowledge (Allport, 1985; Bird, Lambon-Ralph, Patterson, and Hodges, 2000; Cree & McRae, 2003; Mahon & Caramazza, 2009; Martin et al., 2000; Vigliocco et al., 2004), despite the variations among them in terms of the modalities being incorporated and the distribution pattern of modality-specific knowledge across categories. Furthermore, such theories about the representation of object concepts have been extended to the domain of actions (Bird, Howard et al., 2000; Vigliocco et al., 2004), assuming the same organization principal for objects and action concepts. The previously reported evidence for this school of modality-specific representation theories mainly come from observed associations between performances on motor knowledge and on categories for which motor knowledge are assumed important. Here by showing the significance predictability power of charade rating on the patient's performance, we provide the empirical evidence for the significance of motor knowledge in accessing concepts of various semantic categories (living things, nonliving things, and actions). Furthermore, our finding of the predictability effect of motor knowledge on the patient's performance on other types of (e.g., visual) knowledge is also in accord with semantic theories incorporating the interaction of features (Caramazza et al., 1990; Thompson-Schill, Kan, & Oliver, 2006; Tyler et al., 2000; Vigliocco et al., 2004). Our results presented evidence for a specific implementation of featural modulation.

While we have shown that the categorical differences in our patient can be explained by charade effect, we would not generalize such findings to all observed categorical patterns. Categorical dissociation in some cases is not likely to be reduced to the effect of one semantic-feature dimension, such as the double-dissociation patterns observed within one patient across different modalities of processing (e.g., Rapp & Caramazza, 2002). However, our results do suggest further scrutiny of some observations that were assumed to support or challenge modality-specific theories. For instance, some modality-specific theories assumed a general loss of sensory (mainly visual) knowledge to explain the specific living item impairment (e.g., Warrington & Shallice, 1984). This assumption was then investigated using direct assessment of sensory and non-sensory knowledge of individuals with or without category-specific deficits for living things (e.g., Basso, Capitani, & Laiacona, 1988; Lambon-Ralph, Patterson, Garrard, & Hodges, 2003; for a review see Caramazza and Shelton (1998)). Our results on the modulation effect between motor knowledge and visual knowledge, however, demonstrated that the direct assessment of visual knowledge might be contaminated by the effect of other modalities. In fact, it has been explicitly proposed that predictability of visual features from non-visual ones might be stronger for nonliving entities relative to living entities (Thompson-Schill et al., 2006). Further investigations of cross-modal interaction patterns for various categories are therefore warranted.

A final note is that an anatomical signature of semantic dementia is the atrophy in the anterior temporal regions with the brain areas for motor processing less affected. Consistent with this anatomical pattern, our patient showed relatively preserved motor knowledge, advantage of processing actions over objects, and nonliving things over living things. However, mixed results have been widely reported in terms of SD's behavioral patterns. Both direction of object-action dissociations have been reported (for "noun < verb" results see: Bak & Hodges, 2003; Bird et al., 2000; Breedin, Saffran, & Coslett, 1994; Daniele, Silveri, Giustolisi, & Gainotti, 1993; Papagno, Capasso, & Miceli, 2009; Silveri & Ciccarelli, 2007; Silveri, Perri, & Cappa, 2003; for "noun > verb" results see: Reilly, Cross, Troiani, & Grossman, 2007; Rhee, Antiquena, & Grossman, 2001; Yi, Moore, & Grossman, 2007), so have both directions of living–nonliving dissociations (for "living < nonliving" cases see: Barbarotto, Capitani, Spinnler, & Trivelli, 1995; Cardebat, Demonet, Celsis, & Puel, 1996; Lambon-Ralph et al., 2003; Papagno et al., 2009; Zannino et al., 2006; for "living > nonliving" cases see: Lambon-Ralph, Howard, Nightingale, & Ellis, 1998; Silveri et al., 1997). Although the effects of nuisance variables might explain some of these dissociation patterns, they seems insufficient to explain the contradictory observation within SD groups. For example, Bird, Howard et al. (2000) and Bird, Lambon-Ralph et al. (2000) attributed their "noun < verb" findings to the relatively lower frequency of nouns, but the such pattern remained in other studies when the frequencies were well matched (e.g. Silveri & Ciccarelli, 2007; Silveri et al., 2003). Similarly, it has been proposed that the "noun > verb" pattern might be explained by the relatively higher executive resource demands necessary for verb picture naming (D'Honincthun and Pillon, 2008), but this explanation does not applied to similar patterns using verbal stimuli (Reilly et al., 2007; Yi et al., 2007). Given that individuals with semantic dementia vary widely in terms of brain atrophy patterns, it is likely that there is fine specificity for modality- or category- specific knowledge within the temporal lobe (e.g., Bi et al., in press; Damasio, Tranel, Grabowski, Adolphs, & Damasio, 2004; Miceli et al., 2001; Simmons, Reddish, Bellgowan, & Martin, 2010), and it would be premature to generalize the pattern reported here to the whole clinical group.

To conclude, by using the charade rating as a measurement of the significance of motor knowledge for a concept or a semantic feature, we observed the effect of motor knowledge in predicting the patient's performance on semantic processing. These results consolidate the role of motor knowledge, which is represented in areas outside of the temporal regions, in the organization of the conceptual system and underscore the importance of considering cross-modal featural interactions in future studies.

## Ac ed e

This research was funded by Grants NSFC (30770715, 30700224, 30570601) and NSSFC (07CYY009). We thank Brad Mahon and Xi Yu for helpful discussions. We are most grateful to XRK for his participation.

## Refe e ce

Allport, D. A. (1985). Distributed memory, modular subsystems and dysphasia. In S. K. Newman & R. Epstein (Eds.), *Current perspectives in dysphasia* (pp. 207–244). Edinburgh: Churchill Livingstone.

Arévalo, A., Perani, D., Cappa, S. F., Butler, A., Bates, E., & Dronkers, N. (2007). Action and object processing in aphasia: From nouns and verbs to the effect of manipulability. *Brain and Language, 100*(1), 79–94.

Baayen, R. H., Feldman, L. F., & Schreuder, R. (2006). Morphological influences on the recognition of monosyllabic monomorphemic words. *Journal of Memory and Language, 53*, 496–512.

Bak, T. H., & Hodges, J. R. (2003). Kissing and dancing—a test to distinguish the lexical and conceptual contributions to noun/verb and action/object dissociation. Preliminary results in patients with frontotemporal dementia. *Journal of Neurolinguistics, 16*(2–3), 169–181.

Barbarotto, R., Capitani, E., Spinnler, H., & Trivelli, C. (1995). Slowly progressive semantic impairment with category specificity. *Neurocase, 1*(2), 107–119.

Basso, A., Capitani, E., & Laiacona, M. (1988). Progressive language impairment without dementia: A case with isolated category specific semantic defect. *Journal of Neurology, Neurosurgery, and Psychiatry, 51*(9), 1201–1207.

Bedny, M., Caramazza, A., Grossman, E., Pascual-Leone, A., & Saxe, R. (2008). Concepts are more than percepts: The case of action verbs. *Journal of Neuroscience, 28*(44), 11347–11353.

Bi, Y., Wei, T., Wu, C., Han, Z., Jiang, T., & Caramazza, A. (in press). The role of the left anterior temporal lobe in language processing revisited: Evidence from an individual with ATL resection. *Cortex*.

Bi, Y., Han, Z., Shu, H., & Caramazza, A. (2007). Nouns, verbs, objects, actions, and the animate/inanimate effect. *Cognitive Neuropsychology, 24*(5), 485–504.

Bi, Y., Han, Z., Shu, H., & Weekes, B. (2007). The interaction between the semantic and the nonsemantic routes of reading: Evidence from Chinese. *Neuropsychologia, 45*(12), 2660–2673.

Bird, H., Howard, D., & Franklin, S. (2000). Why is a verb like an inanimate object? Grammatical category and semantic category deficits. *Brain and Language, 72*(3), 246–309.

Bird, H., Lambon-Ralph, M. A., Patterson, K., & Hodges, J. R. (2000). The rise and fall of frequency and imageability: Noun and verb production in semantic dementia. *Brain and Language, 73*(1), 17–49.

Bozeat, S., Lambon-Ralph, M. A., Patterson, K., & Hodges, J. R. (2002). When objects lose their meaning: What happens to their use? *Cognitive, Affective, and Behavioral Neuroscience, 2*, 236–251.

Breedin, S., Saffran, E. M., & Coslett, H. (1994). Reversal of the concreteness effect in a patient with semantic dementia. *Cognitive Neuropsychology, 11*(6), 617–660.

Buxbaum, L., & Saffran, E. (2002). Knowledge of object manipulation and object function: Dissociations in apraxic and non-apraxic subjects. *Brain and Language, 82*(2), 179–199.

Capitani, E., Laiacona, M., Mahon, B., & Caramazza, A. (2003). What are the facts of semantic category specific deficits? A critical review of the clinical evidence. *Cognitive Neuropsychology, 20*(3–6), 213–261.

Caramazza, A., Hillis, A. E., Rapp, B. C., & Romani, C. (1990). The multiple semantics hypothesis: Multiple confusions? *Cognitive Neuropsychology, 7*(3), 161–189.

Caramazza, A., & Shelton, J. R. (1998). Domain-specific knowledge systems in the brain: The animate–inanimate distinction. *Journal of Cognitive Neuroscience, 10*(1), 1–34.

Cardebat, D., Demonet, J. F., Celsis, P., & Puel, M. (1996). Living/non-living dissociation in a case of semantic dementia: A SPECT activation study. *Neuropsychologia, 34*(12), 1175–1179.

Chao, L. L., Haxby, J. V., & Martin, A. (1999). Attribute-based neural substrates in temporal cortex for perceiving and knowing about objects. *Nature Neuroscience, 2*, 913–919.

Crawford, J. R., & Garthwaite, P. H. (2005). Testing for suspected impairments and dissociations in single-case studies in neuropsychology: Evaluation of alternatives using Monte Carlo simulations and revised tests for dissociations. *Neuropsychology, 19*(3), 318–331.

Cree, G. S., & McRae, K. (2003). Analyzing the factors underlying the structure and computation of the meaning of chipmunk, cherry, chisel, cheese, and cello (and many other such concrete nouns). *Journal of Experimental Psychology: General, 132*(2), 163–201.

Damasio, H., Tranel, D., Grabowski, T., Adolphs, R., & Damasio, A. (2004). Neural systems behind word and concept retrieval. *Cognition, 92*(1–2), 179–229.

Daniele, A., Silveri, M. C., Giustolisi, L., & Gainotti, C. (1993). Category-specific deficits for grammatical classes of words: Evidence for possible anatomical correlates. *Italian Journal of Neurological Sciences, 14*(1), 87–94.

d'Honincthun, P., & Pillon, A. (2008). Verb comprehension and naming in frontotemporal degeneration: The role of the static depiction of actions. *Cortex, 44*(7), 834–847.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-Mental State": A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12*(3), 189–198.

Funnell, E., & Sheridan, J. S. (1992). Categories of knowledge? Unfamiliar aspects of living and nonliving things. *Cognitive Neuropsychology, 9*(2), 135–153.

Gainotti, G. (2000). What the locus of brain lesion says about the nature of the cognitive defect in category-specific disorders: A review. *Cortex, 36*(4), 539–559.

Gainotti, G., Silveri, M. C., Daniele, A., & Giustolisi, L. (1995). Neuroanatomical correlates of category-specific semantic disorders: A critical survey. *Memory, 3*(3–4), 247–264.

Gao, S., & Benson, D. B. (1990). Aphasia after stroke in native Chinese speakers. *Aphasiology, 4*(1), 31–43.

Gong, Y. X. (1982). *Manual for the Wechsler adult intelligence scale: Chinese revision*. Changsha, Hunan, China: Hunan Medical College.

Gong, Y. X. (1989). *Manual for the Wechsler memory scale: Chinese revision*. Changsha, Hunan, China: Hunan Medical College.

Guo, Q. H., Lv, C. Z., & Hong, Z. (2000). The application of Rey–Osterrieth complex figure test in Chinese healthy elderlies. *Chinese Journal of Clinical Psychology, 8*(4), 205–207.

Hodges, J. R., Bozeat, S., Lambon-Ralph, M. A., Patterson, K., & Spatt, J. (2000). The role of conceptual knowledge in object use: Evidence from semantic dementia. *Brain, 123*(9), 1913–1925.

Howard, D., & Patterson, K. (1992). *The pyramids and palm trees test: A test of semantic access from words and pictures*. Bury St. Edmunds: Thames Valley Test Company.

Laiacona, M., & Caramazza, A. (2004). The noun/verb dissociation in language production: Varieties of causes. *Cognitive Neuropsychology, 21*(2), 103–123.

Lambon-Ralph, M. A., Howard, D., Nightingale, G., & Ellis, A. W. (1998). Are living and nonliving category-specific deficits causally linked to impaired perceptual or associative knowledge? Evidence from a category-specific double dissociation. *Neurocase, 4*(4), 311–338.

Lambon-Ralph, M. A., Patterson, K., Garrard, P., & Hodges, J. R. (2003). Semantic dementia with category specificity: A comparative case-series study. *Cognitive Neuropsychology, 20*(3–6), 307–326.

Magnie, M., Besson, M., Poncet, M., & Dolisi, C. (2003). The Snodgrass and Vanderwart set revisited: Norms for object manipulability and for pictorial ambiguity of objects, chimeric objects, and nonobjects. *Journal of Clinical and Experimental Neuropsychology, 25*(4), 521–560.

Magnie, M., Ferreira, C., Giusiano, B., & Poncet, M. (1999). Category specificity in object agnosia: Preservation of sensorimotor experiences related to objects. *Neuropsychologia, 37*(1), 67–74.

Mahon, B. Z., & Caramazza, A. (2007). The organization and representation of conceptual knowledge in the brain: Living kinds and artifacts. In E. Margolis & S. Laurence (Eds.), *Creations of the mind: Essays on artifacts and their representation* (pp. 157–190). Cambridge: Oxford University Press.

Mahon, B. Z., & Caramazza, A. (2009). Concepts and categories: A cognitive neuropsychological perspective. *Annual Review of Psychology, 60*, 27–51.

Mahon, B. Z., Milleville, S., Negri, G. A. L., Rumiati, R. I., Martin, A., & Caramazza, A. (2007). Action-related properties of objects shape object representations in the ventral stream. *Neuron, 55*(1), 507–520.

Martin, A., Haxby, J. V., Lalonde, F. M., Wiggs, C. L., & Ungerleider, L. G. (1995). Discrete cortical regions associated with knowledge of color and knowledge of action. *Science, 270*(5233), 102–105.

Martin, A., Ungerleider, L. G., & Haxby, J. V. (2000). Category specificity and the brain: The sensory/motor model of semantic representations of objects. In M. S. Gazzaniga (Ed.), *The new cognitive neurosciences* (pp. 1023–1036). Cambridge, MA: MIT Press.

Martin, A., Wiggs, C. L., Ungerleider, L. G., & Haxby, J. V. (1996). Neural correlates of category-specific knowledge. *Nature, 379*(6566), 649–652.

Miceli, G., Fouch, E., Capasso, R., Shelton, J. R., Tamaiuolo, F., & Caramazza, A. (2001). The dissociation of color from form and function knowledge. *Nature Neuroscience, 4*(6), 662–667.

Miceli, G., Silveri, M. C., Nocentini, U., & Caramazza, A. (1988). Patterns of dissociation in comprehension and production of nouns and verbs. *Aphasiology, 1*(3), 351–358.

Papagno, C., Capasso, R., & Miceli, G. (2009). Reversed concreteness effect for nouns in a subject with semantic dementia. *Neuropsychologia, 47*(4), 1138–1148.

Perani, D., Cappa, S. F., Schnur, T., Tettamanti, M., Collina, S., Rosa, M. M., et al. (1999). The neural correlates of verb and noun processing: A PET study. *Brain, 122*(12), 2337–2344.

Pulvermüller, F. (2005). Brain mechanisms linking language and action. *Nature Reviews Neuroscience, 6*(7), 576–582.

Rapp, B., & Caramazza, A. (2002). Selective difficulties with spoken nouns and written verbs: A single case study. *Journal of Neurolinguistics, 15*(3–5), 373–402.

Reilly, J., Cross, K., Troiani, V., & Grossman, M. (2007). Single-word semantic judgements in semantic dementia: Do phonology and grammatical class count? *Aphasiology, 21*(6–8), 558–569.

Rhee, J., Antiquena, P., & Grossman, M. (2001). Verb comprehension in frontotemporal degeneration: The role of grammatical, semantic, and executive components. *Neurocase, 7*(2), 173–184.

Saccuman, M. C., Cappa, S. F., Bates, E. A., Arevalo, A., Della Rosa, P., Danna, M., et al. (2006). The impact of semantic reference on word class: An fMRI study of action and object naming. *NeuroImage, 32*(4), 1865–1878.

Shapiro, K., & Caramazza, A. (2003). The representation of grammatical categories in the brain. *Trends in Cognitive Sciences, 7*(5), 201–206.

Shu, H., Cheng, Y., & Zhang, H. (1989). Name agreement, familiarity, image agreement, and visual complexity for 235 pictures. *Acta Psychologica Sinica, 21*(4), 389–396.

Silveri, M. C., & Ciccarelli, N. (2007). Naming of grammatical classes in frontotemporal dementias: Linguistic and non linguistic factors contribute to noun-verb dissociation. *Behavioural Neurology, 18*(4), 197–206.

Silveri, M. C., Gainotti, G., Perani, D., Cappelletti, J. Y., Carbone, G., & Fazio, F. (1997). Naming deficit for non-living items: Neuropsychological and PET study. *Neuropsychologia, 35*(3), 359–367.

Silveri, M. C., Perri, R., & Cappa, A. (2003). Grammatical class effects in brain-damaged patients: Functional locus of noun and verb deficit. *Brain and Language, 85*(1), 49–66.

Simmons, W. K., Reddish, M., Bellgowan, P. S. F., & Martin, A. (2010). The selectivity and functional connectivity of the anterior temporal lobes. *Cerebral Cortex, 20*(4), 813–825.

Sirigu, A., Duhamel, J., & Poncet, M. (1991). The role of sensorimotor experience in object recognition. *Brain, 114*(6), 2555–2573.

Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms of name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory, 6*(2), 174–215.

Stewart, F., Parkin, A. J., & Hunkin, N. M. (1992). Naming impairments following recovery from herpes simplex encephalitis: Category-specific? *Quarterly Journal of Experimental Psychology, 44*, 261–284.

Sun, H. L., Huang, J. P., Sun, D. J., Li, D. J., & Xing, H. B. (1997). Introduction to language corpus system of modern Chinese study. In M. Y. Hu (Ed.), *Paper collection for the fifth world Chinese teaching symposium* (pp. 459–466). Beijing: Peking University Publisher.

Tettamanti, M., Buccino, G., Saccuman, M., Gallese, V., Danna, M., Scifo, P., et al. (2005). Listening to action-related sentences activates fronto-parietal motor circuits. *Journal of Cognitive Neuroscience, 17*, 273–281.

Thompson-Schill, S. L., Kan, I. P., & Oliver, R. T. (2006). Functional neuroimaging of semantic memory. In R. Cabeza & A. Kingstone (Eds.), *Handbook of functional neuroimaging of cognition* (2nd ed., pp. 149–190). Cambridge, MA: MIT Press.

Tranel, D., Damasio, H., & Damasio, A. R. (1997). A neural basis for the retrieval of conceptual knowledge. *Neuropsychologia, 35*(10), 1319–1327.

Tranel, D., Kemmerer, D., Adolphs, R., Damasio, H., & Damasio, A. R. (2003). Neural correlates of conceptual knowledge for actions. *Cognitive Neuropsychology, 20*(3–6), 409–432.

Tyler, L. K., Moss, H. E., Durrant-Peatfield, M. R., & Levy, J. P. (2000). Conceptual structure and the structure of concepts: A distributed account of category-specific deficits. *Brain and Language, 75*(2), 195–231.

Vigliocco, G., Vinson, D. P., Lewis, W., & Garrett, M. F. (2004). Representing the meanings of object and action words: The featural and unitary semantic space hypothesis. *Cognitive Psychology, 48*(4), 422–488.

Vigliocco, G., Warren, J., Siri, S., Arciuli, J., Scott, S., & Wise, R. (2006). The role of semantics and grammatical class in the neural representation of words. *Cerebral Cortex, 16*(12), 1790–1796.

Warrington, E. K., & McCarthy, R. (1983). Category specific access dysphasia. *Brain, 106*(4), 859–878.

Warrington, E. K., & McCarthy, R. A. (1987). Categories of knowledge: Further fractionations and an attempted integration. *Brain, 110*(5), 1273–1296.

Warrington, E. K., & Shallice, T. (1984). Category specific semantic impairments. *Brain, 107*(3), 829–854.

Wolk, D. A., Coslett, H. B., & Glosser, G. (2005). The role of sensory-motor information in object recognition: Evidence from category-specific visual agnosia. *Brain and Language, 94*(2), 131–146.

Yi, H. A., Moore, P., & Grossman, M. (2007). Reversal of the concreteness effect for verbs in patients with semantic dementia. *Neuropsychology, 21*(1), 9–19.

Yin, W., & Butterworth, B. (1992). Deep and surface dyslexia in Chinese. In H. C. Chen & O. J. L. Tzeng (Eds.), *Language processing in Chinese* (pp. 349–366). Amsterdam: North-Holland.

Zannino, G. D., Perri, R., Pasqualetti, P., Di Paola, M., Caltagirone, C., & Carlesimo, G. A. (2006). The role of semantic distance in category-specific impairments for living things: Evidence from a case of semantic dementia. *Neuropsychologia, 44*(7), 1017–1028.