PAPER

Actions anchored by concepts: defective action comprehension in semantic dementia

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Objective: To study the ability of patients with semantic dementia to understand actions, in order to examine the contribution of semantic memory to action comprehension.

Methods: The ability to comprehend symbolic and instrumental actions was assessed in 6 patients with semantic dementia and 10 healthy controls. The patients were also given the imitation test of meaningful and meaningless actions.

Results: In all patients with semantic dementia, comprehension of both symbolic and instrumental actions was defective. The comprehension of symbolic actions was more impaired than that of instrumental actions. Their ability to imitate other's actions was well preserved.

Conclusion: This study showed that comprehension of action was impaired in semantic dementia, suggesting that semantic memory has an important role in comprehension of human action.

When we observe people's actions, we immediately understand what they are doing. This ability is arguably a fundamental basis for the imitation of other people's behaviours and efficient skill learning. Recent neurophysiological studies propose that mirror neurones in the premotor and inferior parietal cortices of primates, which activate both when a monkey executes a particular action and when it observes similar actions by others, have a pivotal role in production and comprehension of action.^{1–2} According to this view, direct matching between observed actions and the motor representations stored in mirror neurones is a common, crucial process. In humans, however, actions have a much more complex role in social interactions than they have in monkeys. Human actions often serve as a representational system and can convey complex and abstract concepts, as exemplified by symbolic gestures and sign languages.³ In such situations, a simple reference to motor representation is not sufficient, and conceptual knowledge presumably has an important role.

Semantic dementia is a clinical syndrome characterised by the progressive breakdown of semantic memory or conceptual knowledge and the relative preservation of other cognitive domains.^{4–5} Several studies provide evidence that semantic memory impairment is not modality-specific and, in fact, object naming, single-word comprehension, object categorisation, identification of the faces of famous and familiar people, environmental sound recognition and object use are defective in semantic dementia.^{6–8} In this study, we investigated comprehension of action in patients with semantic dementia. If conceptual knowledge markedly contributes to comprehension of human action, this ability should be affected in patients with semantic dementia.

METHODS

Subjects

Six right-handed patients with semantic dementia (mean (standard deviation (SD)) age 61.5 (8.8) years); two women and four men) and 10 healthy, elderly, right-handed

volunteers recruited from the community (mean (SD) age 60.9 (8.6) years; five women and five men) were included in the study. None of the subjects had a history of psychiatric illnesses, or systemic disease or use of drugs that might affect cognition and behaviour. We found no significant difference between the patients and controls in age ($t = 0.13$, $p = 0.90$), sex (Fisher's exact $p = 0.63$) and education ($t = 0.06$, $p = 0.96$).

All the patients underwent detailed clinical assessments by behavioural neurologists, cranial magnetic resonance imaging, positron emission tomography or single-photon emission computed tomography, and laboratory examination. Diagnosis of semantic dementia was made according to the consensus clinical diagnostic criteria for frontotemporal lobar degeneration.⁹ Although mild degrees of behavioural abnormalities—that is, inadequate talkativeness, disinhibition and compulsive–repetitive behaviours—were found in four patients, they were able to complete the tests without any interruption. All patients had asymmetrical focal atrophy in the anterior and inferior temporal lobes (left-sided atrophy in two, left predominant bilateral atrophy in one and right predominant bilateral atrophy in the other three patients). No lesions suspected of being of vascular origin were noted on magnetic resonance imaging in any of the patients. The regional cerebral metabolic rate for glucose or cerebral blood flow was reduced predominantly in the frontotemporal regions and preserved in the posterior cingulate cortex in all patients.

General neuropsychological assessment

The patients underwent the Mini-Mental State Examination^{10–11} and the Wechsler Adult Intelligence Scale—Revised for the assessment of general cognitive function,^{12–13} the Wechsler Memory Scale—Revised for episodic memory,^{14–15} the Western Aphasia Battery for

Abbreviations: ACT, action comprehension test; AIT, action imitation test

language,^{16, 17} a copy of the Rey Complex Figure Test for constructive function¹⁸ and Raven's Coloured Progressive Matrices for executive function.^{19, 20}

Semantic memory assessment

To assess semantic memory or conceptual knowledge, the patients were given neuropsychological tasks of picture naming, word-picture matching, identifying famous faces, and category fluency. The picture-naming test comprised 50 black-and-white line drawings in five categories—vehicles, animals, utensils, vegetables and body parts.²¹ The word-picture matching test consisted of exactly the same line drawings as the picture-naming test.²¹ The test of famous face identification contained grey-scale images of the faces of eight famous Japanese people. Subjects were asked to name them or describe their occupations and events associated with them. Subjects gained 2 points when they produced a correct response within 10 s, and 1 point when they did so within 30 s.²² For category fluency, we evaluated the number of animal names generated in 1 min.²³

Action comprehension test

We introduced two different categories of actions, symbolic actions and instrumental actions, in this study to examine the differential effect of object related and non-related conceptual knowledge on comprehension of action. Symbolic actions were defined as conventional communicative actions without objects, such as goodbye and saluting; instrumental actions were pantomimes of handling objects, such as brushing the hair with a comb and striking a nail with a hammer. In all, 11 symbolic and 13 instrumental actions performed by one author (YN) were presented in a prescribed manner to both patients and controls. Subjects were requested to identify the presented actions by naming or describing situations in which they perform them in their everyday lives. The responses made by subjects were recorded and rated dichotomically—namely, “correct” or “incorrect”. Either adequate naming or a description sufficient to evoke the meaning of the corresponding action was judged as correct. Paraphasia and circumlocution were accepted because patients with semantic dementia are often anomic.

Performance in the action comprehension test (ACT) was expressed as percentage correct, and was analysed using repeated-measures of analysis of variance, with action type (symbolic *v* instrumental) as the within-subjects factor and subject group (SD *v* control) as the between-subjects factor.

Action imitation test

The patients, but not the controls, were requested to copy the 30 actions presented by YN to assess their motor praxis ability. In addition to 22 meaningful actions (11 symbolic and 11 instrumental actions used in ACT), 8 meaningless actions were presented to evaluate the involvement of conceptual knowledge in imitation of action. Five of the meaningless actions involved mainly the arm and hand; the other three actions involved the fingers, specifically “hand open and palm down under the chin”, “fist on the forehead” and “thumb and little finger extended with other fingers bent”. Rating was done in the same way as for ACT. In line with previous studies, we qualitatively assessed errors and categorised them into the following seven types: perseverative, content, sequential, configurational, body part as object, unrecognisable and no response.^{24–26} A content error indicates an action accurately performed but different from the target action—for example, pantomiming the use of a hammer instead of a razor. Sequential errors include addition, deletion and transposition of movement elements. Inappropriate configuration of limbs, hands and fingers in spatial relationship

to the imagined tool and its target object was referred to as configurational error.

RESULT

General neuropsychology

The mean score of the patients for the Mini-Mental State Examination was 24.5 (SD 3; range 19–27; table 1). Verbal IQs of the Wechsler Adult Intelligence Scale—Revised were impaired in all the patients, whereas performance IQs were preserved in the three patients with left dominant temporal lobe atrophy and were mildly impaired in the three patients with right dominant atrophy (“left” group: mean (SD) 104.3 (7.6); “right” group: mean (SD) 81.3 (2.5); $t = 4.99$, $p = 0.008$). Episodic memory was relatively preserved as measured by visual memory of the Wechsler Memory Scale—Revised. As shown on the Western Aphasia Battery, there were difficulties in naming, single-word comprehension, and reading and writing of Kanji. Phonological and syntactical aspects of language, reading and writing of Kana, and calculation were preserved. Performance levels equivalent to those of healthy people in the Rey Complex Figure Test and Raven's Coloured Progressive Matrices indicated that constructional skill and executive function were well preserved.

Semantic memory

Table 1 presents the performance results for the semantic memory tests. All patients showed poor performance on picture naming, word-picture matching and category fluency. The item consistency of errors between picture naming and word-picture matching (two-way anomia) and relative preservation of the body-parts category were evident in all patients. The identification of famous faces was affected, except for patient 1, who presented the mildest semantic memory impairment and had selective left temporal lobe atrophy, with the right hemisphere spared.

Action comprehension test

The patients were impaired in both symbolic (mean (SD) % correct = 35.9 (19.3)%) and instrumental (70 (26.8)%) action comprehension (fig 1, table 2). The performances of the controls were almost perfect (mean (SD) 100 (0)% for symbolic actions; 91.5 (6.7)% for instrumental actions). We found a significant group effect ($F(1, 14) = 39.56$, $p < 0.001$), a significant action type effect ($F(1, 14) = 19.64$, $p = 0.001$) for accuracy of ACT (fig 1), and a significant group $\times$ action type interaction ($F(1, 14) = 47.38$, $p < 0.001$), indicating that patients with semantic dementia had more profound difficulty understanding symbolic actions than instrumental actions, compared with the controls.

Action imitation test

The patients made few errors (mean (SD) % correct = 96.7 (3)%, range 93.3–100 for all 30 items) in the action imitation test (AIT; table 2). Two of the six patients performed perfectly; three patients made errors only in instrumental actions; and one patient made errors only in symbolic actions. All the patients performed without error when imitating meaningless actions. When patients made an incorrect response in AIT, they always failed to recognise the same item in ACT. In other words, there was item-by-item consistency between ACT and AIT. There were no items that patients comprehended but did not imitate correctly. All the errors were categorised as configurational or no response. As an example of a configurational error, a patient simply rotated the fist instead of pantomiming turning a key.

DISCUSSION

This study showed that comprehension of action was impaired in patients with semantic dementia. We suggest

Table 1 Results of neuropsychological and semantic memory tests

Test (full scores)	Patient						Mean (SD)	Normative data
	1	2	3	4	5	6		
Age (years)	50	58	55	74	68	64	61.5 (6.2)	
Sex	M	M	M	F	M	F		
Side(s) of temporal lobe atrophy	L	L	L>R	R>L	R>L	R>L		
MMSE ²⁷	25	24	19	27	27	25	24.5 (3.0)	
WAIS-R—verbal IQ	76	73	NE	88	77	65		
WAIS-R—performance IQ	113	101	99	84	81	79	88.8 (10.4)	
WAIS-R—full IQ	91	86	NE	85	77	70		
WMS-R—verbal memory index	<50	53	50	63	<50	<50		
WMS-R—visual memory index	114	92	101	109	85	100	100.2 (10.6)	
WMS-R—general memory index	62	60	61	77	55	53	61.3 (8.5)	
WMS-R—delayed recall	68	64	<50	70	58	58		
WAB—aphasia quotient	82.7	71.8	63	74	76.6	75.8	74.0 (6.5)	
RCFT—copy ²⁸	36	36	36	36	36	35	35.8 (0.4)	34.6 (2.2)
Raven's Colored Progressive Matrices ²⁸	35	35	36	30	33	27	32.6 (3.5)	29.2 (5.4)
Picture naming ²⁹	21	18	10	29	23	34	22.5 (8.4)	48.6 (0.8)
Word-picture matching ²⁹	41	42	20	45	13	45	34.3 (14.1)	49.1 (0.9)
Identification of famous faces ¹⁶	15	3	5	0	0	0	3.8 (5.8)	15.2 (1.6)
Category fluency	2	4	0	3	0	2	1.8 (1.6)	17.8 (4.8)

L, left; MMSE, Mini-Mental State Examination; R, right; RCFT, Rey Complex Figure Test; WAB, Western Aphasia Battery; WAIS-R, Wechsler Adult Intelligence Scale—Revised; WMS-R, Wechsler Memory Scale—Revised.

that this deficit is a previously unnoticed aspect of semantic memory impairment. The following findings support this view. Firstly, the patients always failed to recognise actions they were unable to imitate (two-way deficit). Secondly, to cite the example of longitudinal performance of a single case, when patient 1 made an error on a particular item during an earlier session, he always failed to comprehend the same item in subsequent sessions (supplementary material and figure available at <http://jnp.bmjournals.com/supplemental>). These kinds of item-by-item consistency are a hallmark of degraded semantic memory or conceptual knowledge.^{4 21 27} Moreover, comprehension of symbolic actions was more impaired than that of instrumental actions. This is likely to reflect the organisation of semantic memory; in instrumental actions, perceptual, structural and functional features of tools and their target objects interconnect actions and the corresponding concepts, whereas symbolic actions are merely arbitrary labels of particular concepts. The relationship between symbolic actions and their content is relatively loose and presumably vulnerable to breakdown of semantic

memory. The dissociation between symbolic and instrumental actions was more striking in patients 4 and 5, who had facial recognition impairment, than in the other patients. Similar to the mapping between symbolic actions and their meanings, there are only arbitrary associations between people and their faces. This similarity may lead to parallel impairments in symbolic action comprehension and face-people association.

Localised atrophy of the anterior temporal lobe is the anatomical hallmark of semantic dementia and is considered to be a primary cause of semantic memory impairment in this syndrome.^{28 29} Impairment in verbal aspects of semantic memory such as object naming and single-word comprehension is observed in left anterior temporal atrophy, whereas the recognition of familiar faces and voices, buildings, and places is observed in right anterior temporal atrophy.^{7 21} Although previous functional imaging studies have shown that the anterior temporal lobe is involved in action comprehension, there is no consensus on its hemispheric specialisation. In one study the left anterior temporal lobe was activated in the observation of meaningful actions,³⁰ and in another study activations were noted bilaterally in the anterior temporal lobes in the recognition of symbolic actions.³³ Defective action comprehension in semantic dementia could be ascribable primarily to left-sided lesions, because the patients with focal atrophy in the left anterior temporal lobe (patients 1 and 2) had a marked deficit in comprehension of action. However, more striking impairment of symbolic actions was observed in the patients who had face-people association deficit with predominant right temporal atrophy (patients 4 and 5), suggesting contribution of the right hemisphere in comprehension of symbolic action.

The issue of comprehension of action is traditionally investigated in association with apraxia.^{24 26 32} There is a longstanding unresolved question concerning whether the key deficit in apraxia is “asymbolia”—a supramodal failure in the expression of concepts that is common in aphasia and apraxia—or a higher-order movement disorder.³³ This study showed an apparent deficit in comprehension of action with no evidence of apraxia. In patients with apraxia, imitation of meaningless actions—an indicator for motor praxis without conceptual mediation—is reportedly defective, whereas patients with semantic dementia showed perfect performance.^{35 38} Although in the present series some patients failed to imitate a few meaningful (symbolic and instrumental)

Figure 1 Accuracy of comprehension of symbolic and instrumental actions for the patient and control groups. There were strong effects for both subject group and action type. Interaction of action type and subject group was also significant. Error bar indicates the standard error of the mean.

Table 2 Results of action comprehension and imitation tests in patients with semantic dementia

Test (full scores)	Patient						Mean (SD)	% Correct	Normal controls	
	1	2	3	4	5	6			Mean (SD)	% Correct
Action comprehension test										
Symbolic ¹¹	8	3	2	2	4	6	4.2 (2.4)	35.9 (19.3)	11.0 (0)	100 (0)
Instrumental ¹³	13	9	5	12	11	10	10.0 (2.8)	70.0 (26.8)	11.9 (0.9)	91.5 (6.7)
Total ²⁴	21	12	7	14	15	16	14.2 (4.6)	59.0 (19.3)	22.9 (0.9)	95.0 (3.6)
Action imitation test										
Symbolic ¹¹	11	11	11	9	11	11	10.7 (0.8)	97.0 (7.4)		
Instrumental ¹¹	11	10	9	11	10	11	10.3 (0.8)	93.9 (7.4)		
Meaningless ⁸	8	8	8	8	8	8	8.0 (0)	100 (0)		
Total ²⁷	30	29	28	28	29	30	29.0 (0.9)	96.7 (3.0)		

actions, they made errors exclusively in the items that they did not correctly recognise. As even normal controls produced errors of the same nature when they failed to recognise the meaning of an action, the failure in action imitation presumably originated not from motor praxis deficit but from the lack of conceptual facilitation of retrieving visual and functional images of previously learnt actions. These results suggest that conceptual knowledge is not a critical factor for action imitation, and do not support the “asymbolia hypothesis” that a common crucial conceptual process underlies both action imitation and comprehension.²⁶ The recognisability of actions depends on relatively crude motor features, whereas the ability to abstract distinct motor elements from another person’s action and to reorganise them into a goal-directed action is necessary for imitation of action.^{2 33 34 36 37} The reorganisation is presumably independent of conceptual knowledge and can be impaired without obvious deficit in comprehension of action.

Recent neurophysiological studies have shown that a particular class of neurones in the premotor and inferior parietal cortices of primates discharge both when the monkey performs particular actions and when it observes similar actions performed by others.¹ These neurones are known as mirror neurones and are considered to be a common neural basis of imitation and comprehension of action.² Many functional imaging studies also provide evidence for functional significance of the premotor and inferior parietal cortices in recognition, imitation and execution of actions in humans.^{1 38} However, the results of lesion studies do not support this hypothesis: action comprehension is preserved or only mildly affected in patients with premotor or parietal lesions.^{32 39} Again, the present study showed a severe deficit in comprehension of action in semantic dementia, in which the premotor and parietal mirror-neurone system escapes the process of degeneration.^{28 29} The discrepancy between the results of the functional imaging and lesion studies arguably derives from the difference between the functions subserved by the mirror-neurone system and those required in action comprehension tasks. As Byrne³⁷ and Rizzolatti² noted, actions are assumed to be a series of simpler motor elements such as arm extension and prehension. The mirror-neurone system is probably engaged in assembling motor elements into actions and segmenting actions into strings of elements. Although these functions are the first step in comprehension of action, the involvement of conceptual knowledge, inference and reasoning is critical in understanding the intentions of those performing actions and of complex social interactions. This study suggests that comprehension and production of action are subserved by interactions between two anatomically and functionally different neural systems: the frontoparietal mirror-neurone system associated with the spatiotemporal aspects of actions and the temporal semantic memory system engaged in concepts and representations. The differential roles of these systems should be carefully

segregated in future studies on the neural basis of action comprehension and production.

The evolving pattern of performance of patient 1 in the action comprehension test is available at <http://jnnp.bmjournals.com/supplemental>

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HISTORICAL NOTE

Von Frey's pain spots

The physiology of sensation began with Johannes Müller (1801–58), who devised the law of specific nerve energies. Magnus Blix first showed the modal character of cutaneous sensation with a tactile stimulator, which dropped a horse's hair. Max von Frey discovered discrete pain points or "Schmerzpunkte" on the human skin when probing it at threshold intensity for sensation with fine needles or plant spicules. Von Frey placed and pressed a single hair on the skin. He determined the threshold force needed to produce the sensation of touch by varying the size of the hair. He used probes to localise cold-, warm- and pain-sensitive spots. He also showed the sensory spots by applying electrical stimulation to discrete points on the skin. He showed points sensitive to pressure, pain and temperature (fig 1). Each sensory modality had a specific, minute, highly specialised receptor. The skin is composed of a mosaic of four types of sensory spots: touch, cold, warmth and pain. This is the foundation of von Frey's (1894) theory of receptor sensitivity

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Figure 1 Von Frey's pain spots. From *Untersuchung über die Sinnesfunktionen der menschlichen Haut, Abhandlungen der mathematisch-physischen Klasse der Königlich Sächsischen Gesellschaft der Wissenschaften*, 1896.