Review

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Modeling the meaning of words: Neural correlates of abstract and concrete noun processing

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We present a model relating analysis of abstract and concrete word meaning in terms of semantic features and contextual frames within a general framework of neurocognitive information processing. The approach taken here assumes concrete noun meanings to be intimately related to sensory feature constellations. These features are processed by posterior sensory regions of the brain, e.g. the occipital lobe, which handles visual information. The interpretation of abstract nouns, however, is likely to be more dependent on semantic frames and linguistic context. A greater involvement of more anteriorly located, perisylvian brain areas has previously been found for the processing of abstract words. In the present study, a word association test was carried out in order to compare semantic processing in healthy subjects (n=12) with subjects with aphasia due to perisylvian lesions (n=3) and occipital lesions (n=1). The word associations were coded into different categories depending on their semantic content. A double dissociation was found, where, compared to the controls, the perisylvian aphasic subjects had problems associating to abstract nouns and produced fewer semantic frame-based associations, whereas the occipital aphasic subject showed disturbances in concrete noun processing and made fewer semantic feature based associations.

Key words: mental lexicon, abstract words, concrete words, semantic frames, semantic features, neurocognition, aphasia

INTRODUCTION

Modeling word meaning: semantic features and frames

Despite much research on the mental lexicon, many questions remain concerning the neural correlates of word meaning. Considerable work has been done on the linguistic modeling of word meaning both in terms of componential analysis – with meaning components being referred to as e.g. 'semantic features' (Weinreich 1966) or 'semantic primitives' (Wierzbicka 1992) – and with reference to larger cognitive structures involved in word processing, e.g. 'semantic frames' (Fillmore 1985), 'idealized cognitive models' (Lakoff 1987) and 'scripts' (Schank and Abelson 1977). Despite certain differences, all frame-based theories have in common that they assume word processing to be dependent on larger structures of encyclopedic knowledge being activated (Geeraerts 2010). Semantic frames may involve whole scenarios and situations, including concrete objects as well as events, actions and more abstract knowledge (Ungerer and Schmid 2006).

Although the frame and the feature views sometimes are seen as opponents, both views are compatible with neurocognitive models assuming different levels of information processing in the brain, and recent research attempts to relate the two views in models of the lexicon (Levinson 2003, Evans 2009, Fortescue 2010). The present study shows how semantic features and frames can be integrated within a general framework of neurocognitive information processing (Fuster 2009). The focus of the study lies on a comparison of the processing of concrete and abstract nouns, including questions about the relative importance of different brain regions for processing of the two word types. Particular focus will be on the assumption of different levels of abstract frame structure, e.g. 'general frames' as compared to more 'personal frames' in addition to the assumption of a hierarchy of concrete features and

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higher level semantic categories. Empirical evidence will be presented which supports the assumption that frontal and temporoparietal brain areas are crucial for the processing of general semantic frames, whereas occipital areas are relatively more involved in the processing of concrete nouns whose meaning is dependent on sensory semantic (e.g. visual) features. The evidence comes from the results of a word association test involving both healthy and aphasic subjects. The basic assumption behind the study is that damage to occipital regions of the brain would lead to problems associating to concrete words whereas lesions of the 'language areas' around the Sylvian fissure, including *inter alia* Broca's and Wernicke's areas, would lead to problems associating to abstract words.

Neurocognitive models of meaning representation

To get a better understanding of the representation of word meaning in the brain, it is important to relate linguistic models of word semantics to a more general framework of neurocognitive processing. One of the most influential models of neurocognitive information processing is that of Fuster (2009), who represents different kinds of meaning in distributed neural networks[1] (Fig. 1). Although semantic networks can be formed between neurons in virtually any parts of the brain, lower-level, perceptual networks have nodes in posterior sensory cortices related to visual, auditory, and tactile processing [dark blue areas (1–3, 17, 41) behind the Rolandic Fissure (RF) in Fig. 1]. Similarly, motion activates the primary motor cortex [dark red area (4) directly in front of RF in Fig. 1]. The greater the complexity of a perception or memory, the more widely distributed neural activity it is expected to be associated with. Higher-level, executive processing is more dependent on frontal executive networks (white on red in Fig. 1) whereas higher-level semantic conceptualization activates temporoparietal and inferior temporal areas involved in integration of different sensory modalities (whiter areas behind RF in Fig. 1) (Fuster 2009).

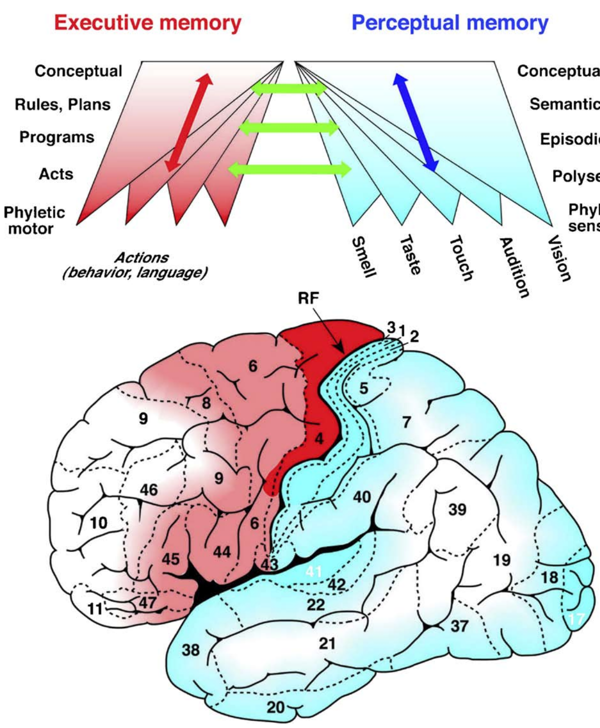

Fig. 1. Hierarchical organization of semantic networks in anterior and posterior cortices (Fuster 2009) (reproduced by kind permission of MIT Press Journals)

Numerous studies have provided evidence that abstract and concrete words[2] are represented and processed differently in the brain. Thus, neuroimaging data support a greater involvement of sensory (e.g. visual) areas in concrete word processing (Martin et al. 1996, Humphreys et al. 1997, Pulvermüller 1999) and a more focal activation of perisylvian 'language' areas[3] for function words as well as abstract nouns (Pulvermüller 1999, Sabsevitz et al. 2005, Noppeney and Price 2004, Binder et al. 2005).

Further support for the idea that a perisylvian network is more involved in abstract word processing comes from studies involving speakers with aphasia. Aphasic speakers with frontal/temporoparietal lesions are generally found to have greater difficulty in processing abstract words (Hagoort 1998, Tyler et al. 1995), whereas posterior[4] damage can be associated with a selective impairment in the naming of visually presented objects and colors (Girkin and Miller 2001, Gainotti 2004, Coslett and Saffran 1992, Forde et al. 1997, Luzatti 2003).

The idea that concrete word processing is more sensory-based has often been interpreted in terms of the 'dual coding theory' (Paivio 2007), which assumes abstract words to mainly activate a language-specific

[1] In this paper, neural meaning representations will be referred to as 'semantic networks'. Other terms include 'memory network', 'cognit' (Fuster 2009) and 'cell assembly' (Pulvermüller 1999).

[2] In these studies, concrete words are defined as words which to a high degree refer to physical objects and easily evoke mental imagery of sensory experiences, whereas abstract words in contrast do not refer to physical objects and do not easily evoke mental imagery.

[3] Associated with e.g. phonological and morphosyntactic processing.

[4] Occipital/occipitotemporal.

Table I

Proposed relations between different levels of cognitive linguistic information (third column) and the levels in the general neurocognitive model by Fuster (2009) (see also Figure 1)

	Executive memory	Perceptual memory	Cognitive linguistic correlates
1	Actions (behavior, language)	Smell, taste, touch, audition, vision	Perceived/produced language
2	Phyletic motor (primary motor cortex)	Phyletic sensory (primary sensory cortex)	Semantic features (e.g. color, shape, taste)
3	Acts	Polysensory	Integrated semantic features, subordinate and basic level categories
4	Programs	Episodic	Personal semantic frames
5	Rules, plans/Conceptual	Semantic/Conceptual	General semantic frames, superordinate categories, abstract processing

system, whereas concrete words additionally activate an imagery system[5]. This view is compatible with the hierarchical model of Fuster (2009), but the latter adds the dimension that higher-level semantic networks are involved in the processing of abstract information in general, not just language-specific information as in the verbal system described by Paivio.

Integrating semantic features and frames in a hierarchical model of word meaning

In this section, it will be shown how modeling of word meaning in terms of semantic features, categories and frames can be related to the hierarchical model of semantic networks described above, with concrete sensory input and motor output at the lowest level, and progressively more abstract frame-related knowledge at higher levels.

In Table I, a proposal is made for how cognitive linguistic information at different levels of abstraction can be related to the hierarchy of semantic networks in Fuster's (2009) model of neurocognition. In what follows, a description of the linguistic information at the different levels in the hierarchy is presented.

[5] Sensory-related information is also assumed to contribute to a general processing advantage of concrete as compared to abstract words, often referred to as the 'concreteness effect'.

Perceived/produced language

This level in Fuster's general model of neurocognition corresponds to the actual input in language perception and the motor output in language production (Table I).

Semantic features

The term 'semantic features' (Weinreich 1966) has frequently been used to describe concrete, sensory-motor-based properties (BANANA: +curved +yellow) and the term is used in this sense in the present study. The processing of basic sensory features such as size, color, shape, movement pattern, sound, taste and smell, activates modality-specific semantic networks at the 'phyletic sensory' level, which are then integrated at the 'polysensory' level in order for events and objects in the environment to be perceived as a seamless whole (Fuster 2009). Following this, sensory-motor semantic features (level 1 in Table II) can be seen as having neural correlates in terms of sensory-motor regions in the brain (level 2 in Table I). A concrete subordinate level word such as STRAWBERRY refers to an object associated with rather specific, sensory-based features and feature constellations, making the lexical form likely to be associated with neural meaning representations at these levels.

Table II

Types of possible relations between cue words and associations

Relation to cue word	Definition	Example
1. Sensory-motor based feature	Association related to a single basic sensory-motor based semantic feature of the cue word, e.g. color, taste, shape.	Strawberry–red
2. Sensory-motor based category	Association related to sensory-motor based semantic features of the cue word. The associated words belong to the same superordinate category.	Strawberry–cherry
3. Sensory-motor based frame a) 'Body/External'-related context b) 'Body/Visceral'-related context	Association which has sensory-based semantic features, but which are not shared with the cue word.	a) strawberry–cream b) strawberry–hungry
4. Personal frame	Association taken from a context which is episodic/autobiographical rather than representative for people in general. Includes associations to person names, episodic memories and evaluating comments.	Strawberry–grandmother (if the person e.g. has a grandmother who loves strawberries) Strawberry–yesterday (if the person had strawberries yesterday) Strawberry–nice
5. General frame	Association occurring in the same general semantic frame as the cue word. The association is not based on clearly identifiable sensory-motor based semantic features.	Strawberry–summer Strawberry–food

Semantic categories

Rosch and colleagues (1976, 1978) proposed that categorical semantic relations are hierarchically ordered, with superordinate (FOOD), basic (BERRY) and subordinate (STRAWBERRY) terms. The cognitive categorization of entities and objects has been suggested to be based on certain essential features (Ungerer and Schmid 2006). Sensory-motor based semantic features (e.g. color, shape, smell) are shared to different degrees by words at different hierarchical levels. The higher the level, the less concrete a word is. In other words, BERRY is less concrete than STRAWBERRY, but their referents still share sensory features (e.g. 'small', 'sweet'). This can be seen as corresponding to the polysensory level in the model of Fuster (2009) (level 3 in Table I) and to be important for word meanings at levels 2 and 3 (sensory-motor-based categories and frames) in Table II. Berries can also be part of categories that are even more abstract and general, such as the superordinate terms FOOD or DESSERT, corresponding to level 5 (semantic/conceptual level) in Table I and level 5 (general semantic frame) in Table II. A mental representation of FOOD may or may not include basic sensory semantic features associated with BERRY. Members of the cognitive category FOOD have the common denominator of 'edibility', but these edible things can have a wide variety of tastes, smells, textures, shapes and colors. In a recent study (Crutch and Warrington 2008), subjects with left middle cerebral artery stroke aphasia were shown to have processing advantages for subordinate level words (e.g. DALMATIAN), in contrast to healthy controls who process basic level terms (e.g. DOG) with greater ease, and semantic dementia patients who are more proficient with superordinate terms (e.g. ANIMAL). One possible explanation for this pattern might be the greater variability of semantic information associated with superordinate categories as compared to the more detailed sensory features defining the referents of subordinate terms. The more diverse and context-dependent the semantic content of a word is, the greater are the demands on controlled access of information. Thus, one suggested reason for this double dissociation is that executive functions are affected by stroke aphasia, whereas detailed semantic representations are degraded in semantic dementia (Jeffries and Lambon Ralph 2006). In particular, superordinate and basic level categories may lack the consistent linkage to sensory semantic features that is present in more specific, subordinate words. Following the models of Fuster (2009) and Paivio (2007), if a subordinate level word, e.g. DALMATIAN is more strongly associated with specific visual features as compared to the basic level word DOG, this would make it easier to access when executive and linguistic processes are impaired but visually related semantic processes are intact.

Semantic frames

The existence of higher level knowledge structures is essential for understanding word meaning, in particular when it comes to abstract words. In this view, more abstract semantic knowledge activates such knowledge structures, which in Fillmore's terms are called semantic frames. For example, the word BACHELOR evokes both abstract semantic properties such as 'male' and 'unmarried' and a semantic frame consisting of encyclopedic knowledge, e.g. the cultural knowledge which makes it possible for us to know that the pope is not a typical bachelor although he is an unmarried man (Fillmore 1982, Lakoff 1987). The less grounded in concrete, sensorimotor experience a word's meaning is, the more integration of diverse, frame-based information the processing of the word can be hypothesized to involve. In neurological terms, accessing more abstract semantic representations would, according to the model outlined by Fuster (2009), be likely to activate higher-level networks in e.g. frontal and temporoparietal areas to a greater extent than concrete word representations. In the present study, two levels of frame structure will be assumed, a 'personal frame level' and a 'general frame level', further described in the following paragraphs.

Personal semantic frames

This level corresponds to Fuster's 'episodic' level (level 4 in Table I), where autobiographical experiences are represented (Fuster 2009). Although the complexity and richness of memory representations increase from the phyletic sensory information level to personal frames consisting of memories of whole scenarios, these levels of representation share the property that they reflect things that have previously been directly perceived in the environment and experienced with the body. We assume, therefore that specific semantic frames associated with personal experiences (level 4, Table I) are to be distinguished from more general semantic frames (level 5, Table I). Personal frames can be hypothesized to activate a large amount of both sensory and emotional information in the brain, making them easier to access even when areas involved in the processing of general frames are damaged.

Right hemisphere cortical regions (e.g. ventromedial prefrontal cortex) and subcortical areas (e.g. the amygdala) have been found to be more active in the processing of socially related concepts as compared to information involving manipulable objects (Martin and Weisberg 2003). Right hemisphere regions have also been shown to be involved to a larger extent in subjects who respond quickly to an emotional Stroop test, suggesting that the right hemisphere is important for directing attention to task-relevant emotional stimuli (Mincic 2010). On the basis of these results, pragmatic and emotional aspects of word associations could also be thought to involve these brain regions to a higher degree, allowing these types of information to be accessed despite lesions in left hemisphere cortical areas.

General semantic frames

The more abstract and general levels above the personal, episodic level correspond to the level of 'general semantic frames' (level 5, Table I). The more diversely distributed semantic networks corresponding to higher, conceptual levels are ”formed to a large extent by the repeated coactivation and instantiation of similar, more concrete (e.g. episodic) memories” (Fuster 2009, p. 2062), which are nested within the larger networks

Table III

Aphasic participants with left hemisphere lesions						
Subject	Age	Sex	Symptom diagnosis	Onset of aphasia	Latest CT-scan	Lesion localization
1	41	F	Broca's aphasia (moderate)	1989.04.25	2000.08.22	CT: Left hemisphere frontoparietal low attenuation, largest extension frontally
2	66	F	Broca's aphasia (moderate)	2004.10.08	2004.10.27	CT: Left hemisphere frontoparietal low attenuation, mainly in frontal cortex
3	31	F	Broca's aphasia (light)	2007.02.17	2007.02.18 MR: 2007.02.20	CT: Left hemisphere temporoparietal low attenuation, beginning in the middle cranial fossa, extending cranially dorsally over the Sylvian fissure at the height of the cella media of the lateral ventricles. Low attenuation also included the insula area and the major part of the external capsule. MR: Lesions in large parts of the irrigation areas of the middle cerebral artery both frontally and temporally.
4	76	M	Anomic aphasia (light)	2004.04.01	2004.04.06	CT: Left hemisphere occipital low attenuation

In all cases medical diagnosis was cerebral infarct. (F) Female; (M) Male

(level 5, Table I). Superordinate categories for concrete words that are not directly associated with sensory-motor semantic features are also assumed to be localized on this level.

Connections between frames and features

Following the connectionistic model of information processing presented in Table I, it is assumed that frame-based representations can be associated with each other as well as directly with sensory features. For example, concrete words such as 'strawberry' can be related directly to features on the lowest phyletic sensory level (e.g. the color 'red') as well as to semantic category related words (e.g. 'berry'). Further, an association from JORDGUBBE ('strawberry') to GRÄDDE ('cream') involves a connection to a non-categorically related word instead of a more direct sensory-based relation with another category-related word as in the relation between JORDGUBBE ('strawberry') and SMULTRON ('wild strawberry'). Words contextually associated to each other but which do not have overlapping sensory features (e.g. JORDGUBBE ('strawberry') and SOMMAR ('summer') are assumed to be related at other, higher levels of common associated frames (Fillmore 1985, Fortescue 2010).

Combining features and frames: a word association experiment using concrete and abstract words

In order to obtain experimental support for models of word meaning combining features and frames, word relations in the mental lexicon were investigated using a word association test. Since features and frames are also assumed to be differently involved in the processing of abstract and concrete words, the test compared the processing of these two different lexical categories. In order to obtain information on the distribution of neural networks involved in the processing of feature and frame-based information, the association test was given to healthy speakers as well as to aphasic speakers with perisylvian or occipital lesions.

Word associations can be expected to reflect the different kinds/levels of semantic information processing (see Table II). Associations might be related to both features and frames in different ways: (1) Associations focusing on a single sensory-based feature, e.g.

STRAWBERRY–RED, (2) Associations sharing several sensory features with the cue word, e.g. STRAWBERRY–RASPBERRY, (3) Associations related to a frame-related word having sensorimotor features, e.g. STRAWBERRY–CREAM, (4) Associations related to a personal frame, e.g. STRAWBERRY–GRANDMOTHER, (5) Associations involving a more general frame, e.g. STRAWBERRY–SUMMER. These association types are summarized in Table II.

The free word association task makes it possible to investigate the association strength between the different word types and semantic feature- and frame-based information.

Hypotheses

On the assumption that semantic features related to lower level semantic networks (phyletic sensory and polysensory), mostly dependent on posterior cortices, would be well-preserved in speakers with perisylvian lesions, it was hypothesized that associations involving shared sensory-based semantic features would be more common in this group than in speakers with occipital lesions, as well as speakers without aphasia. It was further hypothesized that speakers with perisylvian lesions would have difficulty in accessing higher-level, general frame-based associations, both due to the general frames' lack of a direct relation to sensory information and due to the greater demands selecting a word from a general frame may put on executive functions. Conversely, since speakers with occipital lesions could be expected to have problems processing low-level visual features and thus concrete words in general, it was hypothesized that associations involving higher-level (more abstract) words would more likely be produced by such speakers than by speakers with perisylvian lesions and speakers without brain damage.

METHODS

Subjects

Twelve Swedish speakers (ten female) without communication problems in the age range of 23–79 years (M = 47; SD = 19) participated. Contact with four right-handed subjects with left-hemisphere lesions (three female), (Table III) was established through the Neurology Department at Malmö University Hospital and the Aphasia Association in Malmö-Lund. They had all been treated at the Stroke Clinic at Malmö University Hospital. The healthy and aphasic subjects were approximately matched as regards their age and education levels and all subjects gave their informed consent to participate in the study. The subjects with perisylvian lesions all had symptom diagnoses of mild-to-moderate Broca's aphasia, and the fourth subject with occipital lesions[6] had mild anomic aphasia including semantic dyslexia. Diagnoses were made based on Swedish equivalents of the Boston Diagnostic Aphasia Examination (Apt 1997), the Boston Naming Test (Kaplan et al. 1983, Apt 1999), and the Token Test (De Renzi and Faglioni 1978).

Material

Nouns

Thirty nouns with high concreteness values[7] (M = 605, SD = 26) and imageability values[8] (M = 599, SD = 30) (Appendix 1), and 30 nouns with low concreteness values (M = 277, SD = 38) and imageability values (M = 379, SD = 77), were chosen from the Medical Research Council (MRC) Psycholinguistic Database (Coltheart 1981). The words with high concreteness and imageability values can be assumed to be strongly related to the lower sensory-motor levels of processing, whereas the words with low concreteness and imageability values can be assumed to involve higher-level, more abstract conceptual processing. Concreteness and imageability values range from 100–700, with 100 being the least concrete/imageable and 700 the most concrete/imageable. The English nouns from the database were translated to Swedish using Lexin (2007).

The nouns used in the present study had 1–4 syllables (M = 2.55, SD = 0.922), to minimize the risk that word length could affect comprehension negatively for the aphasic participants. The mean number of syllables in concrete nouns (M = 2.43, SD = 0.817) and abstract nouns (M = 2.67, SD = 0.922) did not differ significantly t_{58}=−1.037, P=0.304.

[6] The participant with occipital lesions had reading difficulties and a right-sided homonymous hemianopia, meaning a lack of vision in the right visual field, but no other perceptual deficits. It should also be pointed out that occipital lesions are much rarer than perisylvian lesions, which accounts for the fact that only one person with occipital lesions participated in the present study.

[7] Concreteness values are based on subjects' ratings of the degree of which words refer to concrete, physical objects.

[8] Imageability values are based on subjects' ratings of how easily words evoke mental images.

Written word frequencies from the Stockholm Umeå Corpus (SUC) (Ejerhed et al. 1992) were obtained for the Swedish translations of the nouns. The abstract nouns had a higher mean frequency M = 58.93, SD = 76.368 than the concrete nouns M = 11.83, SD = 25.551, t_{58}=–3.204, *P*<0.01. Familiarity values[9], also obtained from the MRC database (Coltheart 1981), did not differ significantly for abstract nouns M = 526, SD = 38 and concrete nouns M = 503, SD = 56, t_{58}=–1.872, *P*=0.066, although there was a trend for higher familiarity of the abstract nouns.[10]

Procedure

In the word association test, participants were instructed to say the first word that the word uttered by the test leader made them think of, and they were informed that any answer would be correct as long as it was the first word that came to mind. Prior to the test, two practice words, KATT ('cat') and STOL ('chair'), were presented in order to verify that the participants had understood the instructions correctly. Thirty concrete and 30 abstract nouns were then presented orally by the test leader. In the association task, every second noun presented was abstract. The same order of presentation was used for all participants.[11] Pauses and repetitions of the nouns were made when necessary. The speakers' associations were recorded using a Marantz PMD660 Portable Solid State Recorder and an IMG Stage Line ECM-302 B Boundary Microphone.

Data analysis

Coding of semantic relations

The five types of word associations listed in Table II, corresponding to different kinds of semantic relationships (1–5) were labeled. These 5 types of semantic relations can also be seen as associated with five different levels of semantic representations, with level 1 being the least abstract and level 5 being the most abstract. In addition, labeling of perseverations, derivations, absent and unidentifiable associations (6–9), were coded in the material. These latter categories can all be considered to be "unacceptable" associations in the sense that they contain no new semantic information related to the cue words. Coding was carried out by the first author. All labeling was discussed with, and agreed on by the second and third authors.

Statistical analysis

Statistical analyses were performed using Crawford Statistics; more specifically, with the software Singlims[12]. In the first analysis, mean scores were calculated based on the levels (categories 1–5) of the semantically acceptable associations. Mean scores were calculated for all groups (perisylvian, occipital, control) for the responses to concrete and abstract cue words, respectively.

In the second analysis, the number of acceptable associations (max: 30 for concrete cue words and 30 for abstract cue words) produced by occipital and perisylvian subjects were compared with those of the healthy controls. However, this analysis could only be carried out for the associations to the abstract cue words, since a requirement in Crawford statistics is that there be some variability in the material. Contrary to this requrement, the control group produced 100% acceptable associations for concrete cue words, leading to a standard deviation of 0.

RESULTS

Distribution of semantic relations between cue words and associated words

The data, coded according to the previously described labels, was analyzed in order to determine the distribution of the different kinds of relations found between test words and associated words produced by the test participants. Some examples of associations and their relation to cue words are illustrated in Table IV.

In the healthy subjects, concrete cue words gave rise to a large number of sensory-motor based asso-

[9] Familiarity values are based on subjects' ratings of how familiar, i.e. frequently experienced, words are.

[10] Spoken word frequencies from the Brown Corpus for the English translations of the words were also looked up in the MRC database. Although relatively few of the words were found in the corpus (approximately 30% of the concrete words and 60% of the abstract words), nevertheless, judging from this small sample, abstract words also seemed to be more frequent in spoken word production. These differences in written and spoken word frequencies as well as subjectively judged familiarity with the abstract nouns being more common is probably due to the fact that they express more general concepts which can be used in a variety of contexts, whereas the concrete words refer to relatively more specific concepts.

[11] The reason for not presenting the stimuli in randomized order was that it was deemed that if not all aphasic participants could complete the whole test, there would still be a data set consisting of the same words and an equal number of concrete and abstract trials left for analysis.

[12] Downloaded from http://www.abdn.ac.uk/~psy086/dept/SingleCaseMethodology.htm

Table IV

Labeling of the relations between cue words and associations with examples from the data

Relation to cue word	Definition	Example
1. Sensory-motor based feature	Association related to a single basic sensory-motor based semantic feature of the cue word, e.g. color, taste, shape.	gurka-grön 'cucumber'–'green' choklad–sött 'chocolate–'sweet'
2. Sensory-motor based category	Association related to sensory-motor based semantic features of the cue word. The associated words belong to the same superordinate category.	varg–räv 'wolf'–'fox' limousin–bil 'limousine'–'car'
3. Sensory-motor based frame a) 'Body/External'-related context b) 'Body/Visceral'-related context	Association which has sensory-based semantic features, but which are not shared with the cue word.	a) dragkedja–jacka 'zipper'–'jacket' b) makaron–hungrig 'macaroni'–'hungry' glädje–skratt 'joy'–'laughter'
4. Personal frame	Association taken from a context which is episodic/ autobiographical rather than representative for people in general. Includes associations to person names, episodic memories and evaluating comments.	depression–meditation sköldpadda–tant 'turtle'–'(old) lady' fördel–logoped 'advantage'–'speech therapist'
5. General frame	Association occurring in the same general semantic frame as the cue word. The association is not based on clearly identifiable sensory-motor based semantic features.	säckpipa–Skottland 'bagpipe'–'Scotland' optimism–pessimism
6. Perseveration	Repetition of a previously uttered word or word stem which is unrelated to the cue word	samvete–osant 'conscience'–'untrue' kris–osant 'crisis'–'untrue' passion–opassion 'passion'–'unpassion'
7. Derivation	Word based on the same stem as the cue word but involving a change of word class.	glädje–glad 'joy'–'joyful' ärlighet–ärlig 'honesty'–'honest'
8. Absent	The subject is unable to produce any association.	
9. Unknown	Association which could not be categorized as any of the types 1–6.	

Table V

Distribution of association types for concrete cue words produced by healthy, perisylvian aphasic, and occipital aphasic subjects

Nr	Category	Healthy (%)	Perisylvian (%)	Occipital (%)
1	Sensory-motor feature	11.4	2.2	0
2	Sensory-motor category	31.9	42.2	10.0
3	Sensory-motor frame	22.5	35.6	6.7
4	Personal frame	6.7	2.2	0
5	General frame	27.5	12.2	50.0
6	Perseveration	0	0	0
7	Derivation	0	0	0
8	Absent	0	0	23.3
9	Unknown	0	5.6	10.0

ciations, most of which were categorically related based on sensory semantic features or belonged to a related sensory-based semantic frame (54%). However, a large proportion of the associations produced as responses to concrete cue words by the healthy subjects were general semantic frame based (27%, the next largest category) (Table V). In the perisylvian aphasic group, sensory-motor based categorical and sensory-motor frame based associations constituted an even larger proportion of the associations (78%), whereas general semantic frame associations were fewer than in controls (only 12%). The subject with occipital lesions produced fewer sensory-motor based associations (17%), whereas the largest proportion (50%) of his associations were general semantic frame-based. In general, he had difficulties with concrete word associations, and was even unable to produce associations for 23% of the concrete cue words.

Abstract cue words naturally never led to associations based on sensory-motor features or categories as defined in the present study[13] (Table VI). Thus, for the abstract cue words, all associations were considered to be semantic frame-based. In the healthy participants, 83% of the associations for abstract cue words fell into the general semantic frame category. In the perisylvian aphasic group, a dramatically lower proportion of the associations (39%) were based on general semantic frames. Of the remaining associations to test words, many were personal frame associations (22%), perseverations (14%), or even absent (13%), patterns which did not occur for the concrete cue words in the perisylvian group and not for any words in the healthy subjects. The subject with occipital lesions, in a manner similar to the controls, produced mainly general semantic frame associations for abstract words (73%).

Number of acceptable associations for abstract and concrete cue words between groups

The analysis of the number of acceptable (semantically related) associations showed that for the abstract cue words, both clinical groups produced fewer acceptable associations than controls (M controls = 28.75; SD = 0.2) The perisylvian group's test score (M = 19.67) was significantly lower than that of the controls (t=−43.619, P<0.001) as was the score of the

[13] i.e. associated words involving perceptually observable semantic features shared by the cue words.

occipital subject (n=23, t=−27.622, P<0.001). However, as regards the concrete scores, which could not be statistically tested since the controls performed at ceiling yielding no variability, the perisylvian subjects had a mean score of 28.3 acceptable associations, whereas the occipital subject produced 20 acceptable associations, clearly indicating difficulties in producing semantically related responses to concrete cue words.

Mean category level of the responses for abstract and concrete cue words between groups

Figure 2 shows the mean category level of the responses for concrete and abstract cue words in the different groups (controls, perisylvian, occipital). As can be seen in Fig. 2, the subject with occipital lesions produced associations on the highest level of abstraction, both when cue words were concrete (M = 4.35) and abstract (M = 4.96). Controls were intermediate in the overall level of association with associations being at low levels for concrete cue words (M = 3.07) and at high levels for abstract cue words (M = 4.76). The perisylvian subjects were similar to controls but at an overall lower level of abstraction for both concrete cue words (M = 2.79) and abstract cue words (M = 4.53). In the responses for concrete cue words, the mean category level of the associations was significantly higher for the occipital subject (M = 4.35) compared to controls (M = 3.07, SD = 0.073) (t=16.846, P<0.001) and in contrast, significantly lower in the perisylvian group (M = 2.79) (t=−3.685, P<0.05). In the responses for abstract cue words, the mean category level of the occipital subject (M = 4.96) did not differ significantly from that of the controls (M = 4.76. SD = 0.627) (t=0.306, P>0.05) and neither did the mean category level of the perisylvian group (M = 4.53) (t=−0.352, P>0.05).

DISCUSSION

The qualitative analysis of the word association data revealed differences between the participant groups regarding the distribution of the semantic relationships between cue words and associations. In the healthy subjects, a very large proportion of the associations given as responses to abstract nouns, as well as a considerable number of the concrete word associations were words belonging to general semantic frames, e.g. STRAWBERRY–SUMMER, i.e. associations which were not directly associated with any sensory-motor-based features related to the cue word. In the perisylvian aphasic group, abstract nouns triggered repeated associations to words related to personal semantic frames, e.g. REACTION–STROKE whereas concrete nouns mostly gave rise to sensory-based word associations, in particular concrete words sharing sensory-based semantic features with the cue words, e.g. CHAIR–TABLE. The subject with occipital lesions showed the opposite pattern, with mainly general semantic frame-based word associations for abstract as well as concrete cue words and very few sensory/visual-based associations. The results obtained support the hypothesis that concrete and abstract words activate partly distinct neural networks with nodes in different parts of the brain. The results also support a model of the mental lexicon in which semantic features and semantic frames are integrated in word meaning processing and show how such a model fits into a general account of neurocognitive information processing (Fuster 2009). As regards the statistical analysis, some of the results reached significance and some did not. Surprisingly, all aphasic subjects produced significantly fewer acceptable associations for abstract cue words although this was only

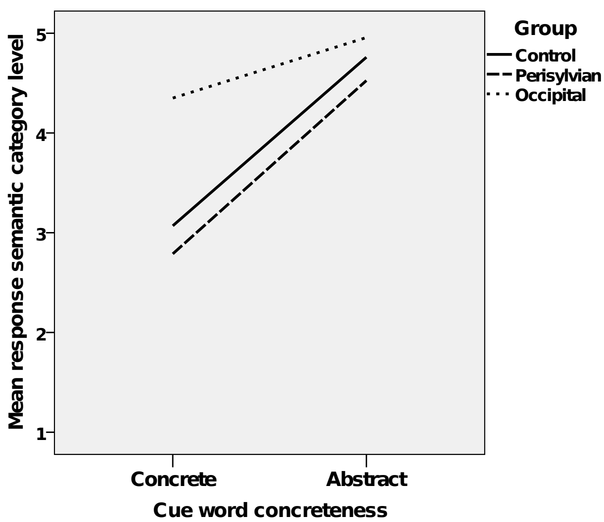

Fig. 2. Mean semantic category levels produced as responses by healthy controls, perisylvian aphasic, and occipital aphasic subjects for concrete and abstract cue words. The degree of abstraction increases from 1 to 5, corresponding to the levels in Table I.

Table VI

Distribution of association types for abstract cue words produced by healthy, perisylvian aphasic, and occipital aphasic subjects

Nr	Category	Healthy (%)	Perisylvian (%)	Occipital (%)
1	Sensory-motor feature	0	0	0
2	Sensory-motor category	0	0	0
3	Sensory-motor frame	10.0	4.4	0
4	Personal frame	3.1	22.2	3.3
5	General frame	82.8	38.9	73.3
6	Perseveration	0	14.4	0
7	Derivation	1.4	1.1	10.0
8	Absent	0.8	5.6	3.3
9	Unknown	1.9	13.3	10.0

expected for the perisylvian aphasics. A possible explanation is that the occipital subject produced a number of derivations, e.g. LOYALTY–LOYAL; REACTION–REACT, (category 7, see Table VI and Appendix 2d), which were considered to be unacceptable associations, as well as a number of associations where the semantic relation to the cue word was unknown e.g. TWEEZERS–HEAD, (Appendix 2c). In the perisylvian group, the failure to associate was more often due to perseveration or omitted associations. As regards concrete cue words, the number of semantically acceptable associations for the perisylvian group (28.3/30) was higher than that for the occipital subject (20/30).

The clearest statistical difference was seen in the mean category levels of the associations for concrete cue words, where a significant double dissociation was seen between occipital and perisylvian subjects as compared to controls, with the occipital subject scoring higher and the perisylvian subjects lower. As regards the associations for abstract cue words, the differences were not significant in any direction, indicating that when the subjects were able to produce acceptable responses for abstract words, they were generally rather high-level associations.

Neural correlates of concrete word meaning

Since the occipital aphasic subject's lesions affects areas involved in primary visual [in the terms of Fuster (2009) 'phyletic sensory'] processing, his difficulties with concrete nouns can be thought to be caused by a failure to access semantic networks involving low-level visual feature representations. Word access from visual input, e.g. naming objects and colors from visual presentation, has previously been shown to be selectively impaired in persons with aphasia due to left occipital lesions[14]. In the present study, occipital lesions were associated with specific problems accessing concrete nouns from verbal presentation, supporting the assumption that posterior areas involved in processing of visual information, e.g. colors and shapes, are intimately involved in the processing of concrete nouns, not only when they are activated by visually presented stimuli. This indicates that low-level semantic networks involved in the perception of concrete objects and entities are crucial for the processing of the concrete words denoting them, even in the absence of visual presentation or explicit mental imagery.

[14] In addition to this, other visuo-verbal disturbances may also be present, such as alexia without agraphia (impaired reading without impaired writing).

Thus, vision-related and other sensory representations are a likely contributing factor to the processing advantage normally present for concrete as compared to abstract nouns, as suggested by e.g. Paivio (2007) and Pulvermüller (1999). The involvement of phyletic sensory, visual semantic networks in the occipital cortex also makes concrete noun processing likely to be relatively well preserved in aphasia caused by left perisylvian lesions. In the present study, this is manifested as the production of a larger proportion of sensory-based associations, in particular words denoting objects sharing sensory-based features with the cue word (Table V; Fig. 2, for examples see Appendix 2c). It has been suggested that concrete and abstract words also differ in their involvement of the two hemispheres, with concrete words and imagery showing a right hemisphere advantage (e.g. Paivio 2010). Binder and others (2005) found that processing of concrete words to a greater extent activated bilateral association cortices, whereas abstract word processing was more localized to the left hemisphere. Even if it is the case that concrete word processing normally activates bilateral areas, the fact that the subject with left occipital lesions in the present study is impaired in concrete word processing suggests that the spared representations in the right hemisphere are not sufficient to allow normal word associations for concrete words when access to low-level visual features is disrupted.

It has been suggested that some more abstract discourse-related aspects of word meaning could be processed in the right hemisphere. In the present study, the speakers with left perisylvian lesions had more problems with abstract words. A possible explanation for this could be that the right hemisphere has difficulty accessing associations to decontextualized abstract cue words. It could, however, also be the case that whereas the left hemisphere is more involved in the processing of lexical meaning, the right hemisphere is involved in association to pragmatically related aspects of word meaning which perhaps cannot be interpreted without access to information in the left hemisphere (Fortescue 2010).

Neural correlates of abstract word meaning

The fact that aphasic subjects with perisylvian lesions showed more atypical patterns of abstract word processing is in line with Fuster's (2009) assumption that the distribution of neuronal activity is more centered in frontal and temporoparietal semantic networks in higher, more abstract levels of processing. Accessing pragmatic and linguistic context (semantic frames) puts greater demands on executive and linguistic processes mediated by perisylvian brain areas. Although the test nouns elicited both categorical and contextual associations in both aphasic and control subjects, the pattern of consistently staying within an episodic memory context was only observed in the perisylvian aphasic group (Table VI, Fig. 2, Appendix 2d). The explanation for this may be that when access to general semantic frames is impaired by lesions in cortical networks important for higher-level processing, personal semantic frames can still be accessed due to their perceptual and emotional content, processed by networks in partly different areas of the brain, e.g. cortical sensory regions and emotional (subcortical) areas. Another aspect of the repeated associations to the same autobiographical context is that it may be considered as a form of perseveration behavior. It is possible that impairments in executive processing in the subjects with lesions in the perisylvian network may have made the personal contexts difficult to inhibit once they were activated. Accessing semantic frame-based word associations, rather than perceptually similar concepts, puts greater demands on selecting the contextually appropriate information and keeping it in working memory while at the same time inhibiting irrelevant information. There is neurobiological support for the idea that selection processes are mediated by anterior, e.g. prefrontal brain areas (Scheler 1999).

Hierarchical categorical relationships and abstraction: general word association patterns in brain-damaged speakers

The subjects with aphasia due to perisylvian lesions mainly produced categorically related words which were on the same, subordinate, visually detailed level as the concrete cue words, whereas the subject with aphasia resulting from an occipital lesion mainly produced categorically related associations which were on a lexically superordinate, more abstract conceptual level and were not related to any specific sensory-based semantic features. For example, several of the food items elicited the unspecific association 'food' by the speaker with occipital lesions, while the other participants' associations were words describing the type of food, its properties or other specifically associated concepts (Appendix 2e). Producing a superordinate instead of a basic level term as response to the subordinate level concrete cue words was very rare in any of the other participants, including the controls.

This contrasting pattern between subjects with perisylvian and occipital stroke aphasia is similar to findings in previous studies comparing subjects with stroke aphasia and semantic dementia (Crutch and Warrington 2008), with occipital lesions being associated with a pattern similar to that found in semantic dementia. Meaning representations dependent on an amodal semantic hub in the anterior temporal lobe have been suggested to be degraded in semantic dementia, leading to the loss of detailed semantic information, whereas executive impairments are the cause of semantic impairments in stroke aphasia (Jeffries and Lambon Ralph 2006, Patterson et al. 2007). In the present study, differences were found between speakers with different types of stroke aphasia. Given the fact that the occipital lobe processes modality-specific (visual) information and that occipital lesions are unlikely to affect executive function, the semantic impairment in occipital aphasia may be a result of a failure to access modality-specific visual meaning representations.

CONCLUSIONS

The present study presents evidence supporting lexical semantic models integrating different kinds of meaning representation. It shows how this kind of linguistic modeling can be related to a general model of information processing assuming different levels of semantic networks. The results from the word association test are consistent with the assumption that different kinds of associated semantic networks are important for the processing of concrete as compared to abstract nouns – more specifically, sensory-based, e.g. visual semantic features for concrete nouns and general semantic frames for abstract nouns. Access to, and coordination of, the more diverse meaning networks related to higher-level semantic frames is probably more dependent on executive function. When access to higher, more abstract levels of representation is hampered by anterior lesions, word processing becomes more dependent on sensory-based information, reflected in the present study as retrieval of representations of perceptually similar objects when associating to concrete nouns. In the case of abstract words, which are not clearly associated with sensory experiences, personal semantic frames based on episodic memories, which are more concrete, are accessed when abstract nouns are given as input and general semantic frames are unavailable. Conversely, damage to the visual cortex may leave higher-level conceptual levels of representation for abstract words well preserved, but cause problems accessing representations at the lower, sensory-based levels and thus impair concrete word access.

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APPENDIX 1: NOUNS

Appendix 1a: Concrete test nouns with concreteness, imageability, and familiarity values

English	Swedish	Syllables	Concreteness	Imageability	Familiarity
amplifier	förstärkare	4	564	559	474
bagpipe	säckpipa	3	601	594	397
butterfly	fjäril	2	593	624	481
camera	kamera	3	627	576	550
carnation	nejlika	3	625	611	490
cauliflower	blomkål	2	642	567	462
chocolate	choklad	2	576	611	560
clarinet	klarinett	3	633	593	464
cottage	stuga	2	593	607	543
crocodile	krokodil	3	583	601	456
cucumber	gurka	2	653	623	536
dress	klänning	2	595	595	588
emerald	smaragd	2	613	602	457
iron	järn	1	584	561	555
leopard	leopard	3	595	635	431
limousine	limousin	3	624	595	505
macaroni	makaron	3	631	608	498
milk	mjölk	1	670	638	588
oak	ek	1	588	590	515
peach	persika	3	617	613	536
revolver	revolver	3	592	629	486
silk	siden	2	538	510	482
strawberry	jordgubbe	3	610	631	539
thermometer	termometer	4	612	581	481
tortoise	sköldpadda	3	602	539	415
tweezers	pincett	2	590	619	415
window	fönster	2	609	602	621
volcano	vulkan	2	591	627	461
wolf	varg	1	595	610	537
zipper	dragkedja	3	599	632	556

Appendix 1b: Abstract test nouns with concreteness, imageability, and familiarity values

English	Swedish	Syllables	Concreteness	Imageability	Familiarity
advantage	fördel	2	282	292	562
anger	ilska	2	315	488	541
beginning	början	2	318	359	593
circumstance	omständighet	4	250	210	511
combination	kombination	4	326	326	493
conscience	samvete	3	255	386	536
crisis	kris	1	319	375	521
depression	depression	3	303	453	541
enthusiasm	entusiasm	4	266	464	506
exception	undantag	3	260	232	512
fear	rädsla	2	326	394	569
future	framtid	2	311	413	612
hatred	hat	1	239	417	544
honesty	ärlighet	3	278	386	578
hostility	fientlighet	4	277	437	472
ideal	ideal	3	253	331	521
insult	förolämpning	4	375	477	552
joy	glädje	2	300	533	545
loyalty	lojalitet	4	261	411	491
mood	humör	2	234	394	541
morale	moral	2	220	341	535
obedience	lydnad	2	238	394	500
optimism	optimism	3	240	418	500
passion	passion	2	300	467	502
prestige	prestige	2	248	394	441
reaction	reaktion	3	312	395	533
responsibility	ansvar	2	222	294	532
tendency	tendens	2	243	261	507
tradition	tradition	3	291	354	526
uncertainty	osäkerhet	4	237	283	451

APPENDIX 2: WORD ASSOCIATIONS[1]

Appendix 2a: Word associations for the concrete nouns produced by healthy participants

Concrete nouns	Participant F44 Control	Participant F58 Control	Participant F25 Control	Participant M78 Control
katt ‘cat’	mjuk ‘soft’	gosig ‘cuddly’	hund ‘dog’	lo ‘lynx’
stol ‘chair’	sitta ‘sit’	bekväm ‘comfortable’	bord ‘table’	måne ‘moon’
krokodil ‘crocodile’	farlig ‘dangerous’	farlig ‘dangerous’	krokodiljägaren ‘crocodile hunter’	varan ‘monitor lizard’
pincett ‘tweezers’	hårstrån ‘hairs’	aj! ‘ouch!’	tops ‘cotton swab’	gripverktyg ‘gripping tool’
klarinett ‘clarinet’	musik ‘music’	musik ‘music’	instrument ‘instrument’	klang ‘timbre’
jordgubbe ‘strawberry’	sommar ‘summer’	sommar ‘summer’	hallon ‘raspberry’	smultron ‘wild strawberry’
dragkedja ‘zipper’	gylf ‘fly’	varmt ‘warm’	knapp ‘button’	blixtlås ‘zipper’
makaron ‘macaroni’	NAMN (NAME)	hungrig ‘hungry’	spaghetti ‘spaghetti’	spaghetti ‘spaghetti’
fönster ‘window’	utsikt ‘view’	glas ‘glass’	dörr ‘door’	dörrar ‘doors’
sköldpadda ‘tortoise’	tant ‘old lady’	hård ‘hard’	katt ‘cat’	djur ‘animal’
persika ‘peach’	len ‘smooth’	len ‘smooth’	hallon ‘raspberry’	plommon ‘plum’
termometer ‘thermometer’	värme ‘heat’	kallt ‘cold’	grader ‘degrees’	barometer ‘barometer’
stuga ‘cottage’	mys ‘cosy’	semester ‘vacation’	hus ‘house’	villa ‘villa’
leopard ‘leopard’	mönstrad ‘patterned’	vig ‘lithe’	kattdjur ‘feline’	jaguar ‘jaguar’
blomkål ‘cauliflower’	gott ‘nice’	grönsak ‘vegetable’	grönsak ‘vegetable’	grönkål ‘borecole’
fjäril ‘butterfly’	sommar ‘summer’	sommar ‘summer’	sommar ‘summer’	dagslända ‘mayfly’
klänning ‘dress’	tyg ‘cloth’	tant ‘lady’	kjol ‘skirt’	kjol ‘skirt’
limousin ‘limousine’	dyrt ‘expensive’	bil ‘car’	bil ‘car’	bil ‘car’
smaragd ‘emerald’	grön ‘green’	ring ‘ring’	smycken ‘jewelry’	diamant ‘diamond’

[1] For anonymity reasons, associations consisting of person names are not specified in any of the following tables (2a–e). Further, words marked with * are novel constructions which do not exist in the Swedish lexicon, most frequently a semantically possible compound word.

mjölk ‘milk’	kaffe ‘coffee’	kossor ‘cows’	mejeriprodukt ‘dairy food’	vatten ‘water’
siden ‘silk’	lyxigt ‘luxurious’	tyg ‘cloth’	silke ‘silk’	silke ‘silk’
choklad ‘chocolate’	sött ‘sweet’	kakao ‘cocoa’	godis ‘candy’	kola ‘toffee’
nejlika ‘carnation’	blomma ‘flower’	blomma ‘flower’	blomma ‘flower’	tulpan ‘tulip’
revolver ‘revolver’	krig ‘war’	skjuta ‘shoot’	vapen ‘weapon’	pistol ‘gun’
järn ‘iron’	hårt ‘hard’	blodvärde ‘blood count’	material ‘material’	koppar ‘copper’
varg ‘wolf’	otäck ‘scary’	Rödluvan ‘Little Red Riding Hood’	hund ‘dog’	schäfer ‘alsatian’
säckpipa ‘bagpipe’	Skottland ‘Scotland’	Irland ‘Ireland’	Skottland ‘Scotland’	blåsinstrument ‘wind instrument’
gurka ‘cucumber’	grön ‘green’	Västerås ‘Västerås’ (Swedish pickle brand)	grön ‘green’	tomat ‘tomato’
förstärkare ‘amplifier’	ljud ‘sound’	högre ‘louder’	gitarr ‘guitar’	tratt ‘funnel’
vulkan ‘volcano’	Etna ‘Etna’	Etna ‘Etna’	bergart ‘rock type’	Etna ‘Etna’
ek ‘oak’	träd ‘tree’	träd ‘tree’	träd ‘tree’	bok ‘beech’
kamera ‘camera’	minnen ‘memories’	foto ‘photo’	fotografi ‘photograph’	bildburk ‘picturebox’

Appendix 2b: Word associations for the abstract nouns produced by healthy participants

Abstract nouns	Participant F44 Control	Participant F58 Control	Participant F25 Control	Participant M78 Control
glädje ‘joy’	kärlek ‘love’	barn ‘children’	lycka ‘joy’	sorg ‘sorrow’
tradition ‘tradition’	jul ‘Christmas’	jul ‘Christmas’	jul ‘Christmas’	följd ‘consequence’
början ‘beginning’	dagen ‘day’	start ‘start’	slut ‘end’	slutet ‘end’
ilska ‘anger’	oro ‘unease’	arg ‘angry’	raseri ‘rage’	aggression ‘aggression’
lojalitet ‘loyalty’	trogen ‘faithful’	godsint ‘kindhearted’	mod ‘courage’	gemenskapen ‘fellowship’
undantag ‘exception’	krig ‘war’	alla ‘all’	ibland ‘sometimes’	regel ‘rule’
depression ‘depression’	jag ‘me’	ledsen ‘sad’	psykofarmaka ‘psychopharmalogical drugs’	nedstämdhet ‘blues’

moral ‘morale’	etik ‘ethics’	etisk ‘ethic’	misstro ‘distrust’	etik ‘ethics’
reaktion ‘reaction’	snabbt ‘quick’	observant ‘observant’	illdåd ‘misdeed’	uppfattning ‘comprehension’
hat ‘hatred’	avsky ‘disgust’	avsky ‘disgust’	glädje ‘joy’	agg ‘grudge’
ärlighet ‘honesty’	positivt ‘positive’	trogen ‘faithful’	trogen ‘faithful’	ärlig ‘honest’
fördel ‘advantage’	bra ‘good’	förmån ‘benefit’	tårta ‘cake’	nos ‘nose’
osäkerhet ‘uncertainty’	olustigt ‘unpleasant’	tveksam ‘doubtful’	blygsam ‘modest’	vaghet ‘vagueness’
samvete ‘conscience’	rent ‘clean’	---	tankar ‘thoughts’	rent ‘clean’
kris ‘crisis’	oro ‘worry’	katastrof ‘disaster’	livskris ‘crisis of life’	osäkerhet ‘insecurity’
passion ‘passion’	kärlek ‘love’	förkärlek ‘fondness’	kärlek ‘love’	lycka ‘joy’
förolämpning ‘insult’	otrevlig ‘unpleasant’	styggt ‘naughty’	vett ‘code of conduct’	motsägelse ‘contradiction’
ideal ‘ideal’	förebild ‘role model’	förebild ‘role model’	livsmål ‘aim in life’	synpunkt ‘viewpoint’
entusiasm ‘enthusiasm’	iver ‘keenness’	---	sprallig ‘peppy’	ivrig ‘keen’
lydnad ‘obedience’	nödvändighet ‘necessary’	respekt ‘respect’	trofast ‘faithful’	respekt ‘respect’
kombination ‘combination’	möjlighet ‘possibility’	både ‘both’	lås ‘lock’	sammansättning ‘composition’
humör ‘mood’	glädje ‘joy’	glad ‘happy’	tankar ‘thoughts’	ilska ‘anger’
prestige ‘prestige’	kämpa ‘struggle’	---	vilja ‘desire’	noggrann ‘scrutinous’
omständighet ‘circumstance’	situation ‘situation’	besvärligt ‘troublesome’	---	svårighet ‘difficulty’
rädsla ‘fear’	obehag ‘unpleasantness’’	oro ‘worry’	olyckor ‘accidents’	skraj ‘harish’
ansvar ‘responsibility’	makt ‘power’	skyldighet ‘onus’	plikt ‘duty’	rädd ‘careful’
framtid ‘future’	tillförsikt ‘reassurance’	snart ‘soon’	nutid ‘present’	ålderdom ‘old age’
optimism ‘optimism’	positivt ‘positive’	glad ‘happy’	pessimism ‘pessimism’	glädje ‘joy’
fientlighet ‘hostility’	obehag ‘unpleasantness’	agg ‘grudge’	vänlighet ‘kindness’	aggression ‘aggression’
tendens ‘tendency’	förmåga ‘ability’	orsak ‘cause’	tyckas ‘seem’	tänker ‘thinks’

Appendix 2c: Word associations for the concrete nouns produced by aphasic participants

Concrete nouns	Participant 1 Anterior	Participant 2 Anterior	Participant 3 Anterior	Participant 4 Posterior
katt ‘cat’	mus ‘mouse’	hund ‘dog’	hund ‘dog’	kvinna ‘woman’
stol ‘chair’	bord ‘table’	bord ‘table’	bord ‘table’	sitta ‘sit’
krokodil ‘crocodile’	giraff ‘giraffe’	fanta* ‘elefant’	ödla ‘lizard’	trädgård ‘garden’
pincett ‘tweezers’	finne ‘pimple’	peang ‘forceps’	ögonbryn ‘eyebrow’	huvud ‘head’
klarinett ‘clarinet’	gitarr ‘guitar’	trumpet ‘trumpet’	spela ‘play’	instrument ‘instrument’
jordgubbe ‘strawberry’	mjölk ‘milk’	hallon ‘raspberry’	hallon ‘raspberry’	mat ‘food’
dragkedja ‘zipper’	knappar ‘buttons’	dragsko ‘~grommet’	jacka ‘jacket’	mage ‘belly’
makaron ‘macaroni’	pasta ‘pasta’	---	pasta ‘pasta’	efterrätt ‘dessert’
fönster ‘window’	dörr ‘door’	karm ‘frame’	putsa ‘polish’	utsikt ‘view’
sköldpadda ‘tortoise’	bur ‘cage’	våreld ‘kalanchoe flower’	hav ‘sea’	---
persika ‘peach’	frukt ‘fruit’	apelsin ‘orange’	banan ‘banana’	efterrätt ‘dessert’
termometer ‘thermometer’	Fahrenheit	feber ‘fever’	kallt ‘cold’	temperatur ‘temperature’
stuga ‘cottage’	hus ‘house’	sommarnöje ‘summer relaxation’	skog ‘forest’	boning ‘dwelling’
leopard ‘leopard’	tiger ‘tiger’	geopard[sic] ‘cheetah’	savann ‘savannah’	djur ‘animal’
blomkål ‘cauliflower’	broccoli ‘broccoli’	rosenkål ‘brussels sprout’	usch ‘yuck’	mat ‘food’
fjäril ‘butterfly’	puppa ‘pupa’	---	himmel ‘sky’	fågel ‘bird’
klänning ‘dress’	kjol ‘skirt’	kostym ‘suit’	fashion	klädnad ‘clothing’
limousin ‘limousine’	taxi ‘taxi’	bil ‘car’	New York	---
smaragd ‘emerald’	diamant ‘diamond’	---	safir ‘sapphire’	---
mjölk ‘milk’	grädde ‘cream’	smörgås ‘sandwich’	laktolmjölk [sic] ‘lactose-free milk’	dryck ‘drink’
siden ‘silk’	tyg ‘fabric’	koppar ‘copper’	Indien ‘India’	plagg ‘garment’

choklad ‘chocolate’	godis ‘candy’	kola ‘toffee’	gott ‘tasty’	mat ‘food’
nejlika ‘carnation’	blomma ‘flower’	ros ‘rose’	jul ‘Christmas’	---
revolver ‘revolver’	gevär ‘rifle’	skott ‘shot’	pistol ‘pistol’	uppskjutningsredskap* ‘~launching device’
järn ‘iron’	guld ‘gold’	koppar ‘copper’	rost ‘rust’	---
varg ‘wolf’	björn ‘bear’	räv ‘fox’	Norrland	---
säckpipa ‘bagpipe’	instrument ‘instrument’	klarinett ‘clarinet’	Skottland ‘Scotland’	blåsinstrument ‘wind instrument’
gurka ‘cucumber’	tomat ‘tomato’	tomat ‘tomato’	grön ‘green’	mat ‘food’
förstärkare ‘amplifier’	högtalare ‘loudspeaker’	radio ‘radio’	högtalare ‘loudspeaker’	höjare* ‘~increaser’
vulkan ‘volcano’	vatten ‘water’	berg ‘mountain’	Etna	---
ek ‘oak’	träd ‘tree’	björk ‘birch’	golv ‘floor’	träd
kamera ‘camera’	lins ‘lens’	foto ‘photo’	digital ‘digital’	tar bilder ‘takes pictures’

Appendix 2d: Word associations for the abstract nouns produced by aphasic participants

Abstract nouns	Participant 1 Anterior	Participant 2 Anterior	Participant 3 Anterior	Participant 4 Posterior
glädje ‘joy’	surhet* ‘~grumpyness’	sorg ‘sorrow’	glad ‘happy’	sorg ‘sorrow’
tradition ‘tradition’	kontext ‘context’	glädje ‘joy’	stenbock ‘capricorn’	sed ‘custom’
början ‘beginning’	the end	slut ‘end’	slut ‘end’	inledning ‘introduction’
ilska ‘anger’	arg ‘angry’	---	arg ‘angry’	arg ‘angry’
lojalitet ‘loyalty’	upprättelse ‘redress’	---	jag ‘me’	mycket lojal ‘very loyal’
undantag ‘exception’	expression	---	odd	bekräftelse ‘confirmation’
depression ‘depression’	meditation ‘meditation’	fönster ‘window’	MAS	sorglighet* ‘~sadness’
moral ‘morale’	etik ‘ethics’	tankeställare ‘eye-opener’	Lund	gärningsåsikt*
reaktion ‘reaction’	kontext ‘context’	sant ‘true’	stroke ‘stroke’	reagera ‘react’

hat 'hatred'	ilska 'anger'	ilska 'anger'	MAS	ilska 'anger'
ärlighet 'honesty'	människa 'person'	sant 'true'	lojal	varar längst 'lasts the longest'
fördel 'advantage'	jobb 'work'	sant 'true'	logoped 'speech therapist'	mitten 'the middle'
osäkerhet 'uncertainty'	skälvningar 'tremblings'	orädd 'unafraid'	feg 'cowardly'	jag 'me'
samvete 'conscience'	moral 'morale'	osant 'untrue'	vän 'friend'	förmåga 'ability'
kris 'crisis'	glädje 'joy'	osant 'untrue'	stress 'stress'	svårighet 'difficulty'
passion 'passion'	NAMN (NAME)	opassion* 'unpassion'	röd 'red'	önskan 'wish'
förolämpning 'insult'	mamma 'mother'	osant 'untrue'	mobba 'bully'	nedsågande*
ideal 'ideal'	NAMN (NAME)	sant 'true'	---	bästis '~best friend'
entusiasm 'enthusiasm'	together	---	NAMN (NAME)	entusiastisk 'enthusiastic'
lydnad 'obedience'	kris 'crisis'	olydnad 'disobedience'	hund 'dog'	eftergöra* '~do as someone says'
kombination 'combination'	arg och ledsen 'angry and sad'	---	dans 'dance'	samband 'relation'
humör 'mood'	ups and downs	ohumör*'unmood'	glad 'happy'	ilska 'anger'
prestige 'prestige'	inte bra 'not good'	---	bra jobb 'good work'	---
omständighet 'circumstance'	väljer 'chooses'	---	läkare 'doctor'	orsak 'cause'
rädsla 'fear'	glad 'happy'	orädd 'unafraid'	inte prata 'not to speak'	feghet 'cowardice'
ansvar 'responsibility'	föräldrarna 'the parents'	oansvarig 'irresponsible'	svara 'answer'	veta 'know'
framtid 'future'	purples?	orädd 'unafraid'	arbeta 'work'	imorgondag* '~tomorrowday'
optimism 'optimism'	glada människor 'happy people'	orädd 'unafraid'	jag 'me'	braåsikt* '~goodopinion'
fientlighet 'hostility'	mamma 'mother'	---	ovänner 'enemies'	ilska 'anger'
tendens 'tendency'	kulturen 'culture'	otendens* 'untendency'	målmedveten 'goal-oriented'	framåtskådande* '~forward looking'

Appendix 2e: Word associations triggered by food-related nouns

	jordgubbe 'strawberry'	makaron 'macaroni'	persika 'peach'	blomkål 'cauliflower'	mjölk 'milk'	choklad 'chocolate'	gurka 'cucumber'
A	grädde 'cream'	spaghetti	nektarin 'nectarine'	soppa 'soup'	kall 'cold'	sött 'sweet'	svalt 'cool'
B	hallon 'raspberry'	spaghetti	hallon 'raspberry'	grönsak 'vegetable'	mejeriprodukt 'dairy product'	godis 'candy'	grön 'green'
C	hallon 'raspberry'	pasta	frukt 'fruit'	grönsak 'vegetable'	bomull 'cotton'	gott 'tasty'	gott 'tasty'
D	smultron 'wild strawberry'	spaghetti	plommon 'plum'	grönkål vegetable'	vatten 'water'	kola 'toffee'	tomat 'tomato'
E	bär 'berry'	pasta	frukt 'fruit'	grönsak 'vegetable'	grädde 'cream'	godis 'candy'	gott 'tasty'
F	äta 'eat'	pasta	luddig 'fuzzy'	huvud 'head'	kaffe 'coffee'	dryck 'drink'	grön 'green'
G	sommar 'summer'	pasta	sharonfrukt 'persimmon'	grönsak 'vegetable'	kor 'cows'	rättvisemärkt 'fair trade'	NAMN (NAME)
H	sommar 'summer'	NAMN (NAME)	len 'smooth'	gott 'tasty'	kaffe 'coffee'	sött 'sweet'	grön 'green'
I	god 'tasty'	god 'tasty'	mjuk 'soft'	stuvning 'stew'	vitt 'white'	mörkt 'dark'	vatten 'water'
J	sommar 'summer'	pasta	luden 'hairy'	nyttigt 'healthy'	ko 'cow'	kexchoklad 'chocolate wafer'	fräscht 'fresh'
K	sommar 'summer'	hungrig 'hungry'	len 'smooth'	grönsak 'vegetable'	kossor 'cows'	kakao 'cacao'	Västerås (Swedish pickle brand)
L	gott 'tasty'	barn 'child'	lent 'smooth'	gott 'tasty'	vitt 'white'	gott 'tasty'	tsatsiki
1	mjölk 'milk'	pasta	frukt 'fruit'	broccoli	grädde 'cream'	godis 'candy'	tomat 'tomato'
2	hallon 'raspberry'	---	apelsin 'orange'	rosenkål 'brussels sprout'	smörgås 'sandwich'	kola 'toffee'	tomat 'tomato'
3	hallon 'raspberry'	pasta	banan 'banana'	usch 'yuck'	laktolmjölk [sic] 'lactose-free milk'	gott 'tasty'	grön 'green'
4	mat 'food'	efterrätt 'dessert'	efterrätt 'dessert'	mat 'food'	dryck 'drink'	mat 'food'	mat 'food'

Words without translation are the same in English as in Swedish. Associations produced by controls (A–L), anterior aphasic subjects (1–3) and the posterior aphasic subject (4). For anonymity reasons, person names are not specified.