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Patterns of dissociation in the processing of verb meanings in brain-damaged subjects

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In recent years an increasing amount of research has focused on the ways in which knowledge associated with verbs can be impaired by brain damage. Many different methods have been used to investigate verb processing disorders, but most of these methods have only been employed in a small number of studies and with relatively small numbers of subjects. As a consequence, very little information is available on the variety of disorders that are possible. In order to explore this issue further, we administered a standardised battery of six tests to a group of 89 brain-damaged subjects. The tests differ systematically with respect to the kinds of verb processing mechanisms on which they depend. The goal of the experiment was to investigate how the patterns of associations and dissociations that emerged across the tests could shed light on the organisation of the functional architecture that underlies the meanings of verbs and the computational operations that are used to manipulate them.

Of the 89 subjects, 30 were impaired on at least one of the six tests. These subjects manifested a total of 22 distinct performance profiles across the tests, and each test dissociated from all of the others. These findings suggest that each test has at least some unique processing requirements that can be independently disrupted. A statistical factor analysis indicted that several distinct factors accounted for 93% of the variance among impaired performances. These factors are interpretable in terms of the major processing similarities and differences across the tests. Some of the results from the study are consistent with previous research on verb disorders. Specifically, tests involving verb production were more difficult than tests involving verb comprehension, and tests involving linguistic stimuli were

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more difficult than tests involving pictorial stimuli. Other aspects of our results are entirely new. Most importantly, a dissociation was found between tests that require referential processing, i.e., mapping verbs onto actions in the world, and tests that require analytic or inferential processing, i.e., decomposing verb meanings into their component semantic features. Thus, the study has significant implications for theories of the nature of verb processing.

INTRODUCTION

Within the past few decades an increasing amount of research has been devoted to investigating how knowledge associated with verbs can be impaired by brain damage, and how different patterns of impairment can provide clues about the mental and neural representations of verbs in the normal cognitive system. Verb deficits have been found not only in many traditional aphasic syndromes such as Broca's and Wernicke's aphasia (e.g., Berndt, Mitchum, Haendiges, & Sandson, 1997, Kohn, Lorch, & Pearson, 1989; Williams & Canter, 1987), but also in neurodegenerative disorders such as Alzheimer's and Parkinson's disease (Grossman et al., 1994, 1996; White-Devine et al., 1996). Although the majority of studies have focused on cases in which verbs are either selectively impaired or preserved relative to nouns, a variety of different aspects of verb-specific processing have been explored, and much has been learned about subtypes of impairment within this particular category of words.

Verb production is usually evaluated by tests that require the subject to name an action shown in a picture, and verb comprehension is usually evaluated by tests that involve matching a verb with a picture in an array. Many other kinds of production and comprehension tests have also been used, however, as summarised in Table 1. This wide range of methods has led to many interesting findings, some of the most general of which are as follows. On average, brain-damaged subjects tend to have greater difficulty with production tasks than comprehension tasks. This asymmetry may be due to the fact that production tasks require deliberate activation of a pool of candidate verbs and controlled selection of the most appropriate one for the given context, whereas comprehension tasks only require recognition of one or more verbs that are explicitly provided by the experimenter. Another common finding is that subjects typically have greater difficulty with tasks involving purely linguistic stimuli than with tasks involving pictorial stimuli (although one very interesting subject has been described who exhibited the opposite pattern—Breedin, Saffran, & Coslett, 1994). A third finding is that dissociations occur between different semantic classes of verbs, roughly analogous to dissociations that have been reported between categories of nouns, such as nouns for living vs. nonliving things

TABLE 1
Types of verb tests that have been used in previous studies

Production tests

1. Naming pictures of actions (virtually all studies use this kind of test)
2. Naming videos of actions (Berndt et al., 1997)
3. Naming real actions performed by a model (Druks & Shallice, 1997)
4. Naming to definitions of verb meanings (Zingeser & Berndt, 1990; Breedin et al., 1994; Berndt et al., 1997; Marshall et al., 1998)
5. Synonym generation (Kohn et al., 1989)
6. Antonym generation (Kremin, 1994)
7. Verb category fluency, i.e., produce as many verbs as possible in 4 minutes (Kremin, 1994)
8. Sentence generation (Kohn et al., 1989; Bastiaanse, 1991)
9. Sentence completion (Zingeser & Berndt, 1988; DeRenzi & Pellegrino, 1995)
10. Story completion (Breedin et al., 1998)
11. Complex picture description (Williams & Canter, 1987; Kremin, 1994; Marshall et al., 1996)
12. Quantity of verbs produced in narrative speech (Zingeser & Berndt, 1990; Berndt et al., 1997; Breedin et al., 1998)

Comprehension tests

1. Match a verb with one of several pictures of actions (most studies use this kind of test)
2. Match a verb with one of several videos of actions (Berndt et al., 1997)
3. Match one of several verbs with a single picture of an action (White-Devine et al., 1996)
4. Determine which participant in a depicted event is performing a particular action—e.g., *giving* vs. *taking* (McCarthy & Warrington, 1985; Marshall et al., 1996)
5. Determine whether a picture shows an action denoted by a particular verb—e.g., *Is this pulling?* (Marshall et al., 1998)
6. Determine whether a definition of a verb is correct (Manning & Warrington, 1996)
7. Determine whether a sentence violates the semantic specifications of a verb—e.g., *The man drinks the cake* (Marshall et al., 1998)
8. Complete sentence with one of several verbs—e.g., *Children {enjoy, entertain, jump, shock} games* (Marshall et al., 1998)
9. Pick "odd one out" in verb triplets—e.g., *hold—release—grasp* (Breedin et al., 1994, 1998; Grossman et al., 1996)
10. Sort cards with nouns and verbs written on them into two piles, one for each category (Berndt et al., 1997

(e.g., Caramazza & Shelton, 1998; Damasio et al., 1996; Hodges & Patterson, 1997; Tranel, Damasio, & Damasio, 1997a; Tranel, Logan, Frank, & Damasio, 1997b). For example, dissociations have been identified between concrete and abstract verbs (Breedin et al., 1994; Berndt et al., 1997), between semantically complex and semantically simple verbs (Breedin, Saffran, & Schwartz, 1998; Kemmerer & Tranel, 2000a), and between reverse-role verbs (e.g., *buy* vs. *sell*) and other classes of verbs such as opposite-role (e.g., *break* vs. *fix*) and manner of motion (e.g., *walk* vs. *run*) (Breedin & Martin, 1996; Byng, 1988; Marshall, Chiat, Robson, & Pring, 1996). These results suggest that verb meanings may be organised in the brain along conceptual dimensions in a principled way. Yet another important finding is that dissociations occur between, on the one hand, knowledge of the semantic properties of verbs, such as motion features and participant roles, and on the other hand, knowledge of the syntactic properties of verbs, such as their subcategorisation frames (Breedin & Martin, 1996). These dissociations provide strong support for the representational modularity of semantic and syntactic information (Jackendoff, 1997). At the same time, however, there is evidence in the neuropsychological literature for a close interactive relationship between the semantic and syntactic properties of verbs. For instance, verb retrieval in both isolated contexts and sentence contexts is influenced by syntactic factors such as transitivity and the number of subcategorisation frames that a verb allows (Caplan & Hanna, 1998; Jonkers & Bastiaanse, 1996, 1997, 1998; Kemmerer & Tranel, 2000a; Thompson, Lange, Schneider, & Shapiro, 1998). These findings are not incompatible with representational modularity, and they fit nicely with recent "lexicalist" movements in grammatical theory which argue that the syntactic properties of verbs are largely a projection of their semantic properties.

A number of questions can be asked about the different ways in which verb meanings, and the ability to manipulate them, can be disrupted. Is it possible for action naming to be normal but for certain analytic tasks involving verb meanings to be impaired? While rare, such dissociations have been described for nouns and have been used to support theories about a fundamental distinction between referential and inferential processing (Brennen, David, Fluchaire, & Pellat, 1996; Marconi, 1997). We are not aware of any studies, however, that have reported a similar dissociation for verbs. A related question is whether good performance on a verb-picture matching test or an "odd one out" test necessarily implies that the subject's knowledge of verb meanings, or ability to process them, is completely intact. Again, we have not encountered any studies in the literature that have carefully investigated this issue.

The purpose of this paper is to describe an experiment in which a large group of brain-damaged subjects was given a battery of six tests that involve different ways of manipulating verb meanings. In two previous papers, we presented detailed analyses of the data for a subset of these subjects on just one of the tests, specifically the Naming test (Kemmerer & Tranel, 2000a, b). In this paper, our aim is to focus on the different processing requirements of the six tests in the battery. In general terms, the main goal is to explore how the patterns of associations and dissociations that emerge across the tests can shed light on the organisation of the functional architecture that underlies the meanings of verbs and the computational operations that are used to manipulate them. The structure of the paper is as follows. In the following section, we describe the tests and argue that they vary systematically in the types of processing mechanisms on which they depend. We then describe the subjects and procedures for the experiment. In the results section we present the subjects' scores on the tests and show that, according to several detailed analyses, each of the tests dissociates from the others, supporting the view that each one has at least some unique processing requirements that can be independently impaired. In addition, we report a statistical factor analysis which indicates that several distinct factors account for a total of 93% of the variance in the data. We argue that these factors can be interpreted in terms of some of the major processing similarities and differences across the tests. Finally, we conclude by summarising the main findings of the study and discussing the implications of these findings for current theories of the functional architecture that subserves the processing of verb meanings.

THE TEST BATTERY

The six tests that make up the battery were standardised by Fiez and Tranel (1997). In terms of design characteristics and processing requirements, they are organised as three pairs with each pair emphasising certain ways of manipulating verbs and their meanings. The first pair includes Naming and Verb-Picture Matching, the second includes Picture Attribute and Word Attribute, and the third includes Picture Comparison and Word Comparison. Before presenting the details of the tests, however, a digression is necessary to explain an important distinction that is relevant to the tests, namely the distinction between language-independent action concepts and language-specific verb semantic structures.

Action concepts vs. verb semantic structures

Although the nature of the relationship between word meaning and other kinds of knowledge is controversial, there are a number of reasons for supposing that they are at least partially independent levels of representation, and an especially strong case for autonomy can be made for the domain of verbs (Kemmerer, 2000; Levinson, 1997; Pinker, 1989; Rappaport Hovrav & Levin, 1998; Ruhl, 1989; Van Valin & LaPolla, 1997; Wienold, 1995). However, because a lengthy discussion of the arguments would take us too far afield, we will simply mention a few pieces of supporting evidence here.

First, a typical motion event contains a "figure" entity that moves, a "ground" entity that serves as a frame of reference, the path of motion, the manner of motion, and the cause and/or effect of motion. While all of these components may enter into our concept of any given type of motion event, only a few components are usually encoded in verb roots, and moreover there is considerable crosslinguistic variation in which components tend to be encoded (Talmy, 1985, 1991, 2000; Weinold, 1995). In some languages the main component is the manner of motion (e.g., English—*walk*, *jog*, *run*, *crawl*, *sneak*, etc.); in other languages it is the path (e.g., Spanish—*entrar* ''move-in'', *salir* ''move-out'', *subir* ''move-up'', *bajar* ''move-down'', *cruzar* ''move-across'', etc.); and in still other languages it is the figure (e.g., Atsugewi—*lup* ''for a small shiny spherical object, such as an eyeball or a hailstone, to move or be located'', *caq* ''for a slimy lumpish object, such as a toad or a cow dropping, to move or be located'', *swal* ''for a limp linear object suspended by one end, such as a shirt on a clothesline or a hanging dead rabbit, to move or be located'', *qput* ''for loosed dry dirt to move or be located'', etc.). Thus, verbs in different languages ''package'' action concepts in different ways for purposes of communication, and as a consequence speakers must engage in a form of ''thinking for speaking'' by translating the contents of their conceptualisations into language-specific semantic structures (Slobin, 1996; Tomasello, 1999).

Second, we are able to take many different perspectives on a particular type of action because our conceptual abilities are quite flexible; however, many verb semantic structures are limited to only one perspective. For example, if you see a man spilling a glass of beer on his pants, you can construe the beer as the main affected entity since it changes location, or you can construe the pants as the main affected entity since they change state. But if you want to talk about the event, the semantic structure of the verb *spill* forces you to focus on the beer as the main affected entity. This is why the sentence *Sam spilled beer on his pants* is well-formed but the sentence **Sam spilled his pants with beer* is ill-formed (Gropen, Pinker, Hollander, & Goldberg, 1991; Kemmerer, 2000; Pinker, 1989).

Third, many action concepts probably include a large amount of frequency-based context-dependent information about features that typically co-occur, whereas many verb semantic structures seem to be organised around a fairly restricted set of schematic, context-neutral features that are obligatory. For instance, it is likely that the average person's concept of breaking includes the knowledge that breaking often involves motion followed by contact, as when one breaks a glass by accidentally knocking it off a table. But the semantic structure of the verb *break* does not have to specify anything at all about motion; instead, *break* is a pure change-of-state verb which only requires that an object loses its structural integrity. This is why a man can break a bicycle by riding it when he's too heavy for it. Recent research has revealed that ''action verbs'' may not even constitute a linguistically natural class, since verbs that are as cognitively similar as *break*, *cut*, *hit*, and *touch* actually belong to distinct semantic subclasses (Levin, 1993; Pinker, 1989).

Although the points just mentioned are not elaborated in much detail, we will assume that for the purposes of this paper they are sufficient to motivate the view that action concepts and verb semantic structures are partially distinct kinds of mental representations. We will make the following additional assumptions. Understanding what kind of action is shown in a picture may depend on activating the relevant action concept. Furthermore, action concepts of varying degrees of complexity are used for reasoning and behavioural planning. Verb production typically involves mapping an action concept onto a language-specific verb semantic structure and then accessing the verb's phonological or orthographic form in the appropriate output lexicon. This mapping from action concepts and semantic structures to verb-forms may not be implemented by direct connection but may instead be mediated by a "third-party" interface mechanism for relating the different types of knowledge (Damasio et al., 1996; Tranel, Damasio, & Damasio, 1997c). Based on convergent data from lesion studies and functional neuroimaging studies, Damasio et al. (1996) have argued that such a mediation system exists in regard to knowledge for concrete entities and the pertinent nouns, and it is reasonable to postulate that a similar mechanism exists for other parts of speech as well. Verb comprehension consists of the reverse processing sequence: the phonological or orthographic input representation of a verb is mapped onto the verb's semantic structure, and it is probably the case that activation of the semantic structure usually leads to activation of multiple features of one or more corresponding action concepts (again, via a third-party mediary mechanism). To take a straightforward example, when one hears the sentence *Sam filled the glass with water*, the semantic structure of *fill* is activated. This semantic structure specifies only that a container changes state from not being full to being full, and in fact the compositional semantic structure of the whole sentence is so schematic that it is compatible with a very wide range of glass-filling scenarios, including relatively uncommon events like dipping a glass in a tub of water or leaving it out in a rainstorm. It is likely, however, that on hearing the sentence in isolation (that is, without a biasing context), the average person constructs a mental model of a fairly standard glass-filling scenario, such as holding a glass under a tap of running water or pouring water from a jug or pitcher into a glass (Levinson, 1995, 2000; Pinker, 1989). Because verb semantic structures and action concepts are often very closely related in this manner, it seems appropriate to use the cover term "verb meaning" to refer to all of the information—semantic and conceptual—that is activated when a verb is processed. In what follows, we will use the term in that sense and will distinguish between semantic and conceptual structures when it is necessary to do so.

Naming and Verb-Picture Matching

Some of the major processing requirements of the six tests in the battery are shown in Table 2, and we will make reference to this table as we describe the characteristics of the tests. The first two tests—Naming and Verb-Picture Matching—are related because they both involve referential processing; more precisely, they both require that the subject use verbs to label real-world actions depicted in photographs. They differ, however, in several important ways.

In the Naming test, the subject is presented with 100 colour photographs of various actions, each of which is intended to elicit a specific verb or else one of a small set of verbs that are all considered to be acceptable responses based on control data (Fiez & Tranel, 1997); the target verbs are listed in Appendix A. The first 75 items are single pictures that show ongoing activities; they are meant to elicit verbs in the imperfective aspect (expressed by the suffix *-ing*). In contrast, the last 25 items are picture pairs that show the initial and final states of causative events; they are meant to elicit verbs in the perfective aspect (expressed by either the regular past tense suffix *-ed* or by an irregular past tense form). Because a great deal of information about the test items is provided in the original article (Fiez &

TABLE 2
Putative processing requirements for the six tests

Processing requirements	*N*	*M*	*PA*	*WA*	*PC*	*WC*
Stimulus processing						
pictures	x	x	x		x	
verbs		x		x		x
Mapping between pictures and verbs (i.e., referential processing)						
Map action concept (from picture) onto "best" verb semantic structure	x				x	
Map verb semantic structure onto one of two action concepts (from pictures)		x				
Analysing internal structures of, and relations between, verb meanings (i.e., inferential processing)						
Just action concepts			x			
Action concepts and verb semantic structures				x	x	x
Single prescribed attribute			x	x		
Multiple unspecified attributes					x	x
Retrieve the forms of verbs in the phonological output lexicon	x				x?	
Generate mental images of typical action scenarios based on semantic structures				x		x

Abbreviations: N, Naming; M, Matching; PA, Picture attribute; WA, Word attribute; PC, Picture comparison; WC, Word comparison.

Tranel, 1997) and by Kemmerer and Tranel (2000a), we will not reiterate those points here. As indicated in Table 2, the Naming test requires visual processing of the pictorial stimuli; this involves not only forming a low-level visual representation of each picture, but also recognising the objects that are present and inferring what kind of action is taking place, i.e., activating the most appropriate action concept. Once an action concept has been activated, the language-specific verb semantic structure that has the closest ‘‘fit’’ with the concept is selected, perhaps through some form of optimisation process. This semantic structure is then mapped onto the corresponding phonological or orthographic output form by means of a third-party mechanism, as alluded to earlier (see Gordon, 1997, and Levelt, Roelofs, & Mayer 1999, for detailed functional models of picture naming).

In the Verb-Picture Matching test, the subject is shown two colour photographs of actions, and above the photographs is a written verb. The task is to determine which action the verb describes. There are 69 items (listed in Appendix B). The first 43 items contain individual photographs of ongoing activities, and the last 26 contain pairs of photographs for causative events, just as in the Naming test. Like the Naming test, this one requires visual processing of pictorial stimuli; however, it is important to note that while the Naming test only has one picture (or picture pair) per item, the Matching test has two, so the visual processing demands are slightly greater for the latter test. Another difference between the two tests is that Matching does not require the subject to search for a verb semantic structure or voluntarily retrieve a phonological output form; instead, it is only necessary to activate the semantic structure of the single verb that is explicitly provided. In this regard, the Matching test has fewer effortful processing requirements than the Naming test, and as we pointed out above, this may be one reason why previous studies have found that brain-damaged subjects generally perform better on comprehension tests like Matching than on production tests like Naming. Last of all, as shown in Table 2, the nature of the referential mapping between pictures and verbs may be somewhat different for the two tests. For Naming it seems that the direction of mapping is primarily from the picture—or, more precisely, the action concept derived from it—to candidate verb semantic structures, whereas for Matching the mapping may be more bidirectional since the subject may be more likely to engage in back-and-forth comparisons between the single verb semantic structure and the action concepts for the two pictures.

Picture attribute and Word attribute

The next two tests—Picture attribute and Word attribute—are similar in so far as both emphasise a certain kind of analytic or inferential processing, specifically the ability to compare the values of two verb meanings for a particular predetermined attribute. Tests that address attribute knowledge have been used in research on how the meanings of concrete nouns can be impaired by brain damage (Bayles, Tomoeda, & Trosset, 1990; Caramazza & Shelton, 1998; Damasio, Damasio, Tranel, & Brandt, 1990; Goodglass & Baker, 1976; Martin & Fedio, 1983; McCarthy & Warrington, 1985; Tranel et al., 1997b, c; Warrington, 1975). However, we are not aware of any studies that have used this type of test to investigate impairments of verb meanings.

In the Picture attribute test, the subject is show two colour photographs of actions and is asked a question about which action satisfies a specific value for a single attribute—e.g., which makes the loudest sound, which requires a tool, etc. (note that some attributes are scalar and others are categorical). The test contains 72 items, 48 of which have individual pictures of ongoing actions, and 24 of which have picture pairs for causative actions (the items and attributes are listed in Appendix C). As with the Naming and Verb-Picture matching tests, this test requires visual processing of the pictorial stimuli, including activation of the appropriate action concepts. The main task of answering the attribute questions involves the following: decomposing the internal structure of each action concept, identifying the attribute at issue, determining its value, comparing the values for the different concepts, and making a decision about which one fulfils the target criterion. It is especially noteworthy that this is the only test in the battery that does not necessarily require the processing of verb forms or even verb semantic structures: all that is needed is the processing of action concepts. Nevertheless, it is quite likely that normal subjects do in fact make use of verbs when they perform the test, if only because using language is a natural, reflexive thing to do and can facilitate performance.

The Word attribute test is parallel in design to the Picture attribute test, the only difference being that the stimuli are verbs instead of pictures. There are 62 items, 40 with verbs denoting ongoing actions and 22 with verbs denoting causative actions (the items and attributes are listed in Appendix D). The fact that the stimuli are verbs instead of pictures is significant for several reasons. Each verb-form must be mapped onto the appropriate verb-specific semantic structure (by means of a third-party mediation system), and we assume that it is through these semantic representations that action concepts are accessed during verb comprehension. In addition, in order to answer the attribute questions for many of the items, the subject may have to evoke visual, auditory, or motor images of typical action scenarios and then inspect the images to determine the values of the relevant attributes. Consider, for example, the very first test item in which the two verbs are *singing* and *yawning* and the question is which action makes the loudest sound. Although the correct answer is clearly *singing*, this is due to our general conceptual knowledge about the standard ways in which the two actions are performed; it is not due to the semantic structures of the verbs since it is obviously possible for someone to sing very softly or yawn very loudly. Because of this, determining the correct answer to the question may require that the subject imagine how the actions of singing and yawning are typically performed and how they typically look and sound (Levinson, 1995, in press). The standard (i.e., most frequent) attribute values are then made explicit (as opposed to being implicitly represented in abstract propositional format) and can be directly ''read off'' the mental images and compared (Kosslyn, 1994). The notion that controlled imagery may be necessary for many of the items in the Word attribute test implies that this test may be more difficult than the Picture attribute test. This is also consistent with the common finding from previous studies that, as mentioned above, verb processing tasks that involve purely linguistic stimuli are usually harder than those that involve pictorial stimuli.

Picture comparison and Word comparison

The last two tests—Picture comparison and Word comparison—are similar to the previous two tests in that they emphasise analytic or inferential processing, but they are unique in the specific nature of these processing requirements. In particular, for both of these tests the subject must compare three verb meanings and identify the one that is unrelated to the other two; moreover, the relevant criteria for comparison are not provided by the experimenter but must be discovered by the subject. This kind of ''odd man out'' paradigm has been employed in a few previous studies of verb processing deficits in brain-damaged subjects, but only with verbs as stimuli, never with just pictures (Breedin, Saffran, & Coslett, 1994; Breedin, Saffran, & Schwartz, 1998; Grossman, Mickanin, Onishi, & Hughes, 1996).

The Picture comparison test has 24 items, and each item consists of three individual photographs of ongoing actions (the items are described in Appendix E). The subject's task, as alluded to above, is to say which picture shows a type of action that is somehow different from the other two. Because there are three pictures, the visual processing demands are substantial. In addition, although verb forms and verb semantic structures are not an explicit part of either the stimuli or the subject's responses, many of the items in the test still reflect the idiosyncrasies of English verbs. This is because what counts as the correct answer often depends on the fact that two different kinds of actions just happen to be treated as belonging to the same semantic category by the English verb system, whereas a third kind of action is treated as belonging to a separate category. For example, in item 14 the three main pictures show (i) a person holding a baby, (ii) a baby crawling, and (iii) two people holding hands. The "odd one out" is the second picture, but this may only be clear from the perspective of English. Some languages (e.g., Spanish) do not conventionally apply the same verb to the first and third pictures, so speakers of these languages may not view these pictures as illustrating similar kinds of actions. As we pointed out above, there are other languages (e.g., Atsugewi and Tzeltal) in which the main component of verb semantic structures is information about the physical properties of the "figure" entity, and there are still other languages (e.g., Kalam and Yimas) that have very small inventories of as few as 100 verb roots and that employ verb serialisation constructions to express specific events (Foley, 1986; Lefebvre, 1991). Although we do not have any evidence about how speakers of these seemingly exotic languages would perform on the Picture comparison test, it is reasonable to suppose that they would have significant trouble with many of the items simply because they do not know the appropriate English verb forms and semantic structures. These considerations lead us to suppose that, as in the Naming test, the Picture comparison test requires the subject to not only activate the appropriate action concept for each picture but also map it onto the "best" verb semantic structure; also, it is likely that normal subjects generally proceed a step further and covertly retrieve the phonological form of the verb (see Table 2). The Picture comparison test may, however, be more difficult than either the Naming test or the Picture attribute test, for the following reasons. First, it is necessary to correctly process three pictures instead of just one; and second, it is necessary to carry out the computational operations involved in identifying the relevant features for comparison and making a final decision about how to sort the pictures.

The Word comparison test is parallel in design to the Picture comparison test, except the stimuli for each item consist of three verbs instead of three pictures. Altogether there are 44 items (described in Appendix F). The subject's task is to determine which verb is somehow different in meaning from the other two. In each item, the two associated verbs have one of four types of semantic relation: synonymy (e.g., *yell* and *shout*); antonymy (e.g., *lengthen* and *shorten*); hyponymy (e.g., *talk* and *lecture*); and cohyponymy (e.g. *bow* and *curtsey*). Some researchers have argued that these types of relations play an important role in the organisation of the associative networks for verbs (Cruse, 1986; Fellbaum, 1998). Thus, the test places a greater emphasis on analytic or inferential processing than on referential processing. Still, for many of the items in the test, it is likely that in order to identify the appropriate relational dimension for grouping the verbs, the subject must activate not only the verb-specific semantic structures but also the more general action concepts, perhaps by means of controlled imagery, as we hypothesised for the Word attribute test. This is because concrete images of particular action scenarios may facilitate recognition of the features that are most relevant to the comparison process. One might think that because the Word comparison test involves purely linguistic stimuli and may require controlled imagery for some items, it is harder than the Picture comparison test. However, the fact that the Picture comparison test probably has several requirements similar to the Naming test increases its difficulty considerably, as pointed out above. Hence it is not possible to make a strong prediction about which of the two Comparison tests is more challenging.

METHOD

Subjects

Eighty-nine brain-damaged subjects were selected from the Patient Registry of the University of Iowa's Division of Cognitive Neuroscience. All subjects gave informed consent in accordance with the Human Subjects Committee of the University of Iowa. The subjects' lesions varied across the frontal, parietal, temporal, and occipital lobes of the left and right cerebral hemispheres, and some lesions also included subcortical structures. Sixty subjects had left-hemisphere damage, twenty-one had right-hemisphere damage, and eight had bilateral damage. Before taking the battery of verb tests, all subjects had undergone extensive neuropsychological and neuroanatomical investigation according to the standard protocols of the Benton Neuropsychology Laboratory (Tranel, 1996) and the Laboratory of Neuroimaging and Human Neuroanatomy (Damasio, 1995; Damasio & Damasio, 1989). Subjects were tested in the chronic phase of recovery, i.e., three or more months after the onset of the brain damage. Demographic characteristics of the subjects were as follows: mean age = 53.3 years ($sd = 15.9$); mean education = 12.6 years ($sd = 2.8$); 55 subjects were male and 34 female; and 85 subjects were right-handed and 4 left-handed, as measured by the Geschwind-Oldfield Questionnaire.

Procedure

The subjects were tested individually in a quiet examination room in the Department of Neurology at the University of Iowa. Details about the manner in which the Naming test was administered are described in detail by Kemmerer and Tranel (2000a). For present purposes, it is sufficient to note that the subjects were instructed to name each picture or picture pair with a single verb that best characterises the action. They were told that only verbs should be used and that other kinds of words and phrases should be avoided. They were also told to include the proper inflection on all verbs. The predetermined target verbs were based on control data (see Fiez & Tranel, 1997). For the Verb-Picture matching, Picture attribute, and Picture comparison tests, the visual stimuli were presented in specially constructed books in such a way that the subjects could easily see all of the photographs for a single test item without having to turn any pages. For the Word attribute and Word comparison tests, separate books were used in which the verbs (and the attribute question) for each test item were presented on a single page. For the three tests in which verbs were overtly presented to the subjects (i.e., Verb-Picture matching, Word attribute, and Word comparison), the verbs were both shown to the subjects in written form and read aloud by the experimenter. Several practice items were included at the beginning of all of the tests to familiarise the subject with the materials and the task. The tests were administered in the following order for all subjects: (1) Naming, (2) Picture comparison, (3) Picture attribute, (4) Verb-Picture matching, (5) Word comparison, (6) Word attribute. Responses were recorded in writing.

Scoring was based on the control data collected by Fiez and Tranel (1997). The percent correct on each test was computed for all of the subjects, and z-scores were generated by comparing a subject's performance with the mean percent correct of the control subjects examined by Fiez and Tranel (1997). For each test, subjects with z-scores two or more standard deviations below normal were classified as impaired, and all other subjects were considered to fall within normal limits and will therefore be referred to as unimpaired.

RESULTS

The results for the experiment are reported in two separate subsections. We first present the main body of data from the experiment and then describe in detail some of the most obvious patterns of association and dissociation that emerged across the tests. We then take a broader perspective by reporting a statistical factor analysis that revealed some of the less obvious patterns in the data.

Descriptive analysis

Of the 89 subjects who participated in the experiment, 30 were impaired on one or more of the tests. The percent correct and z-scores for these subjects on all six tests are shown in Table 3. Of these subjects, 24 had left-hemisphere lesions, 4 had right-hemisphere lesions (1699DB, 1362RM, 1575JG, and 1103HP), and 2 had bilateral lesions (1951RH and 1879DS).

TABLE 3
Percent correct and *z*-scores for all subjects who were impaired on one or more tests (below-normal scores are in bold).

	Naming		*Matching*		*P-attribute*		*W-attribute*		*P-comparison*		*W-comparison*	
Subject	%	*z*	%	*z*	%	*z*	%	*z*	%	*z*	%	*z*
1172JP	**33**	**−10.4**	**72**	**−4.3**	**82**	**−2.0**	**79**	**−4.4**	**25**	**−7.1**	**59**	**−3.4**
1699DB	**64**	**−4.2**	**68**	**−5.2**	**71**	**−4.3**	**74**	**−5.7**	**33**	**−6.1**	**52**	**−4.3**
1709EH	**9**	**−5.6**	**65**	**−5.8**	**67**	**−5.2**	**58**	**−10.2**	**46**	**−4.6**	**39**	**−6.1**
1808VK	**57**	**−5.6**	**78**	**−3.0**	**78**	**−2.9**	**77**	**−4.8**	**21**	**−7.6**	**64**	**−2.9**
868RS	**40**	**−9.0**	90	−0.5	**75**	**−3.5**	**76**	**−5.3**	**58**	**−3.0**	**57**	**−3.7**
1232CH	**56**	**−5.8**	**81**	**−2.4**	**69**	**−4.6**	**85**	**−2.6**	75	−1.0	**70**	**−2.0**
615NJ	**66**	**−3.8**	88	−0.8	**82**	**−2.0**	**87**	**−2.1**	75	−1.0	**61**	**−3.1**
1076GS	**31**	**−10.8**	**83**	**−2.1**	83	−1.7	**66**	**−8.0**	88	0.5	**66**	**−2.6**
1362RM	87	0.4	**80**	**−2.7**	88	−0.9	**47**	**−13.3**	**42**	**−5.1**	**39**	**−6.1**
1575JG	**59**	**−5.2**	**81**	**−2.4**	83	−1.7	**85**	**−2.6**	**33**	**−6.1**	80	−0.8
1726RO	**62**	**−4.6**	97	1.1	88	−0.9	**87**	**−2.1**	**46**	**−4.6**	**70**	**−2.0**
983DR	**56**	**−5.8**	86	−1.4	**81**	**−2.3**	89	−1.7	**58**	**−3.0**	73	−1.7
1359AS	**14**	**−14.2**	91	−0.2	**74**	**−3.8**	89	−1.7	**63**	**−2.5**	75	−1.4
1247HW	**53**	**−6.4**	**81**	**−2.4**	**75**	**−3.5**	92	−0.8	75	−1.0	82	−0.5
1033AN	**59**	**−5.2**	87	−1.1	89	−0.6	**84**	**−3.0**	92	1.0	**66**	**−2.6**
1599EM	**75**	**−2.0**	96	0.8	92	0.0	**84**	**−3.0**	**50**	**−4.0**	75	−1.4
1852MV	**43**	**−8.4**	99	1.4	93	0.3	94	−0.3	**50**	**−4.0**	**66**	**−2.6**
1962RR	**22**	**−12.6**	99	1.4	89	−0.6	94	−0.3	**58**	**−3.0**	**64**	**−2.9**
1312BM	**73**	**−2.4**	96	0.8	**81**	**−2.3**	95	0.1	83	0.0	89	0.4
1103HP	**73**	**−2.4**	91	−0.2	85	−1.5	90	−1.2	**67**	**−2.0**	91	0.7
513MB	**48**	**−7.4**	87	−1.1	86	−1.2	92	−0.8	75	−1.0	**66**	**−2.6**
1504DK	96	2.2	84	−1.7	94	0.6	**87**	**−2.1**	**63**	**−2.5**	77	−1.1
1951RH	87	0.4	97	1.1	92	0.0	**87**	**−2.1**	**67**	**−2.0**	80	−0.8
468JG	80	−1.0	93	0.1	88	−0.9	89	−1.7	**54**	**−3.5**	**55**	**−4.0**
414DM	81	−0.8	94	0.5	83	−1.7	**85**	**−2.6**	71	−1.5	77	−1.1
1584JR	85	0.0	100	1.7	97	1.2	95	0.1	**67**	**−2.0**	82	−0.5
1733RK	77	−1.6	99	1.4	96	0.9	95	0.1	**58**	**−3.0**	77	−1.1
1879DS	**59**	**−5.2**	93	0.1	90	−0.3	90	−1.2	83	0.0	80	−0.8
1379MH	**72**	**−2.6**	99	1.4	96	0.9	95	0.1	96	1.5	95	1.3
1470KB	**70**	**−3.0**	99	1.4	92	0.0	92	−0.8	96	1.5	89	0.4
No. impaired	23 subjects		9 subjects		11 subjects		16 subjects		19 subjects		15 subjects	

Further details about the neural correlates of different performance profiles are not reported here, because this study is explicitly aimed at the cognitive level rather than at the level of brain–behaviour relationships. However, the lesion data are the focus of other studies currently in preparation.

The order in which the subjects are listed in Table 3 reflects the number of tests on which they performed significantly below normal. The first four subjects—1172JP, 1699DB, 1709EH, and 1808VK—were impaired on every test. The next two—868RS and 1232CH—were impaired on five of the six tests. Five subjects—615NJ, 1076GS, 1362RM, 1575JG, and 1726RO—failed four tests. Seven subjects—983DR, 1359AS, 1247HW, 1033AN, 1599EM, 1852MV, and 1962RR—failed three tests. Six subjects—1312BM, 1103HP, 513MB, 1504DK, 1951RH, and 468JG—failed two tests. And finally, six subjects—414DM, 1584JR, 1733RK, 1879DS, 1379MH, and 1470KB—failed only one test. The fact that there is a fairly even distribution of subjects along the dimension of "number of tests failed" constitutes the first piece of evidence from this set of data suggesting that brain damage can lead to different types, or different degrees, of impairment in manipulating verbs and their meanings.

Several interesting patterns emerged from an investigation of the number of subjects who passed or failed the two tests making up each pair. Looking first at the Naming and Verb-Picture matching tests, a total of 23 subjects performed significantly below normal on the former, whereas only nine subjects did so on the latter. In fact, this is the largest group-level performance difference between any two tests in the battery; in other words, no test had more impaired subjects than Naming, and no test had fewer impaired subjects than Matching. There were associations as well as double dissociations for the Naming and Matching tests: eight subjects failed both, fifteen failed Naming but were unimpaired on Matching, and one (1362RM) performed well on Naming but was defective for Matching. Taken together, these findings suggest that the Naming test is more challenging than the Matching test, but that the Matching test may still have at least some unique processing requirements that can be disrupted independently of those needed for the Naming test.

Turning now to the Picture attribute and Word attribute tests, Table 3 indicates that fewer subjects were impaired on the former ($N = 11$) than on the latter ($N = 16$), although the difference is not great. Nevertheless, associations as well as double dissociations were found for the two Attribute tests: seven subjects failed both, four were impaired on Picture attribute but unimpaired on Word attribute, and nine were unimpaired on Picture attribute but impaired on Word attribute. These results provide evidence that each test has processing requirements that are not shared by the other.

As for the Picture comparison and Word comparison tests, more subjects performed poorly on the former ($N = 19$) than on the latter ($N = 15$), but again the difference was not great. It is worth noting, however, that the Picture comparison test turned out to be the second most difficult test in the battery, superseded only by the Naming test.[1] Just like the other pairs of tests, there were associations as well as double dissociations for the two Comparison tests: ten subjects failed both, nine were impaired on Picture comparison but unimpaired on Word comparison, and five were unimpaired on Picture comparison but impaired on Word comparison. These patterns suggest that the two tests have different processing requirements that can be independently affected by brain damage.

Another way of analysing the data in Table 3 is by focusing on variation in the specific performance profiles exhibited by subjects across all six tests. Overall, if we include the profile of normal performance on every test (i.e., the profile displayed by the 59 subjects not reported in Table 3), there were a total of 22 distinct profiles of passed vs. failed tests. We pointed out above that double dissociations emerged for every pair of tests. Even more striking is that, as a careful inspection of Table 3 reveals, each test in the battery dissociates from *all* of the others in at least a few individual subjects or combinations of subjects. The easiest way to see this is by starting at the bottom of the table where subjects are presented who were only defective for one test, and then working up towards the top of the table where subjects have more severe impairments. The Naming test was selectively failed by the last three subjects—1470KB, 1379MH, and 1879DS. The Picture comparison test was selectively failed by the next two subjects—1733RK and 1584JR. The Word attribute test was selectively failed by the subject after them—414DM. The Word comparison test was failed relative to the Naming, Matching, Picture attribute, and Word attribute tests by 468JG, and it was failed relative to the Picture comparison test by 513MB. The Matching test was failed relative to the Word attribute, Picture comparison, and Word comparison tests by 1247HW, and it was failed relative to the Naming and Picture attribute tests by 1362RM. Finally, the Picture attribute test was failed relative to the Matching, Word attribute, Picture comparison, and Word comparison tests by 1312BM, but it was not failed relative to the Naming test by any subjects; nevertheless, there are a large number of subjects who passed the Picture attribute test but failed the Naming test, so the two tests still dissociate from each other. The finding that all six tests in the battery dissociate from each other is quite remarkable and constitutes evidence

[1] This hierarchy of difficulty is similar to the data for control subjects, since Fiez and Tranel (1997) found that the two most challenging tests for their subjects were Naming (mean = 85% correct) and Picture comparison (mean = 82% correct). The other tests all had means of nearly 90% correct.

that each one has at least some unique processing requirements that can be independently disrupted.

Factor analysis

The fact that 22 distinct profiles of passed vs. failed tests are present in the data suggests that the ability to manipulate verbs and their meanings can be impaired in many very specific ways. However, it is not clear to what extent each of these profiles is reliable or interpretable. For this reason, we chose to step back from the details and take a broader perspective on the data. In order to determine whether the wide range of performances across the six tests can be explained in terms of a relatively small number of underlying cognitive deficits, a *post hoc* statistical factor analysis was conducted. Factor analysis can reveal statistically derived factors that may account for significant covariance in impairment across the six tests. Given the finding that the Naming test was clearly the most difficult test in the battery, we expected that one factor would reflect defective ability to retrieve verbs from the lexicon. Based on the distribution of processing requirements listed in Table 2, we also hypothesised that factors might reflect the distinction between processing visual vs. purely linguistic stimuli, and the distinction between referential and inferential processing of verb meanings.

Principal components factor analysis was performed using SPSS for Windows 7.5 software (SPSS Inc., 1997) on the data for the 30 subjects who failed at least one of the tests. Because we were interested in the covariance of *impairment* among the tests and not covariance in *abilities*, we were concerned not with the variance from scores falling within the normal range, only with the fact that these scores were not indicative of impairment. To remove the variance coming from normal performances from the analysis, the distribution of z-scores on each test was truncated at -1.0. That is, all subjects whose score on a specific test was at or higher than one standard deviation below the mean for normal controls were assigned the score of -1.0 for that test. Although this manipulation assigns someone whose performance was excellent the same score as someone whose performance was one standard deviation below the normal mean, the effect is that the factor analysis will yield factors accounting for variance specifically in weak or impaired performances, relatively uninfluenced by factors associated with competence.

The number of factors to be extracted is a complex issue that depends to some extent on the purpose of the analysis. Given the exploratory nature of this analysis, we decided to examine all factors with eigenvalues greater than 0.5. This lenient criterion was selected to reveal a more complete description of the pattern of covariance among impaired or weak test

TABLE 4
Principal components analysis of deficient performances among 30 brain-damaged subjects with impairment on at least one test

Factor	*Eigenvalue*	*% Variance*
I	3.13	52.2
II	1.14	18.9
III	0.72	12.0
IV	0.65	10.9

performances. Extracted factors then underwent oblique rotation to permit correlations among factors if dictated by the data. This may result in particularly meaningful factors because oblique rotation may yield factors which more closely reflect natural factors than orthogonal rotation

TABLE 5
Component correlation matrix after oblique rotation

	I	II	III	IV
I	–	–	–	–
II	.05	–	–	–
III	–.44	–.24	–	–
IV	–.50	–.04	.28	–

procedures. However, we hasten to add that the meaningfulness of resultant factors will be judged in part by their interpretability and, ultimately, by empirical validation.

Principal components analysis yielded four factors with eigenvalues greater than 0.5 (see Tables 4–6). Factor I accounted for 52.2% of the variance in deficient test performances, with an eigenvalue of 3.1. Loading

TABLE 6
Structure matrix showing the correlations between tests and factors following oblique rotation

Test	Factor I	Factor II	Factor III	Factor IV
Naming	.10	.99	–.28	–.09
Verb-Picture matching	.69	.06	–.80	–.67
Picture attribute	.35	.31	–.97	–.18
Word attribute	.95	–.02	–.42	–.45
Picture comparison	.48	.07	–.25	–.99
Word comparison	.94	.14	–.40	–.49

most highly on this factor were the Word attribute, Word comparison, and Verb-Picture matching tests, which were correlated .95, .94, and .69, respectively, with Factor I. What distinguishes these tests from the other three is that they involve linguistic stimuli, and for this reason we will refer to the factor as the ‘‘Linguistic Stimuli’’ factor.

A specific processing requirement that all three tests have in common is accessing verb-specific semantic structures from orthographic or phonological forms. Thus it is plausible that the factor reflects a disturbance of this operation. This factor might also reflect the operation of voluntarily generating mental images of actions, since this operation may be important for the two tests that loaded most highly on this factor—Word attribute and Word comparison.

Factor II accounted for an additional 18.9% of variance in deficient test performances, with an eigenvalue of 1.1. The only test loading on this factor was Naming, which was correlated .99 with the factor. This factor may reflect a disruption of the ability to retrieve or produce the phonological forms of specific verbs in order to name pictures or actions. Hence we will refer to it as the ‘‘Naming’’ factor.

The interpretation of Factors III and IV may benefit from considering the two factors together. Factors III and IV, respectively, accounted for an additional 12% and 11% of variance, with eigenvalues of 0.72 and 0.65. Loading most highly on Factor III were the Picture attribute and Verb-Picture matching tests, which were correlated .97 and .80, respectively, with this factor. Loading most highly on Factor IV were the Picture comparison and Verb-Picture matching tests, which were correlated .99 and .67, respectively, with this factor. All of the tests associated with these two factors require the processing of pictorial stimuli, so for the sake of convenience we will refer to the two factors jointly as the ‘‘Pictorial Stimuli’’ factors.[2] Because the Verb-Picture matching test was highly correlated with both factors, the critical difference between them presumably concerns the nature of the inferential tasks required by the Picture attribute and Picture comparison tests. The Picture attribute test might be construed as a more straightforward recognition-type task in that successful activation of the appropriate action concepts by the pictures should lead rather directly to identification of which action stereotypically satisfies the target value of the presented attribute. In contrast, on the Picture comparison tests, given successful activation of the appropriate action concepts by the pictures, the subject then faces a complex problem-solving task of determining which among the countless aspects of the three

[2] Although this label would, in principle, apply also to the Naming test, we intend it to only refer to the Picture Attribute, Picture Comparison, and Matching tests, and especially to the first two since they loaded most highly on factors III and IV, respectively.

depicted actions is the essential dimension for judging similarity. This difference between the cognitive demands of the Picture attribute and Picture comparison tests does not explain why the Verb-Picture matching test should be so highly correlated with Factor IV. Furthermore, the fact that Factors III and IV have eigenvalues below the conventional 1.0 criterion suggests that they may not be robust factors. Nevertheless, the fact that the Picture attribute and Picture comparison tests dissociated in their factor loadings (with a negligible .28 correlation between Factors III and IV) clearly suggests that some aspects of the processing requirements of the two tests are associated with distinctive patterns of impairment in manipulating verb meanings.

DISCUSSION

A common finding is that brain-damaged subjects often perform worse on verb production tasks like naming pictures of actions than on verb comprehension tasks like matching a verb with one of several pictures in an array (e.g. Berndt et al. 1997; Breedin et al., 1998; Jonkers & Bastiaanse, 1998; Miceli, Silveri, Nocentini, & Caramazza, 1988). The results of the present study are consistent with this tendency. In fact, the largest group-level performance difference between tests was for Naming and Verb-Picture matching, with 23 subjects being impaired on the former and only 9 being impaired on the latter. Both tests share certain processing requirements, including visual processing of the pictures, activation of the appropriate action concepts, and mapping between picture-derived action concepts and verb semantic structures (i.e., referential processing). However, the Naming test may be more difficult than the Matching test because it emphasises recall instead of recognition. More precisely, while the Matching test only requires comprehension of verbs that are explicitly provided by the experimenter, the Naming test requires that the subject (i) deliberately search for the verb semantic structure that corresponds "best" to the action concept derived from the picture, and (ii) actively retrieve the phonological form of the selected verb from the output lexicon via the appropriate third-party mediation mechanism. Thus, it is possible that many of the subjects who failed the Naming test have disorders that affect either or both of these operations. This is especially likely to be true for the 15 subjects who were impaired on the Naming test but unimpaired on the Matching test. Further evidence for the special status of the Naming test comes from the factor analysis, which showed that this test, but none of the others, loaded highly on a single independent factor.

Another common finding is that brain-damaged subjects typically have more trouble with verb processing tasks that involve purely linguistic stimuli than with tasks that involve pictorial stimuli. For example, Zingeser and Berndt (1990) and Berndt et al. (1997) reported that subjects tended to perform worse at naming to definition (e.g., "What do you call it when you put words on paper with a pen?") and at completing sentences (e.g., "To put words on paper with a pen is to __") than at naming pictures of actions. Modest support for this view comes from the finding that slightly more subjects failed the Word attribute test (N = 16), which contains solely linguistic stimuli, than the Picture attribute test (N = 11), which contains solely pictorial stimuli. Stronger support comes from the factor analysis, in which the first and most powerful factor that was extracted reflected impairment specifically on the three tests that involve linguistic stimuli—Verb-Picture matching, Word attribute, and Word comparison—and the third and fourth factors have high correlations with the non-naming tests that involve purely pictorial stimuli—Picture attribute and Picture comparison. All three of the tests that correlated highly with the "Linguistic" factor require activating the language-specific semantic structures of verbs in response to orthographic or phonological input, and one interpretation of the factor is that it reflects an impairment of precisely this capacity. Another interpretation, however, which is not necessarily incompatible with the first, is based on the finding that the Word attribute and Word comparison tests loaded much higher on the "Linguistic" factor than the Verb-Picture matching test. As we pointed out above, it is likely that many of the items in the two former tests require the subject to evoke visual, auditory, or motor images of typical action scenarios in order to answer the questions. Thus it may be that the factor reflects a disturbance of the ability to generate mental images of actions in response to linguistic input. More generally, it is worth noting that the idea that tasks involving purely linguistic stimuli are more difficult than those involving pictorial stimuli may derive from the difference between the representational schematicity of verb semantic structures (and other lexical-semantic structures too) and the representational concreteness and precision of pictures. Such a difference in representational content could make it more difficult to perform computational operations on verbs than on visual images. This is a speculation that deserves to be investigated empirically in further research.

We turn now to aspects of our results that are quite original and that shed new light on the functional architecture of the verb processing system. First of all, it is striking that seven subjects—1362RM, 1504DK, 1951RH, 468JG, 414DM, 1584JR, and 1733RK—performed within normal limits on the Naming test, but were significantly below normal on at least one of the other tests in the battery. This is intriguing because good performance on any kind of picture naming test is usually interpreted as providing strong evidence for intact knowledge of word meaning. After all, in order to name a picture of an object or an action, one must be able to recognise what the picture shows, i.e., activate the appropriate concept, and also map the concept onto the "best" language-specific semantic structure. The performance profiles of these seven subjects, however, suggest that there may be certain mechanisms for manipulating verb meanings which are distinct from those that are necessary for the Naming test. One possible explanation for the results hinges on the putative distinction between referential processing and analytic or inferential processing. Referential processing is essentially about establishing connections between language and the world; in an oversimplified sense, it is about using words to "label" or "point to" various types of perceived phenomena. Analytic or inferential processing, on the other hand, involves decomposing word meanings into their semantic/conceptual features and exploring the vast network of relationships that exist within and between words; no word-world mappings are necessary at all. Philosophers of language, such as Marconi (1997), have developed detailed arguments that support this fundamental processing distinction. In addition, Deacon (1997) recently argued that the analytic or inferential form of processing may depend crucially on the prefrontal cortex and may underlie the ability of humans to acquire and manipulate linguistic symbol systems that are far superior to those that can be learned by nonhuman primates. Consistent with this view is the fact—well-known among professional semanticists—that although people are quite good at using word meanings as "chunks" in referential tasks, they are usually not so adept at breaking these chunks down into their component parts for purposes of, say, providing accurate definitions of the meanings of words. All of these considerations lead us to hypothesise that the subjects who performed well on the Naming test but poorly on one or more of the other tests may have a disorder that spares referential processing but disrupts some aspect(s) of the ability to manipulate verb meanings in an analytic or inferential manner. Because referential processing is necessary not just for the Naming test but also for the Verb-Picture matching test, the hypothesis requires that the seven subjects be unimpaired on both of these tests. This is true for six of the seven subjects, but not for the last one—subject 1362RM, who passed the Naming test but failed the Matching test. It may be, however, that this subject's poor performance on the Matching test was due to an inability to carry out a processing operation that is required for this test but not for the Naming test, such as back-and-forth comparisons between the single verb semantic structure and the action concepts for the two pictures.

A few additional remarks can be made about the dissociation between referential and analytic/inferential processing.[3] One point is that it is not clear if the subjects who exhibited this dissociation manifest it only for

[3] We would like to thank an anonymous referee for bringing these points to our attention.

verbs or if they also manifest it for other classes of words, such as nouns. Further research would be necessary to resolve this issue. Hence the scope, and therefore the precise interpretation, of the dissociation remains an open question. Nevertheless, the data that we have presented indicate that the dissociation does *affect* verbs (in one way or another), and in fact one of the main purposes of our paper is to report this finding, since we are not aware of any other studies that have described it. Another point is that, as Table 3 indicates, the subjects who exhibited a dissociation between intact referential processing and impaired analytic/inferential processing have several different types of performance profiles across the four tests that emphasise the latter type of processing. This suggests that the general notion of analytic/inferential processing is too crude to provide a satisfactory explanation for the subjects' deficits. It may be that the subjects have fairly specific kinds of disorders that involve different forms of analytic/inferential processing (such as the different computational operations described in Table 2). Still, it is useful to invoke the overarching distinction between referential and analytic/inferential processing in the context of these subjects because it helps make sense of the rather surprising discovery that good performance on the Naming and Verb-Picture matching tests does not necessarily imply that verb processing abilities are completely normal.

Perhaps the most impressive new discovery that emerged from this study is the large number of distinct performance profiles across the six tests. Indeed, so many profiles were manifested that it would not be practical, within the scope of this paper, to try to construct explanations for what combinations of impairments could give rise to each one. From a theoretical standpoint, the major finding was that each test dissociated from all the others, which suggests that each test has at least some processing requirements that are unique to it and that can be selectively disrupted by brain damage. The purpose of the factor analysis was to reduce the complexity of the data and reveal statistically reliable patterns that are less directly observable. This analysis indicated that the wide range of distinct profiles of impairment might be largely explainable by a relatively small number of underlying cognitive deficits. Determination of the exact nature of those underlying deficits will require further empirical investigation, but the *post hoc* interpretations that we have suggested are consistent with previous research on verb impairments and also make sense in terms of the putative processing requirements of the different tests.

In summary, we have described how a large number of brain-damaged subjects exhibited a wide range of different patterns of dissociation on a battery of six standardised tests that involve verb processing. Some of these patterns are consistent with generalisations about verb impairments that have derived from previous studies. Other patterns, however, have never been reported before and have significant implications for theories of the architecture that underlies the meanings of verbs and the computational operations that are used to manipulate them. It will be interesting to see how future research continues to illuminate the complexities of verbs and the variety of ways in which knowledge of verbs can be impaired.

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APPENDIX A: TARGET VERBS FOR THE NAMING TEST

1. cutting
2. mailing, sending
3. washing, rinsing
4. following
5. roping, lassoing, catching
6. kissing
7. bouncing, dribbling
8. painting
9. riding
10. erasing
11. sewing, mending, darning
12. boxing
13. mounting
14. winding
15. wrestling
16. raking
17. tracing
18. knitting
19. stirring
20. scratching, itching
21. galloping
22. blowing, extinguishing
23. peeking, hiding
24. laminating
25. hugging, celebrating, rejoicing
26. hanging
27. squeezing
28. bending
29. standing
30. pushing
31. looking, searching, peering
32. slouching, relaxing, lounging
33. spinning
34. smiling
35. straddling
36. spilling, leaking
37. ducking, dodging, avoiding
38. grazing
39. swinging
40. swimming
41. mixing, blending, beating
42. spraying, squirting
43. twisting, wringing
44. shooting, hunting
45. racing
46. juggling
47. bucking
48. tiptoeing, sneaking, dancing
49. loading
50. hobbling
51. marching, parading
52. crashing, wrecking
53. leading, guiding
54. kicking
55. sailing
56. curling
57. weighing
58. saluting
59. dunking, dipping
60. sticking, clinging
61. reaching
62. dialing, calling
63. shaking
64. skating
65. parachuting
66. sneezing
67. receiving, accepting, taking
68. flexing
69. refusing, rejecting, denying, declining
70. walking, strolling
71. fishing
72. slicing
73. plugging
74. colouring, scribbling
75. interviewing
76. turned
77. framed
78. crumbled
79. lit
80. addressed
81. labelled, named
82. nailed, hammered, pounded, drove
83. toasted
84. chopped, diced
85. popped, burst
86. removed
87. spit
88. peeled
89. poked, punctured, punched
90. separated, sorted
91. assembled
92. chewed
93. shredded
94. tied
95. baked
96. developed
97. caught
98. dropped
99. cracked
100. ripped, tore

APPENDIX B: ITEMS FOR VERB-PICTURE MATCHING TEST

Verbs describe the pictures, and italics indicate the target picture

1.	*spraying*	dumping
2.	drying	*rinsing*
3.	*pouting*	crying
4.	throwing	*catching*
5.	*celebrating*	smiling
6.	*threading*	weaving
7.	flexing	*clenching*
8.	rolling	*kicking*
9.	following	*wading*
10.	roping	*herding*
11.	*clinging*	dripping
12.	lecturing	*imitating*
13.	*harvesting*	plowing
14.	*pouring*	grinding
15.	*trimming*	cutting
16.	*refusing*	cringing
17.	*glaring*	winking
18.	*parking*	turning
19.	dragging	*tripping*
20.	connecting	*painting*
21.	*screwing*	beating
22.	serving	*sharing*
23.	*peeling*	grating
24.	*doodling*	writing
25.	drawing	*scribbling*
26.	*tucking*	buckling
27.	rowing	*paddling*
28.	*leaking*	spilling
29.	slamming	*tugging*
30.	sleeping	*reading*
31.	swimming	*floating*
32.	*poking*	dialing
33.	talking	*proposing*
34.	connecting	*winding*
35.	*scraping*	flattening
36.	pouring	*watering*
37.	picking	*passing*
38.	praying	*meditating*
39.	*holding*	bouncing
40.	spinning	*twirling*
41.	*shearing*	spinning
42.	*fencing*	boxing
43.	*tiptoeing*	diving
44.	*extinguished*	lit
45.	flipped	*snapped*
46.	dipped	*chewed*
47.	*dissolved*	melted
48.	*decorated*	carved
49.	reversed	*traded*
50.	*tied*	knotted
51.	wrinkled	*stained*
52.	*spliced*	connected
53.	bent	*folded*
54.	*stacked*	piled
55.	*spread*	glazed
56.	emptied	*filled*
57.	closed	*covered*
58.	*mashed*	crushed
59.	chopped	*crumbled*
60.	tangled	*coiled*
61.	*framed*	labelled
62.	flattened	*punctured*
63.	*cracked*	popped
64.	sharpened	*whittled*
65.	*shredded*	curled
66.	*spit*	smeared
67.	dealt	*sorted*
68.	dropped	*fell*
69.	*straightened*	shortened

APPENDIX C: ITEMS FOR PICTURE ATTRIBUTE TEST

Verbs describe the pictures, and italics indicate the target picture

	attribute:	*loudest sound*
1.	*spraying bottle*	squeezing tube
2.	spreading jam on bread	*chopping green pepper*
3.	*crumpling paper*	wiping table
4.	peeling sticker	*tearing paper*
5.	hanging coat	*knocking on door*
6.	*yelling*	looking
7.	*dripping faucet*	leaking jar
8.	stirring with spoon	*beating with mixer*
9.	measuring with ruler	*sawing*
10.	*bouncing ball*	rolling ball
11.	feeding squirrel	*milking cow*

	attribute:	*most tiring*
12.	*lifting box*	dragging box
13.	sliding down a slide	*swinging on swingset*
14.	*riding rodeo horse*	riding show horse
15.	walking	*running*
16.	*cartwheeling*	rolling
17.	*flexing muscle*	scratching arm
18.	skating	*skiing*
19.	*fighting animals*	feeding baby
20.	standing	*holding bag of groceries*

	attribute:	*longest time*
21.	*opening metal can*	plugging wire in outlet
22.	*packing suitcase*	covering person with blanket
23.	licking envelope	*drinking glass of juice*
24.	mounting horse	*hatching bird*
25.	*peeling carrot*	peeling banana
26.	signing name	*painting picture*
27.	extinguishing candle	*inflating balloon*
28.	*arranging flowers*	watering plant
29.	flipping coin	*winding toy*

	attribute:	*move hands closer*
30.	*bending straw*	stretching rubber band
31.	twisting styrofoam	*loading gun*

	attribute:	*move hands up/down*
32.	curling hair	*brushing hair*
33.	*shaking hands*	passing salt shaker

	attribute:	*move hands in a circle*
34.	waving	*rubbing lotion on hands*

	attribute:	*move object down*
35.	lifting weights	*landing eagle*

	attribute:	*move object in circle*
36.	*juggling grapefruits*	trading baseball cards
37.	*twirling baton*	conducting orchestra

	attribute:	*move object closer*
38.	*reaching for high shelf*	shutting door
39.	pushing cart	*pulling cart*

	attribute:	*fun*
40.	*playing with toy*	pouting
41.	*reading book*	addressing envelope

	attribute:	*harmful*
42.	*erupting volcano*	erupting geyser
43.	grabbing person's shirt	*hitting person's face*

	attribute:	*good/helpful*
44.	choking other person	*catching falling person*
45.	blocking other person	*guiding other person*
46.	wrestling	*celebrating*
47.	*resuscitating person*	branding calf
48.	*petting cow*	shearing sheep

	attribute:	*involves a tool*
49.	*clipped frayed cloth*	straightened tablecloth
50.	*ironed shirt*	ripped jeans
51.	*ground coffee*	smashed potato chips
52.	assmebled toy	*repaired eyeglasses*
53.	shucked corn	*peeled apple*
54.	coiled rope	*cut rope*
55.	decorated pie	*carved pumpkin*

	attribute:	*involves a knife*
56.	peeled carrot	*sliced cucumber*

	attribute:	*involves a hammer*
57.	*pounded nail*	screwed bolt

	attribute:	*causes improvement*
58.	*tied shoelaces*	loosened belt
59.	*ripened banana*	crumbled cheese
60.	squeezed lemon	*cooked steak*
61.	*sorted coins*	reversed playing cards
62.	*loaded stapler*	bent straw
63.	deconstructed blocks	*lit candle*
64.	dropped tissue	*caught ball*

	attribute:	*most permanent effect*
65.	drew with chalk	*drew with pen*
66.	*dissolved butter*	melted ice
67.	mixed clothes	*mixed ingredients*
68.	*tucked shirt*	stained shirt
69.	connected Legos	*spliced wires*
70.	stacked books	*smeared ink on paper*
71.	*twisted plastic strip*	twisted string
72.	*crumpled paper*	folded paper

APPENDIX D: ITEMS FOR WORD ATTRIBUTE TEST

Italics indicate the target verb

attribute: loudest sound

1.	*singing*	yawning
2.	*sneezing*	wiping
3.	*shuffling*	dealing
4.	*ringing*	bending
5.	*pounding*	screwing
6.	squeezing	*cracking*
7.	peeking	*clapping*
8.	scrubbing	*vacuuming*

attribute: most tiring

9.	balancing	*climbing*
10.	*leaping*	diving
11.	*crawling*	sitting
12.	flying	*canoeing*
13.	riding	*jumping*
14.	*swimming*	*floating*
15.	*surfing*	fishing
16.	kneeling	*squatting*

attribute: longest time

17.	inserting	*folding*
18.	*harvesting*	roping
19.	*interviewing*	giving
20.	darning	*knitting*
21.	*dialing*	pushing
22.	*carving*	slicing
23.	praying	*sleeping*

attribute: move arms closer

24.	*rowing*	stretching

attribute: move hands closer

25.	knotting	*threading*

attribute: move hands up/down

26.	*grating*	pouring

attribute: move hands/object in circle

27.	planting	*turning*
28.	*spinning*	shaking

attribute: move object closer

29.	*catching*	kicking

attribute: object moves down

30.	clinging	*sliding*
31.	launching	*parachuting*

attribute: fun

32.	weighing	*watching*
33.	*hiking*	threshing

attribute: harmful

34.	*crashing*	sailing

attribute: good/helpful

36.	*massaging*	slapping
37.	stealing	*tying*
38.	cringing	*offering*
39.	pinching	*holding*
40.	*directing*	chasing

attribute: involves a tool

41.	melted	*beaten*
42.	*cut*	torn
43.	*chopped*	crumbled
44.	filled	*raked*

attribute: involves a pencil

45.	enlarged	*traced*

attribute: involves an oven

46.	fried	*baked*

attribute: causes improvement

47.	snapped	*healed*
48.	cracked	*shelled*
49.	*dressed*	chipped
50.	crushed	*developed*
51.	*filled*	emptied
52.	*connected*	knotted
53.	mixed	*sorted*
54.	*piled*	fell

attribute: most permanent effect

55.	covered	*toasted*
56.	*labelled*	closed
57.	dipped	*chewed*
58.	*shredded*	flattened
59.	*painted*	written
60.	*sprouted*	arranged
61.	filled	*broken*
62.	wrapped	*laminated*

APPENDIX E: ITEMS FOR PICTURE COMPARISON TEST

Verbs describe the pictures, and italics indicate the target picture

1.	person singing	bird singing	*tracing picture*
2.	mixing with spoon	mixing with mixer	*measuring liquid*
3.	dipping green pepper	*packing suitcase*	dipping doughnut
4.	*flattening plastic jug*	bending spoon	person bending over
5.	hitting nail with hammer	hitting person with fist	*sawing board*
6.	sewing sock	sewing button	*threading needle*
7.	*drying plate with towel*	wrapping box with paper	wrapping wrist with cloth
8.	rubbing lotion on hand	*clapping*	rubbing person's shoulders
9.	person biting nails	horse biting something	person frowning
10.	horse eating grass	*stirring coffee*	person eating cake
11.	*sneezing into tissue*	wiping nose with tissue	wiping liquid with paper towel
12.	person licking envelope	*bird hatching*	deer licking fawn
13.	looking for hiding person	looking through binoculars	*listening to walkman*
14.	holding baby	*baby crawling*	holding hands
15.	*spreading jam on bread*	carving pumpkin	carving soap
16.	*polishing shoe*	changing car tire	changing shoes
17.	climbing tree	*balancing on post*	climbing pole
18.	lifting weights	*dragging suitcase*	lifting box
19.	*dodging ball*	catching box	catching ball
20.	*blocking doorway*	pulling door shut	pulling cart
21.	walking outside	walking inside	*running outside*
22.	*holding box*	carrying grocery bag	carrying purse
23.	board leaning against wall	person leaning against wall	*jar lying on table*
24.	*kicking ball*	throwing wadded-up paper	throwing ball

APPENDIX F: ITEMS FOR WORD COMPARISON TEST

Italics indicate the target verb, and the type of association between the two related verbs is indicated in the final column. Abbreviations: HYP = hyponymy; COH = cohyponymy; ANT = antonymy; SYN = synonymy.

1.	*repair*	assemble	build	COH
2.	*straighten*	lengthen	shorten	ANT
3.	spread	scatter	*scoop*	COH
4.	*propose*	lecture	talk	HYP
5.	hop	jump	*walk*	HYP
6.	clap	*snap*	applaud	SYN
7.	injure	heal	*grow*	ANT
8.	*hike*	sit	slouch	HYP
9.	squat	*kneel*	crouch	COH
10.	prune	trim	*whittle*	SYN
11.	gallop	run	stand	HYP
12.	expand	shrink	*sag*	ANT
13.	*punch*	strangle	choke	SYN
14.	clench	flex	*shrug*	COH
15.	buckle	*tuck*	fasten	HYP
16.	blink	*glare*	wink	COH
17.	*salute*	bow	curtsey	COH
18.	grin	smile	*stare*	SYN
19.	start	*race*	finish	ANT
20.	*pluck*	seal	close	HYP
21.	yell	*yawn*	shout	SYN
22.	*order*	interchange	switch	SYN
23.	come	go	*put*	ANT
24.	fry	*freeze*	cook	HYP
25.	*iron*	polish	dust	COH
26.	frighten	scare	*pout*	SYN
27.	light	extinguish	*inflate*	ANT
28.	refuse	*widen*	offer	ANT
29.	give	pass	*wrap*	HYP
30.	*flatten*	crack	break	HYP
31.	accept	*donate*	decline	ANT
32.	connect	splice	*load*	HYP
33.	*borrow*	buy	sell	ANT
34.	duck	*imitate*	cringe	COH
35.	push	press	*knock*	SYN
36.	cling	*flow*	stick	SYN
37.	mash	*crash*	crush	SYN
38.	*bind*	mix	blend	SYN
39.	scrub	wipe	*vacuum*	COH
40.	argue	*gossip*	agree	ANT
41.	*smash*	tear	rip	SYN
42.	grate	*chop*	shred	HYP
43.	pull	drag	*lift*	HYP
44.	cover	*steal*	bury	HYP