Visual Semantics

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'..names heard, almost as readily excite certain ideas as if the objects themselves, which are apt to produce them, did actually affect the senses'

(Locke, 1690, bk. 3, ch. 2)

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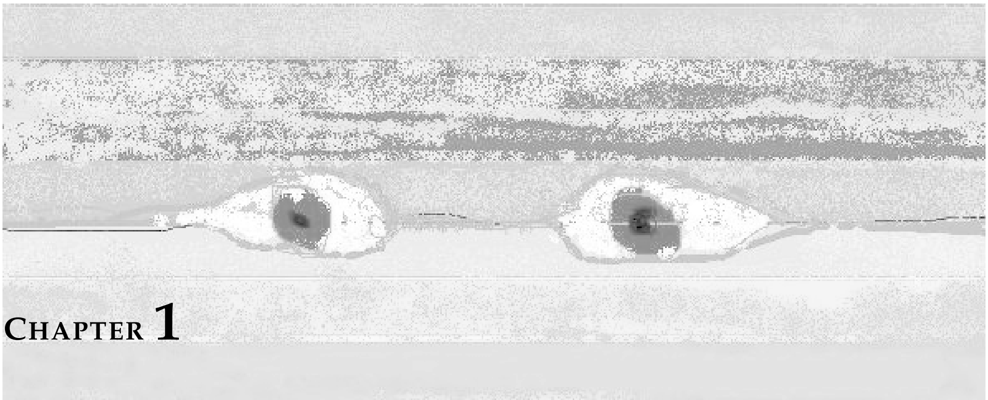

CHAPTER 1

General Introduction

'Listen to someone speaking a language that you do not know. You hear an unusual song, ever changing, rising and falling, occasionally illuminated by flashes of feeling. The sounds themselves are little more than vocal noises. If there are words, you cannot disentangle them; if there is a message you cannot understand it. Interest evaporates. You might as well stare at a brick wall.

Now listen to a good friend. It is the same kind of vocalization, but you cannot hear it in the same way. The noises are there, but they are totally transparent. Your mind passes right through the sounds, through the words, through the sentences, and into the mind of your friend. Your experience is totally different. The difference of course is meaning' (Miller, 1991, (pg. 145-146)).

1.1 Introduction

The example by Miller shows how natural it is for humans to comprehend spoken language. We do not bother about the complexity of the underlying cognitive processes when we are engaged in conversation. Our brains just seem to do the work and we are happy to accept that. But, how do we come to understand language? What is happening in our brains when we listen to speech or read from a book? What exactly is meaning, and how is it represented in our brains? Although we are all experts in the usage of language, we find it difficult to come up with straightforward answers.

In order to answer fundamental questions about human cognitive function and language processing in particular we need to perform psychological experiments. The scientific discipline of psycholinguistics is a branch of cognitive psychology which studies the psychological basis of linguistic competence and performance. Generally, psycholinguistic research is divided into two main branches. One branch focuses on the structure of language and investigates the mental processes that are involved in the analysis of grammatical structure and syntactic content that is present in sentences. The other branch focuses on the semantic content or meaning which is expressed in language.

The nature of meaning has intrigued generations of psychologists, philosophers, and linguists who have tried to understand how meaning is represented in our minds and brains. Historically, inquiry into the nature of meaning was the concern of philosophers. The modern history of philosophical semantics starts with John Locke (1632 - 1704) who argued that the meaning of a word is the idea that speakers have when they use it and that listeners have when they hear it. In Locke's view, ideas were based on experience, which formed the basis of all knowledge. Importantly, ideas (and words) could reflect the sensory experience of objects, but also the more abstract (non-sensory) properties of objects or object-categories (Locke, 1690). Locke's account of human thought and its relationship to language is still a prominent one in cognitive science nowadays. Comparable ideas have been proposed by modern cognitive scientists (e.g. Paivio, 1971; Warrington, 1975; Allport, 1985; Pulvermüller, 1999a) who have suggested that semantic memory for concrete words may be stored in modality specific areas of the cortex (e.g. visual areas) (but see Anderson, 1976; Schwanenflugel & Shoben, 1983, for arguments in favor of amodal semantic memory). In fact, a prominent model in cognitive psychology is that the development of semantic memory originates in everyday life experience with concrete objects such as plants, animals, and tools (e.g. Martin, Wiggs, Ungerleider, & Haxby, 1995; Martin & Chao, 2001). When the meaning of a concrete content word is being acquired, the learner may be exposed to stimuli of various modalities related to the word's meaning, or the learner may perform actions the word refers to. This process of co-activation is believed to link the word's phonological features with visual and action properties in sensory and motor areas of the cortex (Allport, 1985; Pulvermüller, 1999a).

Visual semantics refers to that part of semantic memory that deals with knowledge about visual aspects of elements in the world around us. "We as well as our closest living relatives, are visual animals and the meaning or semantics of things in the world is intimately linked to vision" (Martin, 1998, pag. 71). Questions such as 'is a grapefruit bigger than an orange [y/n]' (Goldenberg et al., 1989), or 'is a canoe widest in the center [y/n]' (Farah, Hammond, Mehta, & Ratcliff, 1989b) are typically resolved by using visual imagery that uses stored knowledge about the physical properties of concrete objects. Martin et al. (1995) suggested that semantic knowledge about objects is stored close to areas that mediate the perceptual processing of those objects. Furthermore, they proposed that the organization of visual semantic knowledge parallels the organization of perceptual function which is known to be separated into several functional areas that each code for a specific visual property (shape, color, motion, etc) (e.g. Felleman & Van Essen, 1991). This proposal is particularly powerful since it suggests the existence of a strong relationship between the structural organization of visual semantics and perceptual function.

Notice that while the current trend in cognitive neuroscience puts a strong emphasis on the distribution and localization of semantic memory, psycholinguistic research on semantic memory has traditionally focused on the functional organization of information within semantic memory. More specifically, it has sought to describe the organizational properties of the mental lexicon. This approach which is known as lexical semantics has resulted in different theories and network models (see reviews in Chang, 1986; Kess, 1991) such as the spreading activation model of the lexicon (Collins & Loftus, 1975) and prototype theory (Rosch, 1978). Typical of the lexical approach to semantics is that the meaning of a word is given by its relationship to other words or lexical elements in the network. Unlike the approach outlined above, these models do not take into account the modality of the semantic representations (e.g. visual or motor) which may represent the meaning of concrete words.

While most psycholinguistic research has aimed to develop formal models of word meaning, cognitive psychologists have adopted a broader perspective on semantic memory. From the psychological point of view, semantic memory (Tulving, 1972) is the system which processes, stores, and retrieves information about the meaning of words, concepts and facts (Warrington, 1975). Semantic memory is considered to hold the information that allows us to give meaning to our sensory experiences (Hodges, Patterson, Oxbury, & Funnell, 1992), the objects we see and the words we read or hear (Humphreys & Forde, 2001). Here, semantic memory is not the exclusive property of words, but is considered to be a general knowledge base which may provide meaning to different types of sensory information, including words.

Note however that the debate about the form and structural organization of semantic memory is still far from being settled, and new perspectives are being developed as we speak. A large part of this development derives from neuropsychological research on brain-damaged patients. Although in most patients with a semantic impairment there is a general degradation affecting all aspects of semantic memory, in some only a part of semantic memory seems to be affected. The first to report a selective impairment of semantic memory was Warrington (1975) who described a patient that had particular difficulty with understanding concrete words, as compared to abstract words. He could, for instance, correctly define words such as ’arbiter’, ’supplication’, and ’satirical’, but not ’needle’, ’poster’, and ’acorn’. The opposite, worse understanding of abstract words than concrete words has also been reported (e.g. Tyler & Moss, 1997).[1] The early paper by Warrington initiated an increasing number of reports about brain-damaged patients with selective impairment or sparing of specific semantic categories (approximately 89 cases at this time according to a recent estimate by Rogers and Plaut (2002)). Category-specific deficits have been reported for broad categories such as living versus nonliving entities (e.g. Forde, Francis, Riddoch, Rumiatti, & Humphreys, 1997; Silveri et al., 1997; Moss, Tyler, Durrant-Peatfield, & Bunn, 1998), but also for smaller semantic categories such as body-parts, animals, fruits and vegetables, musical instruments, clothing, and tools (reviews in Saffran & Schwartz, 1994; Caramazza & Shelton, 1998; Coltheart et al., 1998; Humphreys & Forde, 2001)

Particularly the living - nonliving distinction has received a lot of interest and discussion. Warrington and Shallice (1984) were the first to report this dissociation in four patients suffering from a viral infection (herpes simplex encephalitis) who showed poorer performance in producing and/or comprehending the names of living as opposed to nonliving things. The opposite, better performance on living than on nonliving items has also been reported (e.g. Warrington & McCarthy, 1983, 1987). As an explanation for this double dissociation Warrington and Shallice (1984) proposed that the semantic representations for living and nonliving items involve different semantic features. Identification of living things (e.g. animals) would rely on visual features such as color, shape, size, texture, etc, whereas the recognition of nonliving thing (e.g. tools) would rely on the function for which the object is designed (but see McRae, de Sa, & Seidenberg, 1997; Caramazza & Shelton, 1998). In addition this explanation also accounted for some exceptions to the living nonliving dichotomy. Body-parts for instance have very salient functional attributes and therefor mostly co-occur with impairments to nonliving categories. Gemstones and musical instruments, although not living, have strong visual representations and are more likely to follow or coincide with impairments for living things (see also Farah & McClelland, 1991, for an influential computational model based on the Warrington theory).

Although the explanation by Warrington and Shallice (1984) is still valued by a large part of the neuropsychological society, there are cases that do not support this theory, which has led to different perspectives about the internal organization of semantic memory. While most of the theoretical accounts of semantic memory stress the importance of semantic features, there are different views on what type of features exist, where they are represented in the brain, and how they relate to one another. There are two main competitors to the theory of Warrington and Shallice (1984) that reject the sensory-functional organization of semantic memory. One is the OUCH (the Organized Unitary Content Hypothesis) model (Caramazza, Hills, Rapp, & Romani, 1990; Hillis, Rapp, & Caramazza, 1993) that argues for a unitary semantic system which is organized in clusters that develop because of correlations

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[1] In fact, a common finding is that both healthy subjects and most patients find abstract words more difficult to identify and to remember than concrete words

and overlap between the featural properties of objects (also see Moss et al., 1998). This approach resembles earlier psycholinguistic work that has aimed to describe the organization of semantic information in the mental lexicon. In these models the meaning of a word is given by its relationship to other words or lexical elements in the network. The OUCH uses similar principles of inter-concept association to explain the different types of semantic impairments that have been observed in brain-damaged patients. The second competitor is the domain specific knowledge model of Caramazza and Shelton (1998) that tries to explain category-specific impairments by arguing that different parts of the brain have specialized, through evolution, for storing and processing different semantic categories (e.g. separate brain systems for animals, fruits and vegetables, or artefacts).

Inspired by the extraordinary findings of semantic deficits in neuropsychological patients, there is a growing interest among cognitive scientists to investigate the organization of semantic memory. The arrival of neuroimaging techniques such as PET, fMRI, and MEG[2] provides the possibility of visualizing neural functioning in normal subjects as they are engaged in a cognitive task. A study by Martin, Wiggs, Ungerleider, and Haxby (1996) for instance found that picture naming of animals was associated with increased activity in visual parts of the brain, while naming of tools generated activity in areas that support motor function (comparable but somewhat different results have been found by Perani et al., 1995; Damasio, Grabowski, Tranel, Hitchwa, & Damasio, 1996). Clearly the result of Martin et al. (1996) is in line with the original proposal of Warrington and Shallice (1984).

Neuroimaging techniques offer great opportunities for scientific advance. Lesion sites in patients can be visualized and compared with imaging data of normal subjects, and knowledge can progress as we are no longer dependent on the accidents of nature that provided us with interesting cases in the past. However, although both PET and fMRI generate important empirical evidence on the brain areas that are active in response to specific cognitive tasks, these techniques have a low temporal resolution. As a result they can only inform us about the network of brain areas that is engaged, but not inform us about the timing of processing in these areas. One other type of neuroimaging technique that was not mentioned above is EEG (electroencephalogram) which measures the electrical activity of the brain via electrodes that are placed on the scalp. EEG (but also MEG) is able to provide a high resolution temporal image of neuronal processing. However, since both are recorded outside of the brain, their spatial resolution with respect to localizing function within specific brain areas is much less precise than PET or fMRI.[3]

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[2] PET: positron emission tomography, uses radioactive labelling of the blood to determine changes in blood flow in response to neural activity. fMRI: functional magnetic resonance imaging, employs short changes in magnetic field to determine the amount of blood flow in response to neural activity. MEG: magnetic encephalogram, measures variations in the magnetic field induced by underlying neural activity.

[3] MEG has a better spatial resolution than EEG because the magnetic signal is not contorted due to variations in brain tissue and scalp thickness.

A popular way to analyze EEG is to calculate the brain's electrical signal in response to a specific event (e.g. in response to the presentation of a word or a picture, or a manual key-press by a subject). By averaging together the EEG recorded to a large number of events (typically about 100) the EEG which is unrelated to the event is averaged out, leaving the brain's electrical response that is causally related to the stimulus or the event. This so-called event-related potential or ERP has a long scientific tradition[4], and different ERP effects and components have been mapped for a diverse range of stimuli and conditions (review in Rugg & Coles, 1995). Psycholinguistic research involved with semantics has centered on the N400 component (origninally discovered by Kutas & Hillyard, 1980) which consists of a large negative wave that reaches its maximum amplitude approximately 400 ms after stimulus onset. The N400 is sensitive to semantic relations between words, but is also found with non-linguistic stimuli such as line-drawings (e.g. Holcomb & McPherson, 1994) and faces (e.g. Barrett & Rugg, 1990), suggesting that the N400 reflects the processing of meaningful stimuli in general. Typically the N400 has been used as a research tool to investigate the role of semantics in sentence processing, e.g. in relation to the timing of syntactic processes (e.g. Brown, Hagoort, & Kutas, 2000). Also the N400 has been used to investigate whether there is a common semantic systems for all meaningful stimuli, or whether separate semantic systems exist (e.g. separate systems for pictorial and verbal information) (e.g Federmeier & Kutas, 2001). However, still little is known about the neural generators of the N400 effect, and more importantly, on how semantic information is distributed and processed in different parts of the brain. Although ERPs hold the potential of providing a high resolution temporal image of neural activity in response to semantic processing, this potential has been largely disregarded by focussing too much on the N400 and neglecting other ERP components. For example, research directed at investigating the visual aspects of semantics should not just center on the N400 but should additionally note the involvement of ERP components in the visual domain. Appropriate in this respect would be to use the extensive knowledge on ERP effects of visual attention, working memory, and mental imagery in relation to semantic processes.

Although ERPs can be valuable to the investigation of visual semantics, there are also less complicated techniques that may be used to investigate interactions between semantic and visual processes. The technique most frequently used to investigate psychological processes is the reaction time paradigm, where subjects' responses are used to infer about internal cognitive processing. One type of reaction time paradigm that has proved useful is to present stimuli in different parts of the visual field. This method is often used to investigate the language properties of the left and right hemisphere. Typically words presented in the right visual field are processed faster and more accurate than words presented in the left visual field. This is because information from the right visual field directly enters the left hemisphere which is dominant for language.

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[4] ERPs are being used since the late 1970's

Although less well known, the same crossed organization exists for the upper and lower visual fields which connect to opposite parts of the visual cortex. Information presented in the upper visual field is directed to the lower (ventral) part of the visual cortex, and information presented to the lower visual field is transmitted to the upper (dorsal) part of the visual lobe. Interestingly, there are strong functional differences between ventral and dorsal parts of the visual brain that are particularly interesting with respect to the study of visual semantics. The lower ventral projection is believed to be important for object identification and recognition, and has consequently been labelled the "what" stream (e.g. Ishai, Ungerleider, Martin, Schouten, & Haxby, 1999). The upper dorsal projection is thought to be important for the analysis of spatial properties of objects (e.g. Haxby et al., 1991), and to mediate sensori-motor transformations for visually guided actions involving those objects (e.g. Goodale, 1996; Jeannerod, 1997). The dorsal projection stream has been labelled "where" to characterize its spatial properties, and "how" to show its involvement with motor function (Creem & Proffitt, 2001).

According to Previc (1990) the dorsal stream has evolved in response to reaching and manipulation of objects in the lower visual field. Ventral function, however, is proposed to have specialized for visual search and recognition of objects in the upper visual field. There is evidence which suggests that lesions in the ventral and dorsal visual streams affect the retrieval of semantic knowledge, with ventral lesions affecting the retrieval of visual semantic knowledge about objects, and dorsal lesions affecting the functional knowledge about object use (reviews in Gainotti, Silveri, Daniele, & Giustolisi, 1995; Humphreys & Forde, 2001). This suggests that the evolution of visual semantic organization may have developed in close connection with the evolution of perceptual function. By presenting meaningful stimuli to the upper and lower visual field, and measuring subjects responses to these stimuli, we can infer about the semantic properties of the dorsal and ventral parts of the visual cortex.

1.2 Issues and Outline

The present thesis is organized in two parts. Part 1 (Chapter 2 and Chapter 3) involves reaction time experiments that make use of the crossed organization of the visual system by presenting stimuli in the upper and lower parts of the visual field to infer about the semantic properties of the ventral and dorsal parts of the visual cortex. In Part 2 (Chapter 4 and Chapter 5) event-related brain potentials are used to visualize on-line processing of information within semantic memory.

1.2.1 Chapter 2

Semantic knowledge about visual properties of objects may be of particular importance for the recognition and search for visual objects. Chapter 2 concentrates on functional mechanisms for visual search and object recognition, and investigates whether visual mechanisms for object identification are affected by the visual semantic representations of concrete words.

One of the mechanisms which is considered to play key role in visual search is inhibition of return (IOR). IOR refers to a bias not to return attention to objects or locations which have been recently attended, thereby favoring novel and yet unexplored objects and portions of the visual field. IOR is closely associated with the system for saccadic eye movements which has been claimed to be biased towards visual search and object recognition in the upper visual field (Previc, 1990). Based on this proposed advantage for saccadic eye movements towards the upper visual field we expect that IOR will be stronger for objects presented in the upper visual field. Previous studies have shown that IOR is closely tied to specific objects or parts of objects (Tipper, 1991; Ro & Rafal, 1999) which suggests that IOR is not simply a subcortical (saccade related) process but is associated with the cortical representations of objects. Chasteen and Pratt (1999) found that IOR affects the lexical access of words, and Fuentes, Vivas, and Humphreys (1999b) have found evidence which suggested that IOR may be evoked by the onset of words, and that the inhibitory effect of IOR may extend to or interact with the semantic properties of words (see also Fuentes, Vivas, & Humphreys, 1999a). This suggests that the effects of IOR may transfer up to lexical and semantic representations of objects. However, it is unclear whether the reverse is also true, that is, whether it possible for higher cognitive functions (e.g. semantics) to modulate the behavior of IOR. In order to investigate this hypothesis the experimental design includes words which are either be semantically identical to the object, or unrelated to the object. Semantic priming effects from words are expected to modify the strength of IOR towards those objects.

1.2.2 Chapter 3

Chapter 3 is concerned with the distribution of semantic memory in the dorsal and ventral visual streams, and investigates the possibility that visual semantic memory follows the organization of perceptual function in the brain (cf. Martin et al., 1995). As was noted above, the ventral stream is characteristically involved in the recognition of objects, while the dorsal stream subserves processing of actions directed at those objects. Most studies which have investigated differences between the ventral and dorsal visual streams have focused on the processing of manipulable and nonmanipulable objects (e.g. Martin et al., 1996; Chao & Martin, 2000). However, using objects as stimuli makes it impossible to disentangle perceptual or visual specialization in one or the other pathway from semantic specialization. Words, on the other hand, have the advantage that they directly activate the semantic representation of an object. The present study investigates semantic specialization in the dorsal and ventral visual streams by presenting words referring to manipulable and nonmanipulable objects to the upper and lower visual fields. Under the hypothesis that visually presented words are able to connect to their semantic representations directly, a relative advantage is expected for words denoting manipulable objects when presented to the lower visual field (which is connected to the dorsal visual stream). Words referring to nonmanipulable objects are expected to show an advantage when presented to the upper visual field (which connects to the ventral visual stream).[5]

1.2.3 Chapter 4

An important question with respect to the organization of meaningful information in the brain is how objects are represented. Chapter 4 (van Schie, Wijers, Kellenbach, & Stowe, in press) investigates the hypothesis that objects are represented via a temporary association between sensory, perceptual, and semantic levels of object description. A consequence of such a temporary association may be that a change at one level of the object representation (e.g. at the semantic level) will automatically affect the other levels of the representation (e.g. the perceptual representation of the object). In order to investigate this question, a picture - word repetition paradigm is used in which the semantic relationship between pictures and words is manipulated. Experiment 1 involves two types of trials, one with words that have the same meaning as pictures (matching words), and one with words that are unrelated to pictures (unrelated words). Matching words are expected to connect with the semantic representation of pictures, and, as a result, reinforce the object representation. If perceptual features are linked to the object's semantic representation, we should expect to find effects of matching words feeding back to the perceptual level. Experiment 2 involves a similar setup as in experiment 1, but includes words that are only semantically associated to pictures.

1.2.4 Chapter 5

Chapter 5 investigates the cortical mechanisms that are involved in the activation of visual semantic information by concrete words. It is hypothesized that concrete words will activate visual semantic meaning via the cortical network for object working memory. This hypothesis is investigated by presenting concrete (imageable)

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[5] Notice that the logic involved here is similar to divided visual field experiments which are directed at investigating left and right hemispheric differences in language function. Verbal materials (words or sentences of different sorts) are presented to the left and right visual fields in order to study language function in the respective contralateral hemispheres (review in Chiarello, 1988). In our case we make use of the crossed organization of visual information which directs visual input from the lower visual field to the dorsal occipital cortex, and visual input from the upper visual field to the ventral occipital cortex (e.g. Previc, 1990; Danckert & Goodale, 2001).

words and abstract (non-imageable) words under various amounts of load on object working memory. When words are presented in conditions where object working memory load is high, difficulty in the activation of visual semantic meaning is expected, as compared to words presented in conditions where there is no load on object working memory.

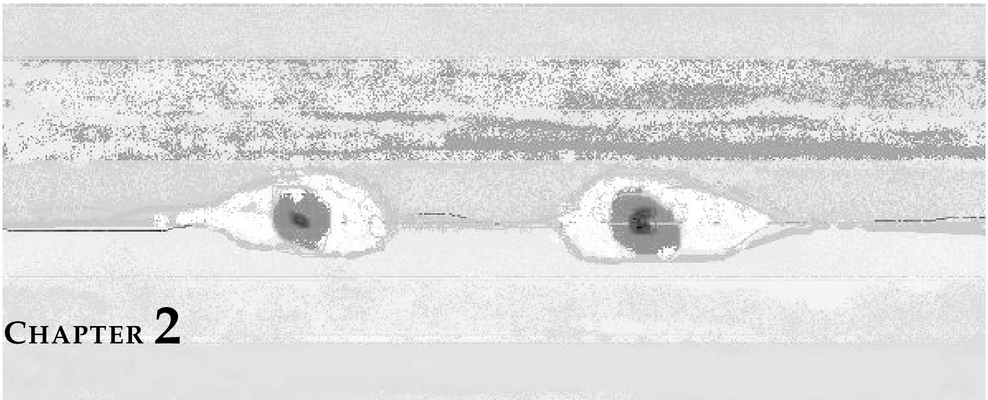
ERPs to concrete and abstract words are recorded in two language tasks, one in which subjects have to decide whether words are lexically valid (lexical decision task), and one in which subjects have to distinguish between concrete and abstract words (concrete-abstract decision task). The investigation of the concreteness effect in both language tasks is important for our understanding of the conditions under which imageable information becomes active. Farah (1995) suggests that the activation of visual semantic or imagistic information is under voluntary control, and will only occur when relevant to the situation. The opposite view is taken by Martin (1998) that visual semantic or imagistic information about words is automatically activated when a concrete word is read, heard, or retrieved in the service of writing and speech. With the current design we hope to address this issue.

1.2.5 Final chapters

Chapter 6 presents a summary of the main results and conclusions of the preceding chapters, followed by a general discussion. References are included right after the general discussion, followed by the appendices in which the materials used for the experiments are reported. In the final section is a summary of the thesis in Dutch.

Part I

Behavioral Experiments



Inhibition of Return and Semantic Priming for Objects Presented in the Upper and Lower Visual Fields

Inhibition of return (IOR) refers to a bias not to return attention to objects or locations which have been recently attended, thereby favoring novel and yet unexplored objects and portions of the visual field. In the present study we investigated the role of IOR in object identification and focused on the possibility that IOR is associated with the semantic representation of objects.

Previc (1990) suggested that there are qualitative differences between the upper and lower visual fields. The upper visual field (UVF) is specialized for visual search and object recognition. It has been associated with an advantage for saccadic eye movements which are believed to be important for object scanning. As IOR is closely tied to the system for saccadic eye movements, we suspected that IOR is also biased to the UVF. In experiment 1 drawings of objects were presented in the upper or lower visual half field, and subjects were instructed to identify each picture without making eye movements. Visual probes were used to investigate the strength of IOR to objects in the upper and lower visual fields. Results of experiment 1 showed a significant difference between IOR in the upper and the lower visual fields (39 ms vs. 21 ms).

A second experiment is reported which involved a standard exogenous cueing design with uninformative peripheral cues and subsequent targets (visual probes) presented in the upper and lower visual half fields. The size of the IOR effect in experiment 2 was 23 ms for probes presented in the lower visual field (LVF), and 22 ms for probes presented in the UVF. It appears that the upper and lower visual fields are equally sensitive to the sudden onset of peripheral stimuli, and that this cannot explain the field asymmetry for IOR as observed in experiment 1.

The sensitivity of IOR to objects presented in the UVF suggests a possible role for object-based representations of IOR in the ventral stream. As such, it would be no surprise to find an association between object-based effects of IOR and the semantic representations of words. However, there was no effect of semantic priming from words, which suggests that it may be difficult for semantic factors to modify IOR. Therefore, a more probable explanation is that the UVF advantage for IOR is contingent on enhanced saccade preparation to the identification of objects in the UVF.

2.1 Introduction

The efficient exploration of a complex environment requires effective allocation of visual attention towards the various elements that are present in our surroundings. Posner and Cohen (1984b) discovered a mechanism which was reported to hold particular relevance to the efficiency of visual search. This mechanism which they labelled inhibition of return (IOR) refers to a bias not to return attention to objects or locations which have been recently attended, thereby favoring novel and yet unexplored objects and portions of the visual field.

IOR is believed to be closely coupled to the eye movement system. Stimuli presented at locations which have been the target of a previous fixation are inhibited as compared to stimuli that are presented at unfixated locations. Peripheral cueing will also result in IOR (Posner & Cohen, 1984b; Maylor, 1985; Maylor & Hockey, 1985). The reason for this is that a peripheral cue calls forth an involuntary shift of attention (Jonides, 1981; Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989) which is thought to be accompanied by the automatic preparation of a saccadic eye movement towards the cued location (Posner & Cohen, 1984a). Rafal, Calabresi, Brennan, and Scoltio (1989) presented evidence which suggested that IOR originates from oculomotor preparation. Their experiment showed that the endogenous preparation of a saccade, although not executed, resulted in effects of IOR for the location to which the saccade had been planned.

Results of Harman, Posner, Rothbart, and Thomas-Trapp (1994) are consistent with the relationship between IOR and the saccadic system. IOR was investigated in infants at three and six months of age. Results showed that IOR does not occur at eccentricities greater than those for which a saccade can be programmed. IOR seems to depend on the development of the midbrain superior colliculus, a phylogenetically ancient visuo-motor system that plays an important role in the regulation of overt and covert visual attention. Patients with progressive supranuclear palsy, who have degeneration of the superior colliculus, are found to have deficiencies in generating IOR (Posner, Rafal, Choate, & Vaughan, 1985).

As suggested by Posner and Cohen (1984b) IOR may have been evolved to maximize the sampling of the visual environment. The close relationship between IOR and the saccadic system seems to be especially important for efficient scanning of visual space in search for particular objects. Previc (1990) noted that visual search is strongly biased towards the UVF. Eye movements performed in the UVF are typically different from the type of eye movements that are carried out in the LVF. The LVF seems to have a superiority for processing and pursuing moving targets, preferably for the tracking of objects as they are brought to the mouth for ingestion. The UVF on the other hand seems to prefer saccadic eye movements for the purpose of object scanning and visual search in extrapersonal space. The UVF specialization for saccadic eye movements in extrapersonal space is supported by saccadic control structures such as the superior colliculus and the frontal eye fields which have similarly been assigned to extrapersonal space (Rizzolatti, Gentilucci, & Matelli, 1985).

The assumption that IOR is somehow sensitive to the presence of objects is supported by a number of empirical observations. Tipper (1991) found that when IOR is linked to a specific object it will follow the object as it moves around in space. The discovery of object-based IOR (Tipper, 1991) triggered a number of studies which further explored the object-based qualities of IOR. Gibson and Egeth (1994) found tagging of IOR to a location within a rotating object, and Ro and Rafal (1999) found object-based IOR in boxes that moved horizontally across the screen. In addition to the observation of IOR with moving displays, object-based IOR has been observed in static displays. Jordan and Tipper (1999) showed that IOR can spread across the object's surface, inhibiting targets presented within the object's surroundings, and Jordan and Tipper (1998) observed the effect of IOR to be much stronger when centered on apparent (Kaniza) objects than in conditions where IOR was evoked at a location where no apparent (Kaniza) object was present.

The above studies suggest that IOR is not simply a subcortical process which is generated in the superior colliculus. Rather, the object-based properties of IOR suggest that there are additional effects at the cortical level (as suggested by Tipper et al., 1997). This proposal is supported by recent electrophysiological investigations (Hopfinger & Mangun, 1998; McDonald, Ward, & Kiehl, 1999) which suggest that IOR is able to modulate the processing of sensory information in extrastriate visual cortex. More specifically, IOR was observed to affect the amplitude of the occipital P1 component. The P1 is the first positive component in the electrophysiological response of the brain[1] which is believed to signal processing of exogenous visual information within extrastriate visual cortex. Interestingly, the P1 is also the first event-related brain potential (ERP) component which has been found to show enhanced processing of stimuli presented within the spotlight of visuo-spatial attention (e.g. Mangun, 1995). P1 amplitude is increased when stimuli are processed attentively, but its amplitude is attenuated when stimuli are processed under the in-

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[1] The labelling of ERP components use P and N to indicate whether peaks are positive or negative, and numbers to mark the latency of the peak (e.g. N2 being the second negative peak).

fluence of IOR. The combination of different neuroimaging techniques such as PET, fMRI, and ERPs (Heinze et al., 1994; Mangun, Jha, Hopfinger, & Handy, 2000) has pointed towards the ventral extrastriate visual cortex including the fusiform gyrus for a possible source for the P1 attention effects. Although it is quite possible that the cortical effects of IOR are dependent on initial activation in the superior colliculus (the superior colliculus interconnects with the thalamocortical loop which is held responsible for effects of attention within the cortex (LaBerge, 2000)), cortical IOR may have a set of qualitatively different properties as compared to the effects of the superior colliculus. Indeed it has been proposed that IOR operating in the superior colliculus may have formed the developmental basis for cortical IOR (e.g. Berger & Henik, 2000).

In addition to the object-based properties of IOR, other studies have suggested that the effects of IOR may propagate to higher order cognitive functions. Chasteen and Pratt (1999) found that IOR affects the lexical access of words. Fuentes et al. (1999b) showed that IOR may be evoked by the onset of words, and furthermore, that the inhibitory effect of IOR may extend to or interact with the semantic properties of words (see also Fuentes et al., 1999a). These results suggest that the effect of IOR is not confined to visual orienting but extends to and possibly cooperates with higher cognitive functions.

The present study was conducted to further explore the object-based qualities of IOR, and investigate the possibility that object-based IOR is associated with the semantic properties of objects. Generally, IOR is studied with exogenous or peripheral cues that have no task relevance. In the present study we tried to come a little closer to the natural situation where visual search is directed to the identification of objects. Instead of measuring IOR in left and right visual fields, which is mostly the case, we chose to present objects in the upper and lower visual fields. This allows us to determine possible differences in the strength of IOR towards objects presented in the upper and lower visual fields. Because of the close association between IOR and the saccadic eye movement system, we expect to find stronger effects of IOR for objects which are presented in the UVF. This would support the role of IOR in object identification and visual search.

Both the object-based qualities of IOR and recent evidence that IOR may be involved with higher levels of cognition suggest that IOR may be associated with the semantic properties of objects. This hypothesis was investigated by the inclusion of words which were presented shortly after the object had disappeared from the screen. In half of the cases the word had the same meaning as the picture, while in the other cases a word was presented which was unrelated to the object. Here we have a situation where both IOR and semantic priming are directed at the same object. If there is a reciprocal relationship between IOR and the semantic system then we may expect an influence of matching words on the level of IOR.

2.2 Method

2.2.1 Subjects

A total of nineteen subjects participated in the experiment, three of whom were excluded from analysis (two because of technical problems and one because of too much difficulty maintaining fixation while identifying peripherally presented pictures). This resulted in sixteen subjects (age 18-27, mean 21; 2 males and 14 females; three were left-handers) that were selected for analysis. All were healthy and had normal or corrected-to-normal vision. Subjects were paid a standard fee for participation.

2.2.2 Materials

The stimuli used in experiment 1 consisted of pictures, words, and probes. Pictures were selected from three partially overlapping sets of linedrawings, which were designed and tested by Martein (1995), Snodgrass and Vanderwart (1980), and Cycowicz, Friedman, Rothstein, and Snodgrass (1998). This resulted in 455 distinct pictures which were selected for a pretest which was used to determine a consistent verbal label for each picture in Dutch. Per picture a minimal criterion of 50% name agreement was set between subjects (total mean average of name agreement was > 80%). This generated 416 pictures and 416 corresponding words that were used in experiment 1. An additional set of 208 words was selected which were unrelated to the picture. This was done by creating 208 pairs of words out of the original list of 416 related words. Pair members were selected by closely matching for word length and word frequency (using the logarithmic transformation of the number of occurrences of the written word in a database of 42 million words (Burnage, 1990)). For each pair of related words an unrelated word was selected with a similar word length (related words: 6.51 letters (SD 2.6), unrelated words: 6.51 letters (SD 1.9)) and a similar frequency (related words: 0.67 (SD 0.65), unrelated words: 0.66 (SD 0.53)).[2] The concurrence of pictures and words was balanced across subjects such that for half of the subjects a certain picture was followed by a related word (a word with the same meaning), while for the other half of the subjects the same picture was followed by an unrelated word with a comparable word length and frequency. See the appendix for chapter 2 on page 137 for the matching and unrelated words used in this experiment.

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[2] SD = standard deviation

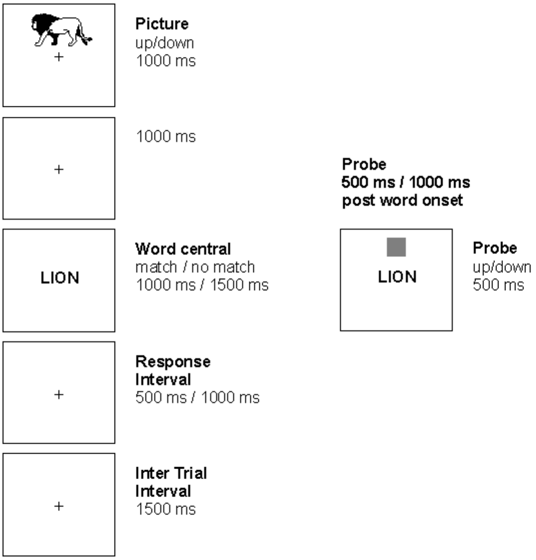

Figure 2.1: Example of a trial as used in experiment 1.

2.2.3 Procedure

Subjects were seated in a dimly lit cabin facing a computer screen at a distance of 45 cm. The index finger of their preferred response hand rested on a touch-sensitive response box which recorded a response when the finger was lifted. A Pentium computer controlled the experiment, which was divided in 8 blocks of 52 trials, preceded by a number of practice trials. During all 8 blocks a fixation crosshair was displayed in the middle of the screen on which subjects had to fixate. Trial length was 5500 ms and each block took approximately 4.8 minutes to complete. Between blocks subjects were presented with four pictures and four words. Two pictures and two words had been presented in the preceding block, while the other four stimuli were not. Subjects were instructed to decide for each picture and each word whether it was 'old' or 'new'. This additional test between blocks was included to make sure that subject actively identified the presented pictures and words. Subjects were informed about the accuracy of their recognition between blocks, but the small number of recognition trials prohibited any reliable analysis of their performance.

At the beginning of each trial a central white crosshair was displayed on the center of a black computer screen for 1500 ms on which subjects were instructed to fixate. Then, a picture appeared in white on the screen, either above or below the central fixation point (6.65 visual degrees of distance between the fixation point and the middle of the picture), and stayed on for 1 second. Subjects were required to identify this picture without making any accompanying eye movements. After disappearance of the picture, a one second inter stimulus interval followed after which a word was presented covering the central fixation point. Note that the presentation of a word in the center of the screen performs a similar function as the usage of a central cue in a typical IOR paradigm, where central cueing is included in order to draw spatial attention back towards the center of the screen. In 50% of all cases the word was the verbal label for the picture, while in the other cases it was unrelated to the picture. Subjects were instructed not to try to remember all pictures and words, since this was not feasible. Rather, subjects were encouraged to identify the pictures and read the words so that they would be able to recognize them later on. The third stimulus in the trial was a visual probe stimulus (a filled square 3.77 degrees wide and high) that was presented for 500 ms, either at the location of the previously presented picture or at the opposite location on the screen (6.55 degrees from center to crosshair). The interval between word onset and probe presentation was either 500 ms or 1000 ms. Subjects had to make a simple response to the detection of a probe. With the offset of the probe, the word also disappeared from the screen. An additional response interval of 500 ms or 1000 ms and an inter trial interval of 1500 ms completed the trial. The response interval was varied between 500 ms and 1000 ms in order to ensure equal trial length for the two (500 ms and 1000 ms soa) probe conditions. [3] See Figure 2.1 on the facing page for an example trial.

2.3 Results

Reaction times and number of misses (with exclusion of reaction times faster than 100 ms and slower than 800 ms, and response times further than two standard deviations away from the mean) were subjected to a MANOVA repeated measurements analysis. This included four separate within subject factors: picture location (picture up versus picture down), word-type (matching words versus unrelated words), probe location (probe up versus probe down), and stimulus onset asynchrony (500 ms (soa1) versus 1000 ms (soa2) interval between word onset and probe onset).

Analysis of misses showed no significant effects, which was probably due to their small percentage (1.1%) of occurrence. Analysis of reaction times however did show a number of interesting effects. First, word-type significantly affected simple detection to probes ($F_{1,15} = 5.91$; $P < 0.028$). When the word matched the picture, reaction times to probe stimuli were faster (303 ms) than with unrelated words (310 ms). Furthermore, probe detection speed was significantly ($F_{1,15} = 79.49$; $P < 0.000$) slower at soa1 (325 ms) than at soa2 (289 ms). In addition to the main effects of word-type and soa, a significant interaction between picture location and probe location was observed ($F_{1,15} = 50.08$; $P < 0.000$). This interaction was found to reflect slower

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[3] Probes presented 500 ms after word onset were followed by a 1000 ms additional response interval, and probes presented 1000 ms after word onset were succeeded by a 500 ms response interval. Note that responses were valid in both the response interval and the subsequent inter trial interval.

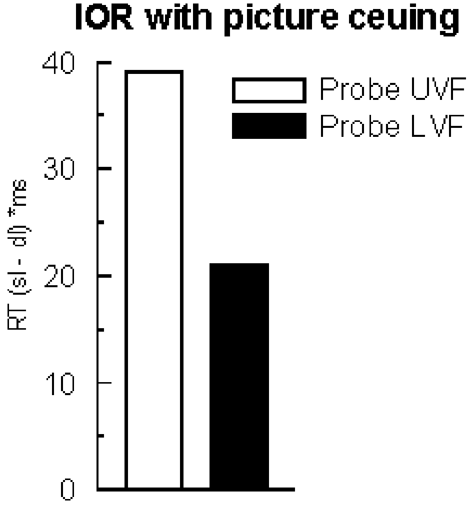

Figure 2.2: Strength of IOR for probes presented in the upper and lower visual fields of experiment 1. The vertical axis displays the amount of IOR as the difference between same location (sl) and different location probes (dl).

responses to probes presented at the same location as the picture (322 ms) than to probes presented at the location opposite to the picture (292 ms), showing the inhibitory effect of IOR for same location probes. No significant three-way interaction was observed between picture location, word-type, and probe location, which would have signalled an effect of semantic matching on the strength of IOR ($F_{1,15} = 0.20$; $P = 0.665$).

In line with the prediction, larger IOR effects were observed in the UVF, with IOR being almost twice as large in the UVF (39 ms), as compared to the LVF (21 ms). See Figure 2.2 for the magnitude of IOR in the upper and lower visual fields. Mean average response times and percentage of misses are reported in Table 2.1 on the facing page.

While the two-way interaction between picture location and probe location informs us that responses to same location probes were slower than responses to different location probes, we cannot conclude from this interaction that the effect size of IOR was actually larger for probes presented in the UVF. In order to do so, we must directly compare the magnitude of the IOR effect in the UVF with the effect size of IOR in the LVF. Strength of IOR was calculated separately for UVF-probes and LVF-probes. Subsequent statistical analysis (MANOVA repeated measurements) of these difference values resulted in a significant effect of visual field ($F_{1,15} = 6.17$; $P < 0.025$) acknowledging larger IOR in the UVF.

Table 2.1: Mean response times and percentage of misses in experiment 1. Standard deviations are given in brackets.

		Matching Words		Unrelated Words	
		Soa1	Soa2	Soa1	Soa2
Response times					
Picture UVF	probe UVF	345 (53)	303 (42)	343 (55)	309 (49)
	probe LVF	314 (46)	271 (31)	321 (45)	284 (36)
Picture LVF	probe UVF	298 (38)	267 (33)	302 (38)	276 (36)
	probe LVF	334 (37)	294 (31)	343 (43)	305 (40)
Misses					
Picture UVF	probe UVF	1.0%	0.7%	0.7%	0.5%
	probe LVF	0.0%	0.5%	1.2%	1.7%
Picture UVF	probe UVF	0.7%	0.7%	0.7%	1.6%
	probe LVF	0.5%	1.7%	2.4%	3.4%

2.4 Discussion

As predicted, clear effects of IOR were observed in probe reaction times. Probes presented at the location of the picture were responded to more slowly than probes presented at uncued locations. Furthermore, we found that the effects of IOR were almost twice as strong for the UVF (39 ms), as compared to the LVF (21 ms). This result is consistent with the hypothesis that IOR follows the specialization for object recognition and visual search in the UVF.

Contrary to our predictions, the inclusion of words did not modify the magnitude of IOR in an interesting manner. Although reaction times showed effects of both word-type and IOR, no significant interaction was observed between these two factors. While it not possible to draw any strong conclusions from the absence of an interaction, the present data do suggest that there is no obligatory relationship between the semantic priming of objects and IOR being directed at the same object. However, previous studies have suggested that the effects of IOR may extend to the higher level representations of words (e.g. Chasteen & Pratt, 1999) or objects (e.g. Tipper et al., 1997). This suggests that the transfer of IOR to other cognitive functions outside of the perceptual domain is relatively anchored in bottom-up analysis of incoming information, while the reverse influence of higher cognitive function on IOR may be less automatically effected. Berger and Henik (2000) reached a similar conclusion in stating that "[the] flexibility of the organism ... might be obtained not by making the automatic procedures [e.g. IOR] themselves flexible, but rather by using them within higher processes (pg. 426)." In our case, the absence of an effect of semantic priming on the level of IOR cannot be taken as evidence that IOR is completely impervious to any influence from higher cognitive function. Rather, the data suggest that there is no obligatory coupling between semantics and IOR, in the way that semantic priming effects would automatically affect the magnitude of IOR.

The present study showed an increase of IOR for objects in the UVF. This result is in agreement with the model of Previc (1990) who proposed functional differences between the processing of stimuli in the upper and lower visual fields. The stronger effect of IOR is consistent with the preference for saccadic search and object identification in the UVF. Note however that there are two possible explanations for this result. One is that reflexive orienting to stimuli in the UVF is stronger than for stimuli presented in the LVF. As was mentioned in the introduction, the superior colliculus is biased towards the UVF. In this case the larger effect of IOR within the UVF may have originated from increased collicular sensitivity for the UVF. The other explanation is that the present results are dependent on the inclusion of objects which needed to be identified. In order to distinguish between these two possibilities, we report a second experiment which may (partially) solve the dispute. Although this experiment was not deliberately configured to serve as a follow-up experiment to distinguish between the two alternatives just discussed, its design and experimental outcome are relevant to the current inquiry.

Experiment 2 involved a standard peripheral cueing paradigm with cues and probes being presented in the vertical hemifields as opposed to the more generally used horizontal mode of presentation. The design of this second study offers an additional examination of the IOR effect in the upper and lower visual fields, with the major difference between the two experiments being the type of stimuli that were presented. In experiment 1 we had used pictures of objects to evoke IOR. In experiment 2 IOR was generated by short exogenous cueing of one of two peripherally presented boxes. The exogenous cues were uninformative and subjects were instructed to ignore them. In both experiments the detection of a peripherally presented probe stimulus was used to determine the magnitude of IOR.

If we were to find a similar UVF advantage for IOR in experiment 2, this would suggest that the field difference for IOR as observed in experiment 1 is not specific for this one experiment. Rather this would suggest a general advantage for IOR towards the upper visual field which is not specific to object processing. A consequence of this outcome would be that the UVF is more sensitive to the onset of stimuli, as compared to the LVF. In this case it does not matter whether we use pictures of objects or simple exogenous cues to generate IOR. If on the other hand we do not find an UVF advantage for IOR in experiment 2, this suggests that the results of experiment 1 are dependent on the inclusion of objects.

2.5 Experiment 2

Experiment 2 was performed in an event-related brain potential (ERP) setting in order to investigate possible electrophysiological differences for IOR in the two vertical hemifields. For present purposes only the behavioral measures will be discussed.

2.6 Method

2.6.1 Subjects

Six undergraduate students participated in the experiment which was administered as part of an introductory course in electrophysiological techniques. All subjects were healthy and had normal or corrected-to-normal vision. Subjects did not receive any financial payment, but obtained study points for taking part in the course.

2.6.2 Procedure

Subjects were seated in a dimly lit cabin, wearing an electrocap, and facing a computer screen at a distance of 45 cm. Two additional electrodes were attached to the face in order to measure eye movements and blinks. The index finger of their preferred response hand rested on a touch-sensitive response box which recorded a response when the finger was lifted. A Pentium computer controlled the experiment, which was divided in 5 blocks of 200 trials, preceded by a number of practice trials. Subjects rested between blocks. During practice subject's ocular activity was closely monitored via the electro-oculogram which was displayed online during the experiment. Direct feedback was given in the case of unwanted saccades.

At the beginning of each trial a central white crosshair was displayed in the center of a black computer screen on which subjects were instructed to fixate[4]. Furthermore, two peripheral unfilled boxes were present on the screen, one in the upper and one in the lower visual field (6.65 visual degrees away from the central fixation point; boxes were 5.7 visual degrees wide and tall). Both the fixation crosshair and the two peripheral boxes were continuously displayed during all 5 experimental blocks. After a variable interval (20 ms - 500 ms) an exogenous cue was presented via a short 50 ms thickening (0.5 visual degrees thick) of the outline of one of the two peripheral boxes. The position of the cue had no predictive value whatsoever, and subjects were instructed to ignore it. Subsequently, 450 ms - 950 ms later in time a 50 ms visual probe was presented (a filled square, 4.6 visual degrees wide and tall) within the outline of one of the two peripheral boxes. Subjects were instructed to respond as fast as possible to the occurrence of the probe stimulus. However, in 20% of all trials no probe stimulus was presented (catch trials), and subjects did not have to respond. A 1000 ms response interval and a 2000 ms blink interval[5] completed the trial.

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[4] All stimuli were presented in white on a black background, unless stated otherwise.

[5] Subjects were instructed only to blink during the blink interval (which was indicated by the fixation crosshair turning green), and to refrain from blinking during the rest of the trial.

Table 2.2: Mean response times in experiment 2. Standard deviations are given in brackets.

	Probe UVF	Probe LVF
Response times		
Cue UVF	369 (48)	338 (45)
Cue LVF	346 (55)	360 (42)

2.7 Results

Reaction times were subjected to a MANOVA repeated measurements analysis which included two within subject factors: cue validity (validly cued probes versus invalidly cued probes) and visual field (probes presented in the upper versus lower visual field).

Statistics showed a main effect of cue validity ($F_{1,5}$ = 8.94; $P < 0.030$) reflecting slower response times for validly cued (364 ms) than for invalidly cued probes (342 ms). No interaction between the factors cue validity and visual field was obtained ($F_{1,5}$ = 2.04; P = 0.867), indicating that there was no statistical difference for the effect size of IOR to the upper and lower visual fields. See Figure 2.3 on the next page for effects of IOR to probes presented in the upper and lower visual fields. Table 2.2 reports mean average response times in experiment 2.

2.8 Discussion

Similar to the earlier experiment, the current results showed clear effects of IOR in both the upper and lower parts of the visual field. Unlike the previous experiment however, which resulted in strong field differences for IOR, the present experiment failed to show such a difference. As argued above, this result does not support a subcortical bias in the saccadic system towards the onset of stimuli in the UVF. Rather, this suggests that the field difference for IOR as observed in the preceding experiment occurred as a consequence of the specific experimental conditions which involved objects instead of artificial exogenous cues.

However, one has to keep in mind that the number of subjects used in experiment 2 was very small (6 subjects in total), and as consequence the statistical power of this experiment was very low (power = 0.22).[6] This means that we have only a 22% percent change of correctly accepting the null hypothesis that there is no significant difference between the effect size of IOR in the upper and lower visual fields. For comparison, the power of experiment 1, using 16 subjects, is 61%. Note however that in experiment 1 we not have a power problem since we observed a significant difference between IOR in the upper and lower visual fields, and as such we can reject the null hypothesis.

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[6] We used the GPOWER program of Faul and Erdfelder (1992) with the following parameters: post-hoc power estimation, large effect size ($f^2 = 0.35$), alpha=0.05; df=(1, 5), N=6

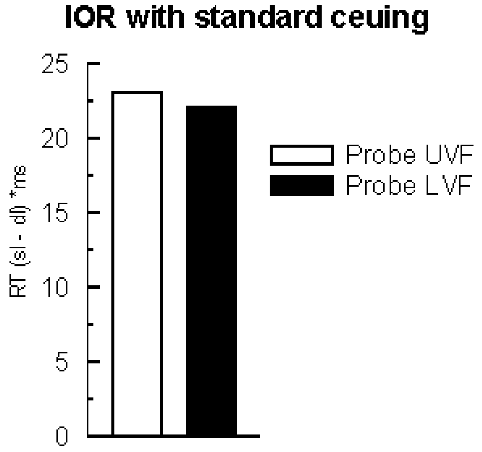

Figure 2.3: Strength of IOR for probes presented in the upper and lower visual fields of experiment 2. The vertical axis displays the amount of IOR as the difference between same location (sl) and different location probes (dl).

Although from a statistical perspective it is difficult, if not impossible, to draw strong conclusions from the absence of an interaction, we feel that the results of experiment 2 are still worth presenting since we did observe clearly significant effects of IOR. Also, considering that the effect size of IOR in experiment 2 approximates the size of the field effect observed in experiment 1, we trust that a similar field effect, if present, should have been visible in the results of experiment 2. Clearly the average response times to visual probes in experiment 2 do not leave much argument to support there being a difference in inhibitory strength in the upper and lower visual fields. We are aware that ideally this experiment should be replicated with more subjects to strengthen this conclusion. However, at present we cautiously interpret these results to support there being no difference in effect size for IOR in the upper and lower visual fields with exogenous cueing.

2.9 General Discussion

IOR is generally conceived of as an automatic mechanism of attention which is closely tied to the oculomotor system. However, recent studies suggest that the realm of IOR may be larger than has been suspected. Some studies have reported on the object-based qualities of IOR (e.g. Müller & Von Mühlenen., 1996), and others have stressed the propagation of IOR to higher cognitive functions (e.g. Berger & Henik, 2000). In the present study we investigated the role of IOR in object identification and focused on the possibility that IOR is associated with the semantic representation of objects.

Results of experiment 1 showed a clear difference between IOR in the upper and the lower visual fields. We argued that the stronger effect of IOR in the UVF is consistent with a bias for saccadic eye movements and object identification in the UVF. As IOR is believed to be an expression of saccadic preparation, a straightforward explanation for this result is that UVF stimuli were associated with stronger preparatory saccadic activity. Experiment 2 investigated the hypothesis that the UVF is more sensitive to the onset of peripheral stimuli. As a result, the reflexive preparation of a saccadic eye movement may have been stronger for UVF stimuli. However, results of experiment 2 suggested that the upper and the lower visual fields are equally sensitive to the onset of peripheral stimuli. There was only a 1 ms difference between the strength of IOR for probes presented in the upper and lower visual fields. This suggests that the field difference for IOR as observed in the earlier experiment occurred as a consequence of the specific experimental conditions that were used. We believe that the inclusion of peripheral objects is the cause of the field asymmetry as observed in experiment 1.

The involvement of IOR with object identification may not be accidental as previous research already found that IOR is closely associated to objects (e.g. Tipper, 1991). Both the saccadic eye movement system and object recognition show a preference to the UVF (Previc, 1990). Possibly this preference is associated with the specialization for object analysis in the ventral occipital stream and the fusiform gyrus (Ungerleider & Mishkin, 1982; Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1991; Haxby et al., 1994; Desimone, 1996). This proposal is supported by recent electrophysiological investigations of IOR (Hopfinger & Mangun, 1998; McDonald et al., 1999) which showed that IOR modulates the processing of sensory information in extrastriate areas of the ventral occipital stream, including the fusiform gyrus (see also Heinze et al., 1994; Mangun et al., 2000).[7]

These studies suggest the existence of cortical IOR that may be associated with the system for object recognition in the ventral visual pathway. The same pathway has been implied for the representation of visual semantic knowledge (Jeannerod, 1997) which is believed to store information about the structural properties of objects (Martin et al., 1996). It is thought that the visual semantic representations of objects are closely associated with the perceptual analysis of objects (Martin et al., 1995)(see following chapters). As such, it would be no surprise to find an association between object-based effects of IOR and the semantic representations of words.

However, there was no effect of semantic priming on the level of IOR. This suggests that it may be difficult for semantic factors to modify IOR (cf. Berger & Henik, 2000), and that some reservation is in place with respect to the hypothesized reciprocity between IOR and the semantic representations of objects. Although it may

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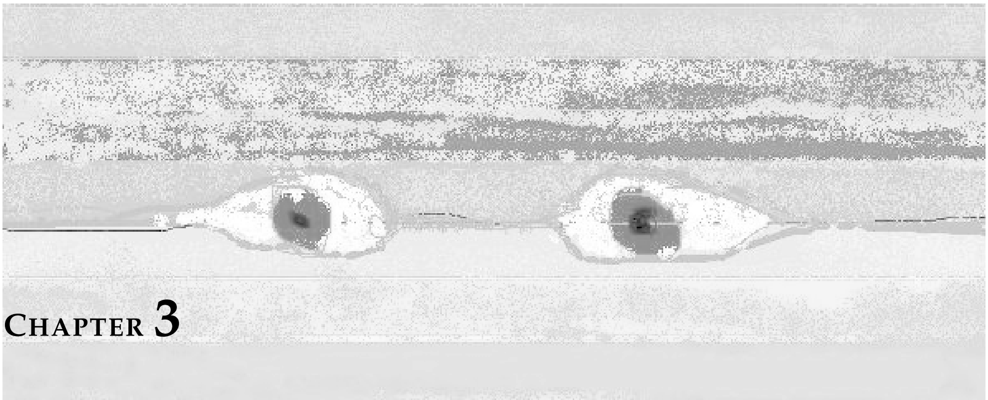
[7] Note however that the cortical effects which were observed in association with IOR may have originated from subcortical structures which are involved in the control of visual attention (see LaBerge, 2000).

very well be that there are object-based mechanisms for IOR in the (ventral) visual cortex, it is not necessarily the case that the UVF effect for IOR is dependent on such a mechanism. If we had found an influence of semantic priming on the UVF effect of IOR then we might have concluded that the UVF advantage of IOR is associated with cortical mechanisms for object representation in the ventral stream. However, as this is not the case, a more probable explanation for the UVF bias of IOR is that there is a stronger tendency to use saccadic eye movements for the identification of objects in the UVF, as compared to the identification of objects presented in the LVF. The inclination to use saccadic eye movements for the identification of objects in the UVF explains the stronger effects of IOR to the onset of objects in this part of visual space.

In this respect it is important to note that the enhanced saccade preparation to the identification of UVF objects, in our view, does not reflect a voluntary strategy, but rather an automatic tendency. It is possible that participants' behavior relied on over-learned scanning strategies, e.g. scanning from top to bottom, which may also explain the stronger effect of IOR in the UVF. However, we do not feel that previously acquired scanning strategies were of much use in the present paradigm, since only one object was presented in each trial. Typically, scanning strategies are used in visual search tasks that involve multiple targets (e.g. Treisman & Gelade, 1980; Treisman, 1988). Furthermore, in a recently performed experiment where we presented words instead of objects in the upper and lower visual fields we found an advantage for word reading in the lower visual field (see the following chapter). If subjects have a consistent preference or bias towards attending the UVF then this should also be evident in response times to words.

In conclusion, we consider the present results to contribute to a better understanding of IOR and its relationship to object identification and visual search. Furthermore, although the present interpretation is consistent with a close coupling between IOR and the saccadic eye movement system, we consider it important to continue the investigation of object-based IOR and its possible interaction with semantics.



CHAPTER 3

Semantic Specialization for Manipulable and Nonmanipulable Objects

The dorsal and ventral visual streams have been identified to subserve separate visual functions. The ventral stream is characteristically involved in the recognition of objects, while the dorsal stream is believed to subserve processing of actions directed at those objects. A similar organization has been suggested for semantic memory, with the ventral stream containing semantic knowledge about the visual characteristics of objects, and the dorsal stream holding functional semantic knowledge of the types of actions that may be afforded by those objects (e.g Chao & Martin, 2000). This suggests that semantic organization follows the existing specialization for object processing in the dorsal and ventral visual streams. In the current study this hypothesis was investigated by presenting words referring to manipulable and nonmanipulable objects to the upper and lower visual fields. A relative advantage was expected for words referring to manipulable objects when presented to the lower visual field (LVF) (which is connected to the dorsal visual stream). Words referring to nonmanipulable objects were expected to show an advantage when presented to the upper visual field (UVF) (which connects to the ventral visual stream).

Consistent with our expectations, behavioral analysis of responses to words showed that words referring to manipulable objects were processed more accurately (less errors) when presented to the LVF. Words referring to nonmanipulable objects on the other hand were more accurately responded to when presented in the UVF. An important fact, however, is that this pattern of results was only found for repeated target words when the same word, presented as a prime, had been in the LVF. We speculate that stronger priming effects from words presented in the LVF may have provided the necessary conditions for this effect to occur. Priming may be necessary to activate the relevant features of manipulable and nonmanipulable items for them to be directly activated by the presentation of the word within the appropriate visual field.

Consistent with this hypothesis, results showed a strong advantage for words presented to the LVF, as compared to words presented to the UVF. Field effects were approximately twice as strong for words than for pseudowords, suggesting an advantage for language materials being presented in the LVF.

3.1 Introduction

Developments in neuropsychological and neuroimaging research (e.g. Allport, 1985; Coltheart et al., 1998; Humphreys & Forde, 2001; Pulvermüller, 1999a) suggest that a substantial part of semantic memory is located in areas outside of the classic (Wernicke's and Broca's) language areas. Especially knowledge of concrete items is believed to be represented within or in close proximity to areas of the brain that participate in perceptual analysis and motor preparation (Martin et al., 1995; Tranel & Damasio, 1995; Martin et al., 1996; Mummery, Patterson, Hodges, & Price, 1998; Pulvermüller, Lutzenberger, & Preissl, 1999b; Kawashima et al., 2000). For example, concrete semantic information (e.g. knowledge pertaining to physical and functional characteristics of a pair of scissors) is believed to activate specific feature representations in visual, tactile, motor, and auditory areas of the brain. This type of semantic organization is said to originate in the process of acquiring knowledge of everyday objects, animals, plants, etc., through experience and interaction (Warrington & Shallice, 1984; Warrington & McCarthy, 1987; Tranel & Damasio, 1995; Pulvermüller, 1999a). Models involving a feature organization of semantic knowledge (e.g. Farah & McClelland, 1991) may account for neuropsychological cases with selective loss of items belonging to living or nonliving semantic categories (Saffran & Schwartz, 1994; Patterson & Hodges, 1995). Knowledge of living items (plants, animals, etc.) is thought to be mainly of a visual nature, represented in inferior occipital-temporal regions extending anteriorly into the temporal lobe. Knowledge of nonliving items or artefacts on the other hand is thought to include a much higher degree of functional or motor specific information which correlates with processes in the left temporal-parietal and parietal-frontal areas of the cortex that are believed to represent visuomotor characteristics of typical actions (Martin et al., 1996; Humphreys & Forde, 2001; Laine, Rinne, Hiltunen, Kaasinen, & Sipilä, 2002).

Consistent with the organization of semantic information in neuropsychological models, several researchers (Goodale & Miller, 1992; Jeannerod, 1997; Creem & Proffitt, 2001) have proposed the existence of specialized systems in the ventral and dorsal visual processing streams that have differentiated towards representing separate properties of objects. In general, these models have postulated a ventral or "what" stream which runs from the striate cortex to the inferior temporal lobe that has specialized for representing the visual properties of objects (e.g. shape and color) (e.g. Corbetta et al., 1991; Haxby et al., 1994). Dorsal projections from visual to posterior parietal areas, on the other hand, have been considered to mediate sensorimotor transformations for visually guided actions directed at objects (e.g. Goodale & Humphrey, 1988). As a consequence, the dorsal stream has been labelled the "how" stream. [1] Previc (1990) offered a theory on the possible ecological origins of specialization within the ventral and dorsal streams. According to Previc the dorsal stream has developed in response to reaching and manipulation of objects in the lower visual field (LVF). Ventral function however is proposed to have specialized towards visual search and recognition mechanisms in the upper visual field (UVF). The proposed specialization in the ventral pathway is interestingly paralleled by the existence of neuropsychological patients who lose semantic knowledge of living things due to lesions in ventral parts of the temporal cortex. This pathway is considered to be especially important for processing visual semantic knowledge that appears to be crucial for defining items within living semantic categories (Forde et al., 1997; Humphreys, Riddoch, & Price, 1997; Tranel, Damasio, & Damasio, 1997; Riddoch, Humphreys, Gannon, Blott, & Jones, 1999; Hodges, Spatt, & Patterson, 1999). In addition, the suggested specialization in the dorsal system for processing of manual actions is paralleled by neuropsychological patients who lose artefactual knowledge (e.g. how to use a certain tool) due to temporal-parietal and parietal-frontal lesions (Gainotti et al., 1995; Silveri et al., 1997; Tranel et al., 1997).

The postulated overlap between models of semantic organization and object analysis is especially interesting since it may open up new ways of thinking about the organization of semantic information and object representation in the brain. Furthermore, the coupling of these two relatively separate areas of investigation may further increase our understanding of the relationships between object-based representations and semantic knowledge pertaining to the characteristics of those objects. One interesting relationship which is pursued in the current study concerns the proposal that semantic organization follows visual function (Allport, 1985; Martin et al., 1995; Tranel & Damasio, 1995; Pulvermüller, 1999a). This hypothesis is especially relevant to the neuropsychological literature and theories of semantic organization since it provides a framework in which to understand the distribution of semantic knowledge. The specific hypothesis which is investigated in the current study is that semantic representations for manipulable objects are processed in the dorsal visual pathway or "how" stream that is proposed to code for object-directed actions. In line with Previc's ecological theory for functional specialization within the dorsal and ventral streams, we expect that the presentation of manipulable items within the LVF are preferentially processed in the dorsal visual stream. Nonmanipulable or

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[1] Note however that there is also a second, more frequently used label for this pathway, which is "where", signifying the analysis of spatial properties of objects that are also believed to be processed in the dorsal pathway (Ungerleider & Mishkin, 1982; Smith et al., 1995; Smith, 2000).

visual items on the other hand are expected to benefit from presentation in the UVF which connects to the ventral visual stream. Note that the logic involved here is similar to experiments directed at studying left and right hemispheric differences in language function where verbal materials (words or sentences of different sorts) are presented to the left and right visual fields in order to investigate language function in the respective contralateral hemispheres (review in Chiarello, 1988). In our case we make use of the crossed organization of visual information which directs visual input from the LVF to the dorsal part of the primary visual cortex (V1), and visual input from the UVF to the ventral part of the primary visual cortex.

Note that the topographic organization of visual information which is characteristic of V1, is maintained throughout a fair part of extrastriate visual areas (V2, V3, and V4) (Sereno et al., 1995; DeYoe et al., 1996). Further along the visual system (subsequent to V4) the topographic organization with respect to the upper and lower parts of the visual field is less clearly separated. Visual input to the temporal cortex (of monkeys) is most sensitive to the central part of the visual field, while the parietal cortex seems to favor peripheral parts of visual space (e.g. Baizer, Ungerleider, & Desimone, 1991). However, there is some neurophysiological evidence (from monkeys) which suggests that some of the higher order extrastriate areas in the dorsal stream (MT and V6a) do maintain an over-representation of the LVF (Maunsell & Van Essen, 1987; Galletti, Fattori, Gamberini, & Kutz, 1999), (see also Danckert & Goodale, 2001).

In the present study we used words referring to manipulable and nonmanipulable objects, instead of presenting the actual objects themselves. With the presentation of objects it is very difficult and perhaps impossible to disentangle semantic specialization from visuo-perceptual specialization within the two visual streams. If, for example, we find a LVF advantage for manipulable objects, then we cannot be sure that this advantage reflects a semantic specialization within the dorsal stream, rather than a perceptual advantage for the processing of manipulable objects. By using words, this problem is circumvented, since then a perceptual explanation is no longer applicable.

Words included in the experiment were of two types: words referring to manipulable objects, and words referring to nonmanipulable objects. Both sets of words were presented in the upper and lower visual fields in order to determine whether semantic distribution follows the organization of visual information within the ventral and dorsal streams. An advantage was expected for words referring to manipulable objects (we will call these items 'manipulable words') when presented in the LVF (dorsal stream), and for words denoting nonmanipulable objects (which will be called 'nonmanipulable words') when presented to the UVF (ventral stream). However, manipulable objects are generally biased to the LVF, and the opposite may be true for nonmanipulable objects, although possibly less strongly. Thus, these sets may be confounded with the visual field in which objects are generally observed to occur. In order to control for this confound, visual field-bias was included in the design, although words rather than the objects themselves were presented. The collection of manipulable words was divided into two sets, one with manipulable objects generally biased towards the LVF (e.g. 'keyboard'), and a second set with manipulable objects biased towards the UVF (e.g. 'clothesline'). The same was done for the nonmanipulable words, resulting in two additional sets which included nonmanipulable objects with a LVF bias (e.g. 'railway'), and nonmanipulable objects with an UVF bias (e.g. 'chimney').

An important prerequisite for the current design to show effects is that visually presented words need to be able to connect to their semantic representations directly. If, for example, words presented to the LVF and UVF are first analyzed in a structurally separate orthographic lexicon, before activating their semantic meaning, we should not expect to find any significant effect of the visual fields in which these different types of words are presented. Historically, a visual word form area has been localized by Dejerine (1892) and others (e.g. Geschwind, 1965; Howard et al., 1992, for an accurate overview) to the left angular gyrus. More recent neuroimaging experiments by Petersen et al. (Petersen, Fox, Posner, Mintun, & Raichle, 1988, 1989; Petersen, Fox, Snyder, & Raichle, 1990) have found a region in the left middle extrastriate cortex as the possible locus for orthographic analysis of word form. Subsequent investigations with positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) produced activation in the left middle posterior temporal cortex (Howard et al., 1992; Menard, Kosslyn, Thompson, Alpert, & Rauch, 1996), and left occipital-temporal cortex (Kuriki, Takeuchi, & Hirata, 1998; Pugh et al., 2000). Although most studies agree in finding a visual word form area in the posterior parts of the left hemisphere, there is considerable inconsistency as to the exact locus of the orthographic lexicon. Tagamets, Novick, Chalmers, and Friedman (2000) failed to observe evidence for a specific word form area in a recent fMRI study. Their data suggest that there is a large cortical network that subserves the processing of orthographic strings, with differences between string types (words, pseudowords, letter strings, and false-font strings) being expressed as graded changes in the balance of activations. This would suggest that orthographic word form recognition is processed in parallel throughout the posterior visual cortex. A related view is expressed by Kosslyn and Koenig (1992) who note that the brain cannot know in advance whether a set of lines and curves represent a word, a picture or neither, and hence the same initial process must occur during reading and object recognition. Others have suggested that processing systems involved in orthographic analysis probably grew out of, and share neural networks with those subserving object recognition (Nelson, Reed, & McEvoy, 1977; Lupker, 1985; Bajo, 1988).

While the evidence regarding the distribution of orthographic lexical representation is relatively mixed, the relations between lexical (word form) and semantic representations are also not without debate. The finding that semantic attributes of words may influence word recognition (e.g. in some cases, concrete words are more quickly recognized than abstract words) has been taken to suggest that orthographic and semantic processes are highly involved with one another. Absence of any significant influence from semantic attributes on word recognition, however, has been taken to be consistent with a more discrete relationship between orthographic and semantic representation (see Boles, 1989, for a discussion). The ambiguous evidence to date suggests that the relationship between orthography and semantics may be influenced by several experimental factors. In order to enhance the relationship between lexical orthographic representations of words and their semantic counterparts we decided on using a repetition setup. The repeated presentation of a word may benefit from the earlier presentation. As such, the word may have a better chance of more directly activating its semantic meaning.

The repetition setup involved words and pseudowords, presented in the upper or lower visual hemifields, which were either repeated or not repeated in the following frame. A lexical decision response was required to both primes (S1) and targets (S2).[2] Interactions between word-type (manipulable words versus nonmanipulable words) and visual field were expected to be strongest in repetition trials.

3.2 Method

3.2.1 Subjects

Twenty subjects participated in the experiment (mean age: 20.6; 9 males and 11 females; two subjects were left handed). All subjects were healthy and had normal or corrected-to-normal vision. Subjects volunteered for participation and received no financial incentive.

3.2.2 Materials

Four sets of forty experimental words were created: (1) words referring to manipulable objects generally found in the UVF, (2) words referring to manipulable objects generally found in the LVF, (3) words referring to nonmanipulable objects generally found in the UVF, and (4) words referring to nonmanipulable objects generally found in the LVF. All four sets were equated on word length (mean word length between 8.0 and 8.3 letters; standard deviation of word length between 2.7 and 3.5 letters) and written frequency (Burnage, 1990) indicated by the number of occurrences of the word in a database of 42 million words (mean frequency between 131 and 134 occurrences).

In addition to the 160 experimental words an extra set of 320 filler words was selected, matched on word length (mean number of letters: 8.2; standard deviation 2.7) and written frequency (mean number of occurrences: 132) to the experimental

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[2] The labels ’prime’ and ’target’ are mostly used in associative priming paradigms were the first stimulus (the prime) primes, or facilitates processing of, a second stimulus (the target). For convenience we will continue to use ’prime’ and ’target’ to refer to S1 and S2.

set. For both the experimental words and the additional set of filler words selection criteria excluded words referring to animals, fruits, musical instruments, and food, resulting in a relatively homogeneous set of common objects, consisting of both man-made and natural types. This selection criterion was intended to control for a possible confound between sets of experimental words. The defining characteristics of the rejected object categories are known to include a relatively high percentage of visual semantic features. Since the current experiment aimed to distinguish between semantic characteristics of manipulable and nonmanipulable items, we wanted to make the distinction as clear as possible.

The total of 480 words was supplemented with 480 pseudowords matched on word length (mean number of letters: 8.1; standard deviation: 3.0) to the genuine words. Pseudowords were selected to be pronounceable and not to be associable with any real word. See the appendix for chapter 3 on page 141 for the experimental words, filler words, and pseudowords used in this experiment.

3.2.3 Procedure

Subjects were seated in a dimly lit cabin facing a computer screen at a distance of 100 cm. The index fingers of both hands rested on two touch-sensitive response boxes which recorded a response when a finger was lifted. Half of the subjects used their right hand to respond to genuine words and their left hand to respond to pseudowords. For the other half of the subjects response hands were reversed. In advance of the experiment subjects were trained using a set of words and pseudowords which were not used in the actual experiment. Training involved close monitoring of subject's continuous fixation on the central fixation point, using a video-camera zoomed in on the subject's eyes, while subjects were reading aloud words and pseudowords which were presented above and below the central fixation point. A chinrest ensured a stable position of the subject's head and eyes, which was necessary for accurate monitoring. When subject's performance had become reliable, the actual experiment began. A trial consisted of two consecutive items, with the first item presented in upper-case spelling and the second in lower case. Subjects were instructed to decide on the lexical validity of each item (word or pseudoword), resulting in a response to both the prime and the target stimulus. Trials could be of the following types: (a) word – word repetition trials (using words from the experimental set), (b) word – pseudoword trials (using filler words and filler pseudowords), (c) pseudoword – pseudoword repetition trials (using filler pseudowords), and (d) pseudoword – word trials (using filler pseudowords and filler words). All four possible types were equally frequent and randomized within the experiment, resulting in an equal 50% chance on a word or a pseudoword for each item presented. In half of all trials targets were displayed at the same location as primes. In the other half, primes and targets were presented in opposite fields. Both primes and targets were presented for 1000 ms, with a 500 ms inter-stimulus-interval. All stimuli were presented 2.5 cm above or below the central fixation dot (center to center). Stimuli were approximately 1 cm high and varied in width depending on the number of letters. A total of 10 blocks were administered, with each block taking about 7 minutes to complete. The materials used in blocks 1-5 were used again in blocks 6-10. It was made sure that all trials in blocks 6-10 were different from trials in blocks 1-5. Filler words and filler pseudowords were shuffled over conditions in blocks 6-10. Experimental words were used again in repetition trials but appeared at different locations as compared to the first 5 blocks of the experiment.

3.2.4 Data analysis

Reaction times and number of errors (with exclusion of reaction times faster than 100 ms and slower than 1500 ms, and response times further than two standard deviations away from the mean) were subjected to statistical testing (within subjects MANOVA repeated measurements).

Statistical analysis was done in two main parts. First, an overall analysis of all response data (including experimental words, filler words, and pseudowords) was performed separately for primes and targets. The overall analysis was performed in order to examine general effects of word-type (words versus pseudowords), repetition (repeated versus non-repeated items), and stimulus location (UVF versus LVF presentation). The second part of the statistical analysis focused on the set of experimental words (manipulable and nonmanipulable words with an upper or lower visual field-bias), again with separate analyses for primes and targets.

3.3 Results

3.3.1 Overall analysis

Primes

The overall analysis of primes included two within subject factors: word-type (real words versus pseudowords), and prime-location (primes presented in the lower versus the upper visual field).

Table 3.1 on the next page reports mean average response times and percentage of errors for prime words and pseudowords. Both reaction time and error analysis showed a main effect of word-type indicating faster but less accurate processing of words than pseudowords (RT: 734 ms for words versus 787 ms for pseudowords, $F_{1,19} = 50.10$; $P < 0.000$; errors: 15.5% for words versus 8.9% for pseudowords, $F_{1,19} = 30.25$; $P < 0.000$), consistent with a speed-accuracy tradeoff. Second, a main effect of prime-location was observed, both in the analysis of response times ($F_{1,19} = 23.46$; $P < 0.000$) as for the analysis of errors ($F_{1,19} = 7.19$; $P < 0.015$). Primes presented in the LVF were responded to more quickly (RT: 750 ms), and more accurately (errors:

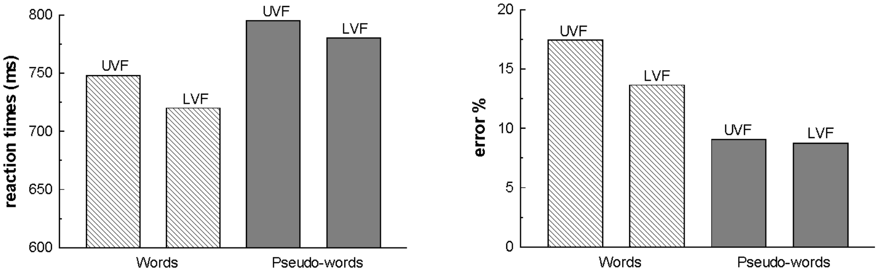


Figure 3.1: Mean response times (left) and mean error percentage (right) to word and pseudoword primes presented in the upper visual field (UVF) and the lower visual field (LVF).

11.2%), than primes presented in the UVF (RT: 777 ms; errors: 13.3%). The advantage for primes presented in the LVF was more pronounced for words (28 ms faster RT, 3.79% less errors) than for pseudowords (15 ms faster RT, 0.31% less errors) as shown by the significant interactions between word-type and prime-location in the analysis of response times ($F_{1,19}$ = 4.80; P < 0.041) and errors ($F_{1,19}$ = 6.22; P < 0.022). See Figure 3.1, for the response times and errors to words and pseudowords presented in the UVF and LVF.

Targets

The overall analysis of targets involved four within subject factors: in addition to word-type and prime-location (see above), factors were repetition (prime-target repetition of the same item versus a different item) and target-location (targets presented at the same location as the prime, or at a different location).

Table 3.2 on the next page reports the mean average response times and percentage of errors for word and pseudoword targets. Prime-target repetition facilitated

Table 3.1: Mean response times and percentage of errors for word and pseudoword primes in the upper and lower visual fields. Standard deviations are given in brackets.

	UVF	LVF
Response times		
Words	748 (62)	720 (63)
Pseudowords	795 (73)	780 (79)
Error percentage		
Words	17.43	13.64
Pseudowords	9.06	8.75

Table 3.2: Mean response times and percentage of errors for word and pseudoword targets. Standard deviations are given in brackets.

		Repetition		no Repetition	
		Prime UVF	Prime LVF	Prime UVF	Prime LVF
Response times					
Words	target UVF	592 (83)	617 (81)	736 (49)	747 (60)
	target LVF	613 (80)	575 (83)	724 (63)	722 (56)
Pseudowords	target UVF	632 (67)	658 (66)	775 (73)	777 (89)
	target LVF	663 (62)	620 (67)	780 (73)	769 (67)
Errors					
Words	target UVF	3.94	3.75	18.25	19.94
	target LVF	4.50	3.19	16.81	17.06
Pseudowords	target UVF	4.25	6.81	11.50	11.13
	target LVF	5.38	3.75	11.00	11.06

responses to targets. Reaction times were faster ($F_{1,19}$ = 109.11; $P < 0.000$) and less errors were made ($F_{1,19}$ = 59.88; $P < 0.000$) in repetition trials (RT: 621 ms; errors: 4.45%) than in trials without repetition (754 ms; errors: 14.55%). Furthermore, repetition of words led to more facilitation than repetition of pseudowords as shown by the interaction between repetition and word-type in the error analysis ($F_{1,19}$ = 40.03; $P < 0.000$). This interaction was not significant in the analysis of reaction times ($F_{1,19}$ = 0.03; P = 0.855).

Targets presented on the same location as a previously presented prime improved performance, as compared to targets presented on a different location. The significant interaction between prime-location and target-location in both the analysis of reaction times ($F_{1,19}$ = 29.78; $P < 0.000$) and errors ($F_{1,19}$ = 5.52; $P < 0.030$) signals faster responses (678 ms) and less errors (9.12%) to 'same location targets' than to 'different location targets' (RT: 698 ms; errors: 9.86%). Interestingly, the reaction time benefits observed to same location targets were much larger in repetition trials than in trials without repetition, as shown by the three-way interaction between repetition, prime-location, and target-location ($F_{1,19}$ = 31.88; $P < 0.000$) in the analysis of reaction times. This three-way interaction was not significant in the error analysis ($F_{1,19}$ = 2.91; P = 0.105).

3.3.2 Analysis of experimental words

Some of the effects observed in the overall analysis, such as the main effect of visual field are also present in the analysis of experimental words. For reasons of redundancy these will not be further discussed.

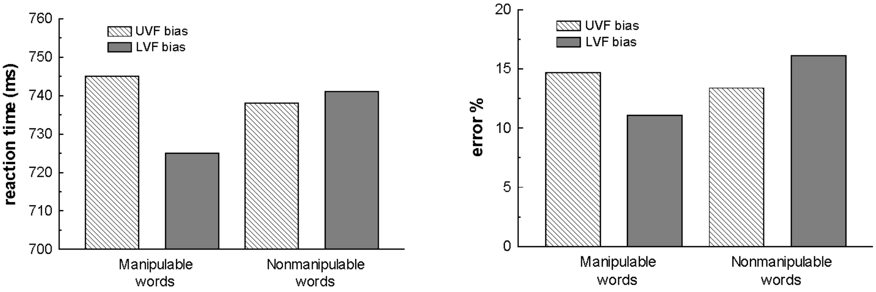


Figure 3.2: Mean response times (left) and mean error percentage (right) for word-primes referring to manipulable and nonmanipulable objects. Separate bars are shown for words denoting objects with upper and lower visual field biases.

Primes

Analysis of responses to experimental word-primes involved three within subject factors: prime-location (UVF versus LVF presentation of word-primes), manipulability (words referring to manipulable objects versus words referring to nonmanipulable objects), and field-bias (words referring to objects which are more frequently found in the LVF versus objects more frequently found in the UVF).

Response times and error percentages of experimental primes are reported in Table 3.3 on the following page. The expected two-way interaction between manipulability and prime-location was absent in the analysis of reaction times ($F_{1,19} = 1.39$; $P = 0.253$) and the analysis of errors, although the error analysis was close to reaching significance ($F_{1,19} = 3.50$; $P = 0.077$). The factors manipulability and field-bias interacted for both the reaction times ($F_{1,19} = 7.61$; $P < 0.012$), and errors ($F_{1,19} = 11.42$; $P < 0.003$) showing faster and more accurate responses to manipulable words with a LVF bias, as compared to manipulable words with an UVF bias. Nonmanipulable words showed the opposite pattern. Responses to nonmanipulable words with an UVF bias were both faster and more accurate than responses to nonmanipulable objects with a LVF bias. See Figure 3.2 for the reaction times and error percentages to the four types of experimental words. Paired comparisons between manipulable words with a LVF-bias, and manipulable words with an UVF-bias showed a reliable difference, both for reaction times ($F_{1,19} = 8.85$; $P < 0.008$) and errors ($F_{1,19} = 7.65$; $P < 0.012$). The paired comparison between nonmanipulable words with an LVF-bias and nonmanipulable words with an UVF-bias was only significant for errors ($F_{1,19} = 6.40$; $P < 0.020$), not for reaction times ($F_{1,19} = .31$; $P = 0.585$).

Table 3.3: Mean response times and percentage of errors for manipulable and nonmanipulable word-primes. Standard deviations are given in brackets.

		Prime UVF	Prime LVF
Response times			
Manipulable Words	UVF bias	758 (70)	732 (71)
	LVF bias	730 (56)	720 (64)
Nonmanipulable Words	UVF bias	751 (64)	725 (63)
	LVF bias	754 (65)	727 (61)
Errors			
Manipulable Words	UVF bias	15.25	16.63
	LVF bias	11.25	10.86
Nonmanipulable Words	UVF bias	15.25	11.50
	LVF bias	18.38	13.88

Targets

Analysis of experimental target words involved four within subject factors. Target-location was added to the three within subject factors (prime-location, manipulability, and field-bias) which were used in the analysis of experimental primes.

Table 3.4 on the facing page reports the average response times and percentage of errors for experimental targets words. In addition to the main effect of prime-location which was reported in the overall analysis, prime-location was found to have an effect on subsequent target processing ($F_{1,19} = 5.05$; $P < 0.037$), resulting in faster reaction times for targets, when primes had been presented in the LVF (596 ms), as opposed to primes presented in the UVF (602 ms).

Analysis of targets showed a similar difference between the four types of experimental words as was observed in the previous analysis of experimental primes. Manipulable words having a LVF-bias, and nonmanipulable words with an UVF-bias produced faster reaction times as compared to the other two categories (interaction between manipulability and field-bias: $F_{1,19} = 11.90$; $P < 0.003$). The interaction was not significant for the analysis of errors ($F_{1,19} = 0.90$; $P = 0.354$).

Although the analysis of experimental primes had not indicated any significant interaction between manipulability and field of presentation, the analysis of experimental targets did show an interaction between these factors on the percentage of errors (manipulability by target-location: $F_{1,19} = 6.63$; $P < 0.019$). This effect reflects more accurate processing of manipulable words (less errors) when they were presented to the LVF target-location, as compared to the same words when presented to the UVF. Nonmanipulable words showed the opposite pattern: more accurate processing when nonmanipulable words were presented in the UVF as opposed to the LVF. However, the interaction between manipulability and target-location was not reliable for reaction times ($F_{1,19} = 0.77$; $P = 0.392$).

Table 3.4: Mean response times and percentage of errors for manipulable and nonmanipulable word-targets. Standard deviations are given in brackets.

		Prime UVF		Prime LVF	
		Target UVF	Target LVF	Target UVF	Target LVF
Response times					
Manipulable Words	UVF bias	595 (86)	626 (91)	628 (90)	584 (95)
	LVF bias	583 (105)	603 (75)	607 (91)	573 (84)
Nonmanipulable Words	UVF bias	586 (81)	609 (83)	618 (78)	567 (78)
	LVF bias	602 (78)	612 (89)	616 (82)	577 (95)
Errors					
Manipulable Words	UVF bias	4.50	4.75	5.50	2.50
	LVF bias	3.25	3.50	3.75	1.75
Nonmanipulable Words	UVF bias	4.25	5.25	2.25	4.00
	LVF bias	4.25	4.50	3.50	4.50

In addition to the two-way interaction between manipulability and target-location, the analysis of errors to experimental targets further showed a three-way interaction between manipulability, prime-location and target-location ($F_{1,19} = 5.31$; $P = 0.033$). As is shown in the left panel of Figure 3.3, the field advantage as observed for manipulable and nonmanipulable target words is only found in conditions where the experimental prime word was presented in the LVF. This was confirmed by two separate posthoc analyses for conditions with prime words in the upper and lower visual fields. With primes presented in the LVF, responses to subsequently repeated target words showed a strong interaction between manipulability and target-location ($F_{1,19} = 13.64$; $P < 0.002$) (see left panel of Figure 3.3 on the

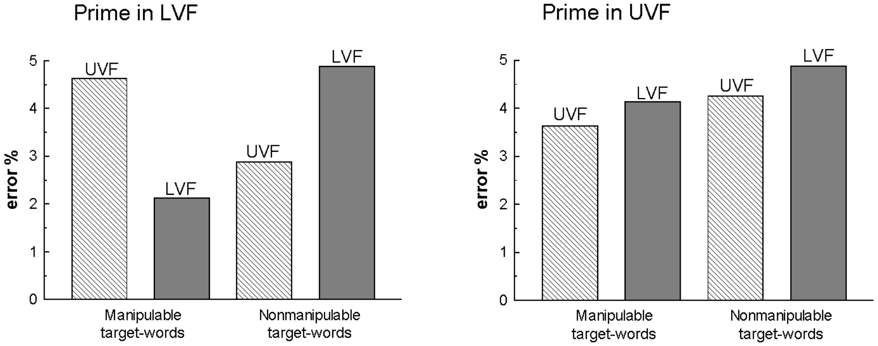


Figure 3.3: Mean error percentages for word-targets in conditions where the prime had been presented in the LVF (left). Mean error percentages for word-targets in conditions where the prime had been presented in the LVF (right). Separate bars are shown for manipulable and nonmanipulable target words, presented in the upper and lower visual fields (UVF, LVF).

preceding page). However, the effect is absent when the prime had been displayed in the UVF ($F_{1,19} = 0.98$; $P < 0.334$). See right panel of Figure 3.3 on the page before. This pattern of results suggests that the field advantage for manipulable and nonmanipulable words is dependent on primes presented in the LVF.

3.4 Discussion

3.4.1 LVF specialization for written language?

In order to investigate semantic organization in the dorsal and ventral visual streams the current study made use of the crossed organization of the visual system in which visual input from the upper and lower visual half fields connect to the ventral and dorsal visual streams. An unexpected but nonetheless interesting side-effect resulting from stimulus presentation along the vertical meridian was the prominent advantage for both words and pseudowords when presented to the LVF, as compared to presentation in the UVF. This field effect was found to be approximately two times stronger for words than for pseudowords. Previous studies have found that the LVF has some advantages over the UVF. He, Cavanagh, and Intriligator (1996) for example observed greater attentional resolution in the LVF than in the UVF. Rubin, Nakayama, and Shapley (1996) showed improved figure-ground separation in the lower versus upper visual field. Christman (1993) found a LVF preference for global information, and Skrandies (1985) showed that the LVF is more sensitive to a wide range of spatial frequencies. Likewise, UVF advantages have been observed for the detection of alphabetic and non-alphabetic stimuli (Chastain & Ersoff, 1997), preference for local information (Christman, 1993), improved object recognition and more effective control of visual search (Previc, 1990), as compared to the LVF. Although general differences in (for example) attentional resolution or figure-ground separation may have caused the overall effect of visual field seen in this experiment, it is difficult for these factors to explain the observed difference in effect size for words and pseudowords.

Although psychological research on language has extensively focused on word processing in the left an right visual fields (Coltheart, 1987), the upper and lower visual fields have been largely neglected. However, there have been a few studies to which we may compare the present results. An early study by Mishkin and Forgays (1952) investigated the accuracy of word recognition in the upper and lower visual fields. Recognition of words presented below fixation was nearly twice as good as compared to words presented above fixation. However, it must be noted that lighting conditions were not equal for the upper and lower visual fields, as lighting was stronger for the UVF. Lambert, Beard, and Thompson (1988) investigated category decisions to words presented very shortly (15 ms) in the upper and lower parts of the peripheral and parafoveal fields. 7 subjects were better at discriminating words presented in the UVF, and 6 subjects showed an advantage for the LVF. 12 subjects showed either no bias or an inconsistent bias. McCann, Folk, and Johnston (1992) investigated the effect of spatial attention on lexical decisions to words and pseudowords. Statistical analysis of stimulus position (UVF versus LVF) was only reported for one experiment (experiment 1), showing no reliable effect of visual field. A recent experiment by Hagenbeek and Van Strien (2002) investigated visual field asymmetries for face matching, letter naming, and lexical decision. No differences between the upper and lower visual field were found for lexical decision. Goldstein and Babkoff (2001) performed a number of experiments specifically directed at investigating lexical processing in the upper and lower visual fields. Remarkably, the results of Goldstein are opposite to the present results, showing an UVF benefit for lexical decisions to words, but no field effect to pseudowords. Clearly these results are inconsistent. Although it seems possible to find differences with respect to word processing in the upper and lower visual fields, it may be very difficult to predict in which visual field an advantage will occur.

However, as suggested by Goldstein and Babkoff (2001) the UVF advantage for word reading may be explained by the facility of access to the ventral pathway in which visual word recognition is believed to take place (e.g. Kuriki et al., 1998; Pugh et al., 2000). Oppositely, words presented in the LVF may benefit from specialization in the dorsal pathway. Several experiments by Smith and co-workers (Smith & Jonides, 1997, for an overview) have suggested a role for the left posterior parietal cortex in the storage of verbal phonological information. A recent model by Hickok and co-workers (e.g. Hickok, 2000) proposes that the posterior parietal area mediates between an articulatory system (Broca's area) and a phonological system for speech recognition (Wernicke's area). Hence, a possible advantage for LVF words may be superior phonological processing in the dorsal pathway. Although this interpretation is highly speculative, it may explain the differences in experimental results. If the experimental conditions put a strong emphasis on visual (word form) processing, there may be an advantage to words presented in the UVF. If on the other hand the task emphasizes phonological processing, there may be an advantage to LVF words. In the experiments performed by Goldstein and Babkoff (2001), words were only presented shortly (150 ms), which may have put emphases on visual word form recognition in the ventral visual pathway. In the present study, subjects were required to verbally repeat the words during practice trials, which may have led them to adopt a strategy which involved phonological encoding and covert articulation. Furthermore, words and pseudowords were presented for a much longer time (1000 ms), as compared to the experiments performed by Goldstein and Babkoff (2001). Clearly, additional research is necessary to develop a better understanding of word processing differences in the upper an lower visual fields, and the conditions under which these effects occur.

3.4.2 Word-type differences

Analyses of reaction times and errors were found to show differences between the four experimental sets of words. Both words denoting manipulable objects with a LVF bias (e.g. "shoelace"), and words referring to nonmanipulable objects with a bias towards the UVF (e.g. "chimney"), showed an advantage in reaction time speed and accuracy, compared to the other two word categories denoting manipulable objects with an UVF bias (e.g. "clothesline"), and nonmanipulable objects with a bias toward the LVF (e.g."railway"). See Figure 3.2 on page 39. The difference between word-types cannot be explained by differences in word length and written frequency since all four sets had been equated on these variables. However, the specific pattern of results suggests a possible correspondence with the natural frequency of manipulable and nonmanipulable objects in the upper and lower visual fields. Since manipulable objects more frequently occur in the LVF, and nonmanipulable objects are said to be biased to the UVF (Previc, 1990), these may be more typical, as compared to the other two categories (Das-Smaal, 1990). Lexical decision responses to words denoting objects from the four different classes may have reflected an advantage for LVF manipulable objects and UVF nonmanipulable objects since these types of objects are more representative of the natural organization of elements in the visual world (Hayes-Roth & Hayes-Roth, 1977).

3.4.3 Manipulability and interactions with visual field

The main focus of the present study was directed at the organization of semantic memory in the brain. It was hypothesized that the organization of semantic knowledge follows the distribution of function within the visual system. With the dorsal visual stream having specialized for object manipulation, we expected that semantic memory for manipulable objects would be stored within, or close by to regions subserving the manipulation of objects. Alternatively, the specialization for object recognition within the ventral stream was expected to be associated with storage of the visual semantic properties of objects. In order to investigate this, we made use of the existing crossed organization within the visual system which directs visual information from the LVF to the dorsal part of the visual cortex, and visual input from the UVF to ventral areas. Since the focus of the present study was specifically directed at the distribution of semantic knowledge, we presented words referring to manipulable objects and nonmanipulable objects, instead of presenting the objects themselves. An advantage was expected for manipulable words when presented to the LVF (dorsal stream), while nonmanipulable words were expected to benefit from presentation in the UVF (ventral stream).

Consistent with these expectations, behavioral analysis of responses to manipulable and nonmanipulable words showed that processing of manipulable words was more accurate (less errors) when presented to the LVF. Nonmanipulable words on the other hand showed an advantage when presented to the UVF. An important fact, however, is that this pattern of results was only found for repeated target words when the same word, presented as a prime, had been in the LVF. We had assumed beforehand that effects of semantic distribution may only become evident with repeated presentation of the same items. However, the fact that the significant interaction between manipulability and target-location was only observed when the prime had been in the LVF did come as a surprise. We speculate that stronger priming effects from words presented to the LVF may have provided the necessary conditions for this effect to occur.

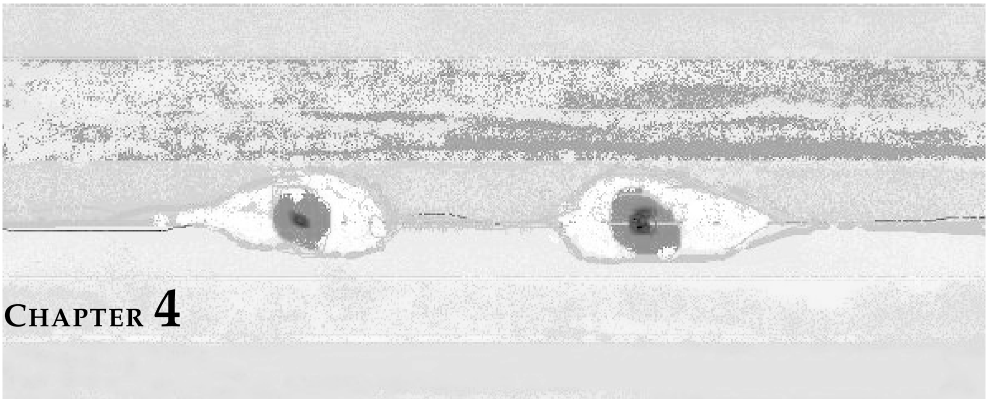
3.5 Conclusion

We consider the present results supportive of the hypothesized relationship between visual specialization (in dorsal and ventral streams) and the distribution of semantic function. Both the pattern of results, and the level of significance (F=13.64) strongly argue in favor of the idea that semantic processing of manipulable items is biased towards the dorsal visual stream, and semantic processing of nonmanipulable items is biased to the ventral stream. The dependence of this result on the presence of a LVF prime, suggests that the organization of semantic memory may only become apparent under specific experimental conditions, such as repetition priming. Priming may be necessary to (pre-) activate the relevant features of manipulable and nonmanipulable words for them to be directly activated by the presentation of the word within the appropriate visual field.

The general advantage for words in the LVF suggests that there are qualitative differences between language processing for words in the upper and lower visual fields which may be related to functional differences in the dorsal and ventral pathways. We consider the present results to be an invitation for further research directed at the organization of language function and semantics in the dorsal and ventral visual areas. It is our belief that more frequent use of the upper and lower visual fields, in addition to the more generally investigated left and right visual half fields, will add to a broader and more complete understanding of semantic organization and language function in general.

Part II

Event-related Potentials



CHAPTER 4

An Event-related Potential Investigation of the Relationship between Semantic and Perceptual Levels of Representation

The present study was conducted to investigate relationships between semantic and perceptual levels of representation. A picture - word repetition paradigm was used in which we manipulated the semantic relationship between pictures and words. Experiment 1 involved two types of trials, one with words that had the same meaning as pictures, and one with words that were unrelated to pictures. In Experiment 2 we replaced words that were identical in meaning with words that are semantically associated to pictures.

In both experiments, visually presented probe stimuli were used to determine the presence of perceptual effects within the visual system, originating from the semantic interaction between words and pictures. In both experiments, conditions with unrelated picture - word pairs generated a search process following the N400 which included processing within the visual system. Probe stimuli were found to attenuate the amplitude of the search related negativity. The latency of the interaction, which was significant at the time of the N1 response to the probe, suggested that the attempt to find a relationship between the picture and the word involved processing within extrastriate visual areas. UVF probes provided stronger attenuation, possibly because the UVF has direct transmission to the ventral processing stream which is believed to be involved in visual semantic processing.

Semantic interactions between matching picture - word pairs in experiment 1 were found to have an effect on the ERPs to probes presented at the same location as pictures. Probes pre-

sented under these conditions showed a stronger P2 over frontal areas followed by a more negative P3 over occipital areas. Although we had expected beforehand to find earlier effects in the latency of the probes' P1 and N1 responses, this result is consistent with the idea that retinotopic levels of object representation are linked with the semantic level of object description. Unlike experiment 1, same location probes presented in associated picture - word conditions of experiment 2 did not result in any specific ERP effects on the P2 and P3 components. This suggests that semantic interactions between pictures and words do not automatically propagate to the perceptual level, unless there is direct reference from the word to the visual representation of the object.

4.1 Introduction

Although language research has long been considered a separate cognitive domain, more and more evidence suggests that language is integrated with, and shares neural resources with other cognitive functions. While there are numerous examples that may be put forward to make this point (e.g. Just & Carpenter, 1992, for the use of executive working memory in language), perhaps the most compelling evidence is found in the area of research which is directed at the organization of semantic memory.

Both the neuropsychological literature and recent neuroimaging experiments suggest that knowledge of concrete concepts is distributed in modality specific brain regions. The neuropsychological literature (e.g. Silveri & Gainotti, 1988; Warrington & McCarthy, 1994; Saffran & Schwartz, 1994; Coltheart et al., 1998; Humphreys & Forde, 2001) describes patients with selective impairments of visual or functional knowledge after specific brain damage. The selective loss of visual or functional knowledge may express itself in category-specific impairments of living things or nonliving artefacts or tools. Loss of visual knowledge affects mainly living things (e.g. animals or fruits) since items belonging to this category are mainly defined by their visual appearance. Loss of functional knowledge or motor knowledge on the other hand affects mainly artefacts or tools since these items are mostly defined by their functional properties. Corresponding evidence is provided by neuroimaging studies (e.g. Gauthier, Anderson, Tarr, Skudlarski, & Gore, 1997; Kounios & Holcomb, 1994) that investigate the organization of concrete semantic information in the brain. A study by Martin et al. (1996) for instance found that picture naming of animals was associated with increased activity in the left medial occipital lobe, while naming of tools selectively activated the left middle temporal gyrus which is also activated by imagined hand movements and is adjacent to an area which is sensitive to object motion. In addition tool naming activated a region in the left premotor area which is also activated by generation of action words.

Several theories that concern the organization of conceptual information in the brain have derived from the assumption that words referring to concrete objects activate specific experiences which have been recorded in previous interaction with these objects (Allport, 1985; Damasio et al., 1996; Tranel et al., 1997). According to Pulvermüller (1999a), when the meaning of a concrete content word is being acquired, the learner may be exposed to stimuli of various modalities related to the word's meaning, or the learner may perform actions the word refers to. This process of co-activation results in the development of a functional unit or cell assembly that links the word's phonological features with visual and action properties in sensory and motor areas of the cortex. Neurons in a cell assembly are said to act together as a group, resulting in so-called ignition of the assembly if a sufficiently large number of assembly neurons are activated.[1] According to Fuster (1999) both episodic and semantic memories may be considered as (short-term memory) activations within a (long-term memory) cortical network that has formed connective links by experience. Most theories that have proposed a distributed account of semantic memory would argue that activated visual semantic knowledge is encoded in or near to visual perceptual cortical areas. Whether we see an object (e.g. an apple), or read its name ('apple') does not really matter in this perspective, since both types of stimuli should result in the same pattern of activation that reflects our earlier experience with the object. However, it is by no means certain whether the structures that are used to represent visual semantic information are also directly involved in perception (e.g. see Martin et al., 1995; Kellenbach, Brett, & Patterson, 2001).

The current study was performed to increase our understanding of the relationship between semantic and perceptual representation. While previous reports have mainly been involved with the long-term representation of semantic knowledge, the current study focused on the short-term activations within semantic memory. The question is addressed whether semantic and perceptual features are temporarily connected in the short-term representation of concrete objects. In order to investigate this question a picture - word repetition paradigm was used, in which we manipulated the semantic relationship between pictures and words, in two different experiments. Experiment 1 involved two types of trials, one with words that had the same meaning as pictures (matching words), and one with words that were unrelated to pictures (unrelated words). Matching words were expected to connect with the semantic representation of pictures, and, as a result, reinforce the object representation. If perceptual features are linked to the object's semantic representation, we should expect to find effects of matching words at the perceptual level. Experiment 2 involved a similar setup as in experiment 1, but included words that are only semantically associated to pictures.

The paradigm that was used involved the presentation of line-drawings depicting common objects, such as tools, animals, plants, buildings, and so on, viewed from an ordinary perspective. A recent series of fMRI studies by Kourtzi and Kanwisher (2000) showed considerable overlap between neural structures activated by

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[1] The same principle of cortical association lies at the heart of electrophysiological experiments that investigate neural synchronization and coherence between various structures in the brain (e.g. Weiss & Rappelsberger, 2000; Klimesch, 1999; Koch & Crick, 1994).

gray-scale images (vs their scrambled controls) and line-drawings (vs their scrambled controls), in the ventral visual pathway. In a second experiment they found a reduced response when objects were repeated, independent of whether they appeared in the same or a different format (gray-scale image or line-drawing) (also see Kanwisher, Chun, McDermott, & Ledden, 1996). A related result has been reported by Halgren, Raij, Marinkovic, Jousmäki, and Hari (2000) using EEG and MEG recordings to a variety of different images, including photographs and schematic drawings of faces. Both photographed and schematic faces generated dipole activation in the fusiform gyrus in the ventral visual stream, as compared to other scrambled and unscrambled images. However, schematic faces resulted in 30% less activation as compared to face photographs. This may explain why neuropsychological patients with deficits in shape perception are often more impaired in recognizing line-drawings than gray-scale photographs (Farah, 1990). These results suggests that the neural processing of schematic images corresponds to the processing of photographic images of objects.

Pictures of line-drawings were presented in the upper or lower visual field and had to be identified without accompanying eye movements. Subsequently a word was presented in the center of the screen. In half the cases, words were the appropriate verbal label for the picture (matching words), while in the other half of the cases, words were used that were unrelated to pictures (unrelated words). Matching words were expected to increase activation of the object representation, and additionally increase activity in those cortical areas which had been involved in perceptual analysis of the picture. In case an object had been presented to the upper visual field (UVF), we would expect to find increased activation for those areas of the visual cortex that are responsive to the UVF. For objects presented to the lower visual field (LVF), matching words should result in increased activation in those areas of the visual cortex that are responsive to the LVF. In order to determine the presence of retinotopic effects in trials with matching picture - word pairs, we used probe stimuli, presented at the location of the object, or at the opposite vertical location on the screen. There was no behavioral task associated with the presentation of probes. The main function of probes was to generate ERPs that may inform us about the state of the perceptual system at the time of their presentation. Trials with matching words were expected to modify the ERPs to same location probes. The advantage of using ERPs to study this specific question is that it affords a high temporal resolution view of the processing of information in the brain. If the semantic relationship between words and pictures is effective in modifying aspects of processing within the perceptual system, then we may expect to find early bottom up effects (modulation of P1 and N1 amplitude) on the ERPs to same location probes over the posterior visual cortex. Amplitude enlargement of the P1 and N1 components are typically found for stimuli presented at attended locations (reviews in Mangun & Hillyard, 1995; Wijers, Mulder, Gunter, & Smid, 1996). Similar effects have been observed for task-irrelevant probe stimuli that were presented at locations where a task-relevant stimulus was memorized (Awh, Anllo-Vento, & Hillyard, 2000; Driver & Frith, 2000).

4.2 Method

4.2.1 Subjects

A total of nineteen subjects participated in the experiment, three of whom were excluded from analysis (either because of technical problems or inappropriate task performance). All remaining sixteen subjects (8 male, 8 female, aged 18 - 30 (mean age of 22)) were right handed, healthy, and had normal or corrected-to-normal vision. Subjects were paid a standard experimental fee for participation.

4.2.2 Materials

The stimuli used in experiment 1 consisted of pictures, words, and probes. Pictures were selected from three partially overlapping sets of line-drawings, which were designed and tested by Snodgrass and Vanderwart (1980), Martein (1995), and Cycowicz et al. (1998). This resulted in 455 distinct pictures which were selected for a pretest which was used to determine whether a consistent verbal label for each picture exists in the Dutch language. Per picture a minimal criterion of 50% name agreement was set (total mean name agreement was > 80%). This generated 416 pictures and 416 corresponding words. Unrelated words were selected by 1) creating 208 pairs of words out of the original list of 416 related words which were selected by closely matching for word length and word frequency (using the logarithmic transformation of the number of occurrences of the written word in the CELEX database consisting of 42 million words (Burnage, 1990)), and 2) selecting an unrelated word with a similar word length (related words: 6.51 letters (SD 2.6), unrelated words: 6.51 letters (SD 1.9)) and a similar written frequency (related words: 0.67 (SD 0.65), unrelated words: 0.66 (SD 0.53)). See the appendix for chapter 4 on page 148 for the matching and unrelated words used in this experiment. The presentation of pictures and word pairs was balanced across subjects such that for half of the subjects a certain picture was followed by a related word, while for the other half of the subjects the same picture was followed by its matched unrelated word.

Interspersed with the selected set of pictures and words, pseudo-pictures (Martin, Wiggs, Altemus, Rubenstein, & Murphy, 1995) and pseudowords were presented, paired with 16 additional words and 16 line-drawings respectively.

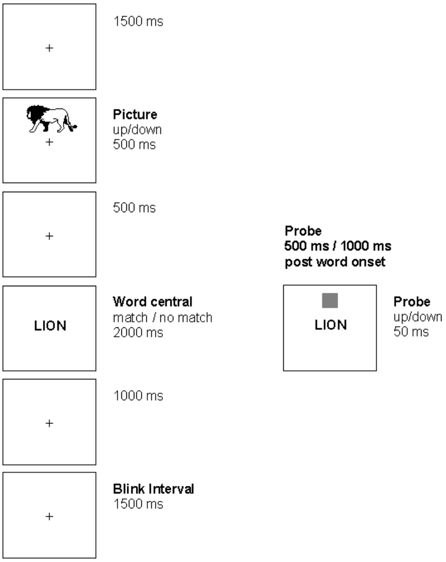

Figure 4.1: Example of a trial.

4.2.3 Procedure

Subjects were seated in a dimly lit, sound attenuated, and electrically shielded cabin facing a computer screen at a distance of 45 cm with their head in a chin-rest. Chair and chin-rest were adjusted to fit individual demands. The index finger of the subject's right hand rested on a touch-sensitive response box which recorded a response when the finger was lifted. A Pentium computer controlled the experiment, which was divided in 8 blocks of 56 trials, preceded by a number of practice trials. See Figure 4.1 for an example trial.

At the beginning of each trial a central white crosshair, on which subjects were instructed to fixate, was displayed in the center of a black computer screen for 1500 ms.[2] Then, a picture appeared on the screen, either above or below the central fixation (6.65 visual degrees of distance between the fixation point and the middle of the picture), and stayed on for 500 ms. Subjects were instructed to identify the picture without making eye movements towards the location of the picture. Eye movement behavior was continuously monitored during the experiment using both online recorded EOG, and a video camera zoomed in on the subject's eyes. After disappearance of the picture, a 500 ms inter stimulus interval followed after which a word was presented covering the central fixation point. In 50% of all cases the word was the verbal label for the picture, while in the other cases it was unrelated to

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[2] All stimuli were presented in white on a black background, unless stated otherwise.

the picture. Subjects were not informed about this relationship beforehand, but all reported having noticed the frequent presentation of words denoting a previously presented picture.

Although the relationship between pictures and words is a critical factor in the experimental design, the actual task to be performed by the subjects was not explicitly directed at this relationship. Rather, subjects were instructed to respond to occasional pseudo-pictures and pseudowords. A total of 32 out of 448 trials contained a pseudo-item (16 trials with a pseudoword, and 16 trials with a pseudo-picture). Subjects were informed that only one pseudo-item could be presented per trial, and were instructed to respond as quickly as possible whenever a picture or word was not identified. The third stimulus in a trial was a visual probe stimulus (a filled square 3.77 degrees wide and high) that was presented during presentation of the word for 50 ms, either at the location of the previous picture or at the opposite location on the screen (6.55 degrees from center to crosshair). Probes were presented at one of two different latencies (500 ms or 1000 ms post word onset) to examine the state of the perceptual system in trials with matching and unrelated picture - word pairs. There was no task to be performed to probes. Rather, subjects were instructed to ignore their presence. Following the word, a 1000 ms fixation interval, and a 1500 ms blink interval ended the trial. During the blink interval the fixation point turned green, signaling to subjects the opportunity to blink their eyes. The blink interval was included to reduce the number of blinks in critical ERP intervals.

4.2.4 EEG recordings

The electroencephalogram (EEG) was recorded with 37 Sn-electrodes placed in an electrocap (Electro-Cap international) at positions Fp1, Fp2, Fz, F3, F4, F7, F8, FC3, FC4, FC7, FC8, Cz, C3, C4, T7, T8, TP7, TP8, Pz, P3, P4, P7, P8, P9, P10, POz, PO3, PO4, PO7, PO8, PO9, PO10, Oz, O1, O2, O9, and O10 according to the revised 10-20 system as presented by Pivik et al. (1993). Electrodes were referred to the left and right mastoids. Bipolar horizontal EOG was recorded via two Sn-electrodes situated on the outer canti of the left and the right eye. Bipolar vertical EOG was recorded with two Sn-electrodes placed above and below the left eye, one on the cheekbone and one above the eyebrow. The ground electrode was on the sternum. Electrode resistance was kept below 2K-Ohm. EEG and EOG signals were amplified (EEG: 0.2 mV/V; EOG: 0.5 mV/V; time constant: 10 sec.), sampled at 1000 Hz, digitally lowpass filtered with a cutoff frequency of 30 Hz and reduced to a sample frequency of 100 Hz on-line.

4.2.5 Data Analysis

Experimental design

A total of 16 stimulus categories were defined by four within subject factors: PICLOC (pictures presented in the UVF versus pictures presented in the LVF), MATCH (words that matched the picture versus words that did not match the picture), PROBELOC (probes presented in the UVF versus probes presented in the LVF), and PROBELAT (probes presented at 500 ms post word onset versus probes presented 1000 ms post word onset).

Behavioral analysis

Analysis of pseudo-items was performed separately for pseudowords and pseudo-pictures. Multivariate analyses of variance (MANOVA repeated measurements) were carried out separately for reaction times to correctly identified pseudo-items (hits), and for the number of undetected pseudo-items (misses). Inappropriate responses to genuine items (false alarms) were analyzed in a similar fashion, with separate analyses for the number of false alarms and the reaction times of false alarms.

ERP analysis

ERPs were calculated for a 3000 ms interval encompassing picture, word, and probe stimuli, running from 100 ms before picture onset until 100 ms before word offset. For each stimulus category separate ERPs were calculated per individual electrode. Trials containing amplifier artefacts, and trials with vertical eye movements were excluded from analysis, as were trials with false alarms and trials in which pseudo-pictures or pseudowords had been presented. Blinks and small horizontal eye movements were corrected using the ocular correction method of Gratton, Coles, and Donchin (1983). Averaged ERPs were aligned to a 100 ms pre-stimulus (picture) baseline and tested for significance (MANOVA repeated measurements) using separate analyses for each individual 10 ms sample point. To avoid false positives, a statistical threshold of three consecutive samples being significant ($\alpha < 5\%$) was adopted. Four midline electrodes and sixteen lateral electrodes were analyzed in separate statistical designs (only electrodes part of the 10-20 electrode system were selected for statistical analysis), with PICLOC, MATCH, PROBELOC, PROBELAT, and ELECTR as within subject factors. An additional within subject factor HEMI (left versus right hemisphere) was used in the analysis of lateral electrodes.

4.3 Results

4.3.1 Behavior

On average, subjects correctly responded to 81.9% of all pseudo-pictures being displayed. 18.1% remained undetected. The analysis of the number of misses to pseudo-pictures showed an effect of picture location ($F_{1,15}$ = 5.00; $P < 0.041$), with more misses for pseudo-pictures presented in the LVF (23.6%), as compared to the number of misses for pseudo-pictures presented in the UVF (13.0%). Analysis of reaction times showed no significant difference ($F_{1,15}$ = 0.42; $P = 0.528$; LVF=1021 ms, UVF=987 ms). Of all pseudowords 93% were detected correctly (7% misses). Analysis of reaction times and misses to pseudowords showed no significant effects of picture location.

On trials which contained only genuine pictures and words an average of 5% false alarms were registered. It is difficult to determine whether false alarms were made in response to picture stimuli or to words, since responses to both types of stimuli were made throughout the trial. Analysis of the number of false alarms involved two within subject factors, PICLOC (picture location up or down) and MATCH (words identical to pictures versus unrelated picture - word pairs). Both the number of false alarms and the response times of false alarms showed no main effects of either PICLOC or MATCH. However, an interaction between these factors was found ($F_{1,15}$ = 11.45; $P = 0.004$), suggesting differential effects of picture location in matching and unrelated picture - word conditions. In matching conditions, more false alarms were made when pictures had been presented in the UVF (4.9%), as compared to the LVF (3.4%). In unrelated picture - word conditions the effect was reversed, showing less false alarms for UVF pictures (4.3%), than for LVF pictures (5.7%).

4.3.2 Event-related Potentials

Effects of picture location

The presentation of picture stimuli in the upper and lower visual fields yielded a typical pattern of ERP responses. Pictures presented to the LVF generated a prominent N1 response over occipital electrodes, while picture stimuli presented to the UVF, evoked a large occipital P1 response, peaking at approximately the same latency (140 ms post picture onset) as the N1 component. Following the early P1 / N1 difference for upper and lower visual field pictures (110 ms - 200 ms after picture onset; $F_{3,13}$ = 18.440; $P < 0.000$ for the ELECTR * PICLOC interaction in the analysis of midline electrodes) a prolonged occipital difference (relative positivity for UVF pictures) developed from about 300 ms which gradually decayed over the rest of the ERP interval (midline: ELECTR * PICLOC; $F_{3,13}$ = 18.954; $P < 0.000$; significant from

300 ms - 690 ms, 750 ms - 780 ms, 840 ms - 900 ms, 930 ms - 1400 ms, 1410 ms - 1490 ms, 1540 ms - 1590 ms, 2260 ms - 2310, and 2860 ms - 2890 ms after picture onset).

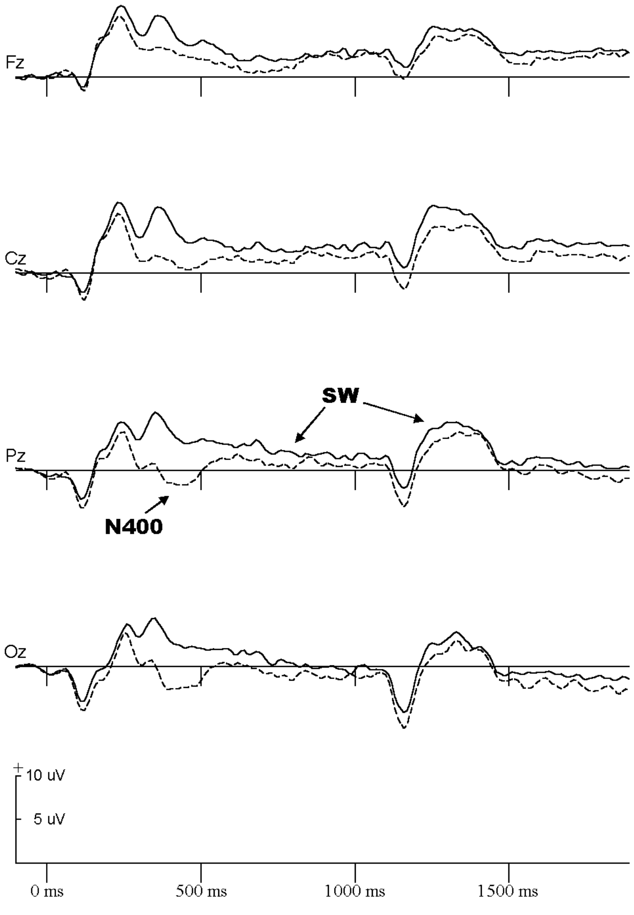

Figure 4.2: Word ERPs. Solid lines represent ERPs to words that match with pictures. Dashed lines display ERPs to words that are unrelated to pictures. The graph shows the -100 ms – 1900 ms ERP interval, relative to word onset. ERP components to probes presented 1000 ms after word onset can additionally be seen in the plot.

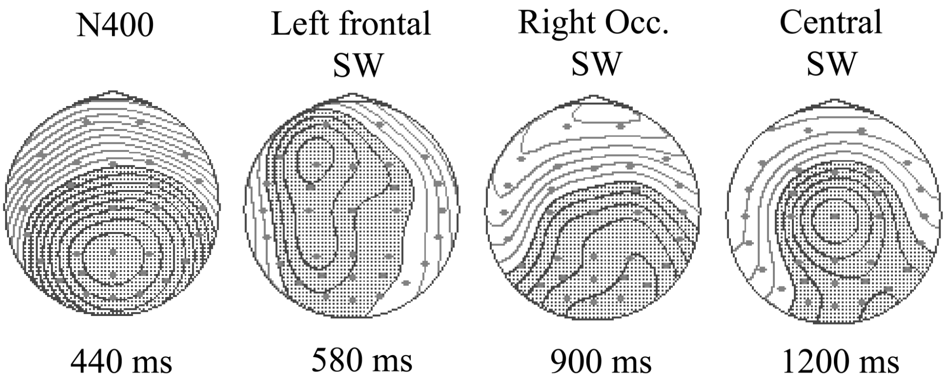

Figure 4.3: Topographic distribution of matching effects at four different latencies. Latencies are relative to word onset. The N400 effect to unrelated words is followed by a negative slow wave (SW) with consecutive foci at left frontal, right occipital and central scalp locations. The distribution of these effects is seen from the top, looking down on the head (nose is pointing upwards). Gray areas reflect negative polarity, white areas show positive polarity. The left map (N400) displays isopotential lines that are separated by $0.8\mu V$. For the two middle maps (left frontal SW and right occipital SW) isopotential lines are separated by $0.4\mu V$. Isopotential lines in the outer most right map (central SW) are separated by $0.2\mu V$

Effects of picture - word matching

Figure 4.2 on the facing page displays the ERPs to words, aligned to a 100 ms pre-word baseline. Unrelated words generated a clear N400 effect, as compared to matching words ($F_{1,15} = 193.15$; $P < 0.000$). The N400 effect was maximal at around the Pz - POz electrode pair. See Figure 4.3 (left) for the distribution of the N400 effect at 440 ms post word onset. A closer examination of the word ERPs displayed in Figure 4.2 on the facing page shows a prolonged negative slow wave following the initial N400. The effect of MATCH continued to be significant until 1590 ms after word onset, while interactions between MATCH and ELECTR were significant until the end of the recording epoch 1890 ms after word onset. Interestingly this prolonged negativity seems to involve three subsequent stages. Following the N400 effect, which is centered on the Pz electrode, the effect of word-type shifted towards the left frontal F3 electrode in the 570 ms -730 ms interval post word onset. Subsequently, from 810 ms - 930 ms, the negative slow wave for unrelated words as compared to matching words shifted towards the right occipital O2 electrode. Finally, from about 960 ms after word onset, the effect of MATCH centered on the central Cz electrode, showing an additional effect over the posterior occipital scalp. Figure 4.3 displays three topographic maps of the post N400 picture - word matching effect, that are considered to be typical of the distribution of the effect as observed in the three consecutive stages.

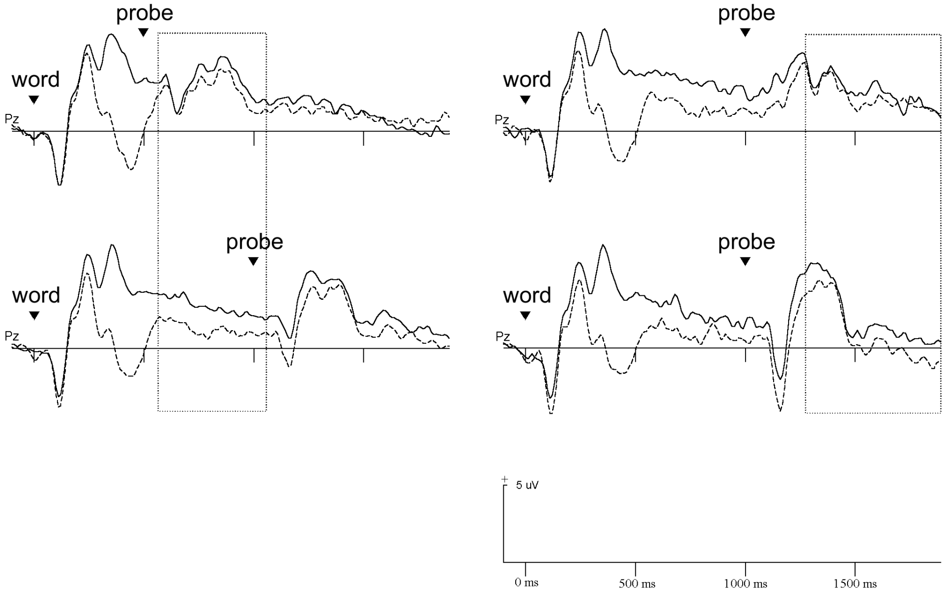

Figure 4.4: Word ERPs at the Pz electrode for matching words (solid lines) and unrelated words (dashed lines), interrupted by probes presented at 500 ms and 1000 ms post word onset. The left panel shows the N400 effect to unrelated words, followed by a post N400 slow wave that is attenuated by the presentation of probes presented at 500 ms post word onset (upper graph), as compared to conditions where probes were presented later in time (1000 ms after word onset; lower graph). The highlighted area (rectangular box) indicates the period that showed interference of early probes, as compared to late probes. The right panel displays ERPs recorded in conditions where probes had been presented at the second probe latency (1000 ms post word onset). The attenuating effect of probes are stronger when probes had been presented in the UVF (upper graph), as compared to conditions where probes were presented in the LVF (lower graph).

Probes interfere with picture - word matching

As can be seen in the left panel of Figure 4.4, the matching process is affected by probes being presented at the first probe latency (500 ms post word onset). The attenuating effect of probe presentation becomes significant shortly after probe onset. The interaction between MATCH and PROBELAT in the midline analysis was found significant at the latency of the probe N1 response (130 ms - 160 ms post probe onset; $F_{1,15} = 6.59$; $P < 0.021$). Compare the inhibition of probes presented at the first latency (top left graph in Figure 4.4) with the ongoing effect in the bottom left graph of Figure 4.4. Interestingly, the attenuating effect of UVF probes was stronger than the effect of LVF probes. This effect was reflected in the analysis of midline electrodes which showed a significant interaction between MATCH, PROBELOC, and PROBELAT ($F_{1,15}$ = 8.38; P $<$ 0.011) in the 280 ms - 350 ms interval following probe onset. The analysis of lateral electrodes showed additional interactions of MATCH, PROBELOC, and PROBELAT, with HEMI (130 ms - 200 ms, 210 ms - 380 ms, and 590 ms - 630 ms post probe; $F_{1,15}$ = 36.57; P $<$ 0.000) in the interval between the first and the second probe (see highlighted period within the left panel of Figure 4.4 on the preceding page). The interactions with hemisphere reflect the attenuating influence of UVF probes on the lateralized effects of the post N400 slow wave.

Probes presented at the second latency (1000 ms post word onset) showed a pattern of attenuation similar to that observed at the earlier probe latency. UVF probes were again more effective in inhibiting the post N400 slow wave than LVF probes. This effect is visualized in the right panel of Figure 4.4 on the facing page which shows the ERPs to matching and unrelated words at the Pz electrode, interrupted by probes presented at the second probe latency. Comparison of the upper and lower graphs shows a stronger attenuation of the post N400 slow wave for conditions with UVF probes (upper graph), as compared to conditions that involved presentation of LVF probes (lower graph). The stronger inhibitory effect of UVF probes was reflected in the MATCH * PROBELOC * PROBELAT interaction in the analysis of midline electrodes (480 ms - 530 ms, and 580 ms - 610 ms post probe onset; $F_{1,15}$ = 10.45; P $<$ 0.006). Analysis of lateral electrodes showed the effect to be significant throughout most of the interval highlighted within the right panel of Figure 4.4 on the preceding page (280 ms - 320 ms, 360 ms - 410 ms, 470 ms - 510 ms, 540 ms - 610 ms, 690 ms - 720 ms, 790 ms - 850 ms, and 870 ms - 900 ms post probe; HEMI * MATCH * PROBELOC * PROBELAT; $F_{1,15}$ = 29.13; P $<$ 0.000).

Retinotopic effects of picture - word matching

The purpose of probe stimuli presented in this experiment was to investigate the possible relationship between semantic and perceptual levels of representation extending into retinotopic visual areas. Matching words were expected to result in feedback to retinotopic areas of the visual cortex that had been involved in the initial perceptual analysis of picture stimuli. Activation within the visual system was expected to affect the early ERP effects to same location probe stimuli. Neither the early ERP components to same location probes presented at the first probe latency (500 ms post word), nor the early responses to same location probes presented at the second latency (1000 ms post word) were found to be affected by the semantic relationship between the picture and the word. Although early visual effects were absent at both probe latencies, the semantic relationship between picture and word was found to modulate later ERP components for probes presented at the second latency (1000 ms post word). As can be seen in Figure 4.5 on the following page, which displays the ERPs to probes presented at the second latency, same location probes presented in matching conditions resulted in a prominent frontal positivity at around the P2 component, 250 ms - 280 ms post probe onset (midline: ELECTR * MATCH * PICLOC

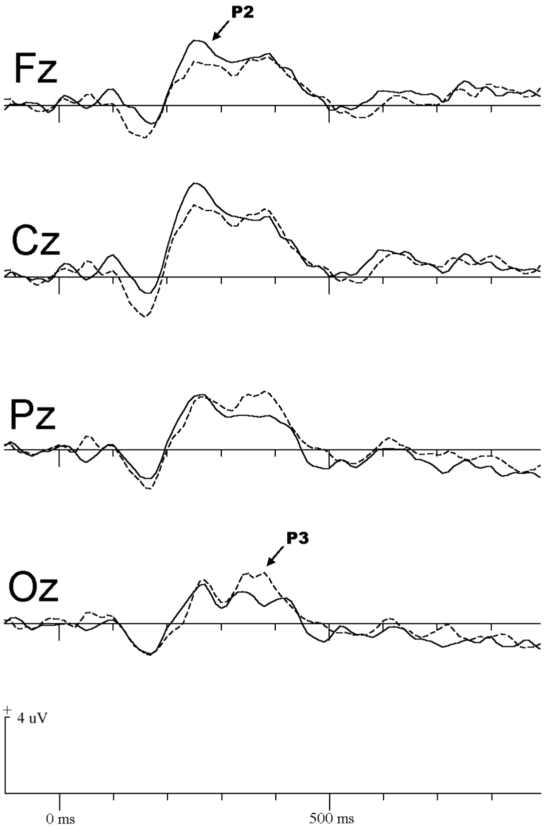

Figure 4.5: ERPs for probes presented at the second probe latency (1000 ms post word onset). Solid lines represent ERPs to same location probes presented in conditions with matching pictures and words (UVF probes and LVF probes pooled together). Dashed lines show ERPs to same location probes presented in conditions with unrelated pictures and words. Same location probes presented in matching conditions elicit a frontal (P2) positivity at approximately 270 ms post probe onset, followed by a central occipital (P3) negativity, with its maximum 380 ms after probe presentation.

* PROBELOC * PROBELAT ($F_{3,13}$ = 3.858; $P < 0.036$)). The frontal effect on the P2 component is shortly followed by a posterior negativity in the 360 ms - 390 ms post probe interval (midline: ELECTR * MATCH * PICLOC * PROBELOC * PROBELAT; $F_{3,13}$ = 6.657; $P < 0.006$). See Figure 4.6 on the next page for the distribution of the P2 positivity and the distribution of the subsequent negativity coinciding with the P3. No interaction between ELECTR * MATCH * PICLOC * PROBELOC * PROBELAT was observed for probes presented at the 500 ms probe latency (P2: $F_{1,15}$ = .133; $P = 0.938$, P3: $F_{1,15}$ = .185; $P = 0.905$).

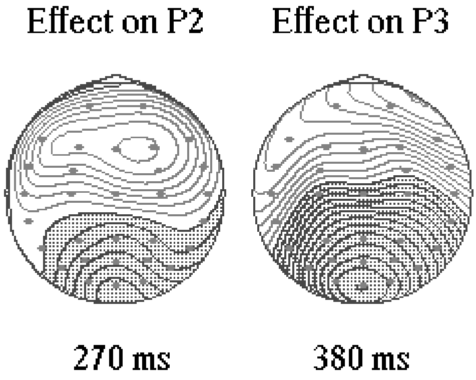

Figure 4.6: Topographic distribution of probe effects. Left: the distribution of the frontal P2 positivity for same location probes presented in conditions where pictures and words matched. Right: distribution of the subsequent occipital negativity at 380 ms post probe onset. The distribution of these effects is seen from the top, looking down on the head (nose is pointing upwards). Gray areas reflect negative polarity, white areas show positive polarity. Isopotential lines are separated by 0.1μV.

Although there were no specific P1 - N1 attention effects to same location probes presented in matching conditions, one might suspect that subjects shifted attention towards the location of the picture in both matching and unrelated picture word conditions. However, ERPs did not show any indication of increased P1 - N1 components for probes presented at the same location as pictures. Both the analysis of midline electrodes and the analysis of lateral electrodes showed no significant interactions between ELECTR, PICLOC, PROBELOC, and PROBELAT in the latency range of the P1 and N1 components to probes presented at either the first or the second probe latency. However, although there were no endogenous effects of attention being directed at the location of the picture, ERPs showed significant exogenous effects for probes presented at the same location as pictures. At both probe latencies, probes presented at the same location as pictures resulted in a broadly distributed sustained negative difference, as compared to probes presented opposite to the picture location. However, the interaction between PICLOC, PROBELOC, and PROBELAT was only reliable for probes presented at the second probe latency (midline: 400 ms - 470 ms post probe; $F_{1,15} = 8.86$; $P < 0.009$; lateral: 440 ms - 470 ms post probe; $F_{1,15} = 7.05$; $P < 0.018$). This negative difference to same location probes is typically observed as an effect of exogenous cueing (peripherally presented pictures acted as an exogenous attentional cue) (Eimer, 1994; van Schie, Wijers, & Mulder, 1997; McDonald et al., 1999). Consistent with the present experimental results, the effects of exogenous or peripheral cueing have been observed to operate within a time-frame of several seconds (e.g. Posner & Cohen, 1984b; van Schie et al., 1997). See the following section for a more elaborate discussion of this effect.

4.4 Discussion

The purpose of the present experiment was to investigate relationships between semantic and visual levels of representation. A non-explicit picture word repetition priming paradigm was used which included visual probe stimuli to study transient connections between verbal and perceptual levels of representation.

4.4.1 Picture - word matching and interactions with probes

Picture - word repetition was found to result in clear effects on the N400 component to words, with unrelated picture - word pairs generating more negative ERPs than matching picture - word pairs. The N400 effect reached its maximum at around 440 ms post word onset, with a distribution centered over the posterior parietal scalp. Following the N400, a sustained slow wave continued which was observed to involve three consecutive stages. The first stage (570 ms - 730 ms post word onset) showed a left frontal negative slow wave for unrelated versus matching words. In the second stage, the center of the sustained slow wave shifted towards scalp locations overlying the right occipital cortex (810 ms - 930 ms post word onset). In the third stage (960 ms - 1900 ms post word onset) the slow wave centered on the Cz electrode in the middle of the scalp. Although effects succeeding the N400 interval are not uncommon (e.g. McPherson & Holcomb, 1999), the distribution and polarity of these effects seem to vary with the type of stimuli and tasks that are used (e.g. Holcomb, 1988; Ganis, Kutas, & Sereno, 1996). Previous research has demonstrated localized slow wave activity for retrieval from long-term memory (LTM) (review in Roesler, Heil, & Hennighausen, 1995), with a left frontal distribution for the retrieval of verbal information, a parietal distribution for spatial information, and a right occipital distribution for the retrieval of color information. Comparable effects have been observed in studies directed at the organization of working memory, with left frontal slow wave activity for retention of verbal information (Ruchkin, Johnson Jr, Grafman, Canoune, & Ritters, 1992; Ruchkin et al., 1994), and posterior negative slow waves for the retention of visuo-spatial and visuo-object information (Ruchkin, Johnson Jr, Grafman, Canoune, & Ritters, 1997; Mecklinger & Muller, 1996). Right occipital slow wave activity during object retention has been observed by Löw, Rockstroh, Hauk, Berg, and Maier (1999). Negative slow waves centering on the Cz electrode have been consistently observed for conditions where subjects had to compare presented items (letters) to a memory set of varying size (e.g. 1 letter memory set versus 4 letter memory set) (Okita, Wijers, Mulder, & Mulder, 1985; Wijers, Mulder, Okita, & Mulder, 1989a; Wijers, Mulder, Okita, Mulder, & Scheffers, 1989b). A prolonged negativity over Cz is thought to reflect a serial search of memory (Shiffrin & Schneider, 1977).

The ERP results discussed above suggest a possible functional interpretation of the slow wave activity recorded over left anterior and right occipital cortices in the present study. Trials with unrelated picture - word pairs first generated a clear N400 effect, as compared to trials with matching picture - word pairs. The general conception of the N400 effect is that it reflects an attempt for semantic integration in conditions with semantically unrelated items. The smooth transition between the N400 effect and the post N400 slow wave suggests that lack of success in integration causes subjects to initiate an additional search for a relation between the word and the picture. The initial left frontal distribution of the effect may reflect retrieval and/or maintenance of additional verbal information from LTM. The shift towards the right occipital area may reflect the additional activation of visual or visual semantic information in right occipital cortex. The third stage of the slow wave negativity, centered over the Cz electrode, may reflect further search of memory in the attempt to find a match between the picture and the word.

The early probe was presented just as the N400 transited into slow wave activity. Slow wave activity to unrelated words was significantly attenuated by visual probe stimuli presented at the first latency. This effect is consistent with the proposal that parts of the visual system are involved in the continuing attempts to match word and picture in the unrelated condition. Although probe stimuli had no task relevance, and subjects had been explicitly instructed to ignore them, probes clearly attenuated match related processing that followed on the N400. This would suggest that picture - word matching, at least in its initial stages, overlaps with processes within the visual perceptual system.

More direct evidence for this suggestion comes from the fact that the interaction of probes with the post N400 slow wave was already significant in the latency range of the N1 component elicited by the probe. Both the latency of this interaction, and previous suggestions on the neural locus of the N1 (e.g. Mangun, Hillyard, & Luck, 1993), suggest that picture - word matching may recruit areas in extrastriate visual cortex. Hence, the current data provide a number of arguments that consistently point towards the visual perceptual system being involved in picture - word matching.

It must be clear however that the search related visual processing does not reflect increased attention or additional processing directed at the picture's visual (retinotopic) representation. Directing attention in space has been associated with a series of positive and negative deflections over posterior and central cortical areas (Mangun, 1994). In the current study we only found negative slow waves for unrelated picture - word pairs. In addition, spatial attention directed at a certain (retinotopic) location in space has been consistently found to result in enlarged P1 and N1 amplitude for stimuli presented at the attended location (e.g. Hopfinger, Jha, Hopf, Girelli, & Mangun, 2000). In the present study there were no P1 - N1 attention effects to same location probes presented in unrelated picture - word conditions. Rather, ERPs showed a sustained negative potential to same location probes versus probes presented opposite to the location of the picture. This effect is typically observed when attention is attracted by a peripheral exogenous stimulus (in this case the presentation of the picture). A marked characteristic of exogenous cueing of attention is that it will result in the activation of 'inhibition of return' which is thought to inhibit attention from returning to the cued location.[3] Rather than signalling the presence of spatial attention being directed at the location of the picture, ERP effects signal the absence or inhibition of spatial attention at the location of the picture. A final argument that is in contradiction with the idea that search related negativity reflects attention towards the picture is that the interference effect of probes is not limited to same location probes. That is, if the post N400 slow wave to unrelated picture - word pairs would reflect attention being directed at the location of the picture, than we would have expected stronger interference by probes presented at that location.

The interference effect of probe stimuli was stronger when probes had been presented to the UVF, as compared to conditions where probes had been presented to the LVF. We speculate that UVF probes may have had more success in interfering with the search for a relationship because UVF stimuli are directly transmitted to the ventral occipital stream (e.g. Previc, 1990; DeYoe et al., 1996), in which (visual) semantic properties are presumably processed (e.g. Damasio et al., 1996; Martin et al., 1996; Jeannerod, 1997). The UVF advantage for the detection of pseudo-pictures, which was observed in the behavioral analysis, is consistent with this idea.

In sum, both the distribution of the post N400 slow wave effect and the interference by probes strongly suggest that semantic processes in unrelated picture - word conditions invoke visual match related processes in extrastriate visual areas. Furthermore, stronger interference from UVF probes suggests that this process is biased towards ventral parts of the visual cortex.

4.4.2 Retinotopic effects of picture - word matching

Although the previous discussion noted significant interactions between semantic and perceptual levels of representation in conditions where search for a semantic relation is necessary, the purpose of the present experiment was directed at investigating effects of matching picture - word pairs. More specifically, a semantic match between picture and word stimuli was expected to activate the visual memory trace

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[3] There are relatively few studies that have investigated the ERP effects of exogenous cueing. Although most of these have found similar ERP effects as in the present study, it is not entirely clear whether the negative difference to same location probes really reflects inhibition of return, or arises from sensory refractoriness of the cue (McDonald et al., 1999). We however believe that the negative difference to same location probes is a genuine signature of inhibition of return. In a previous study directed at the inhibition of return effect (van Schie et al., 1997), we observed a similar negative difference effect for probes that were presented at the same environmental locus as the exogenous cue, but at a different retinotopic location (the eyes moved towards a different location in the interval between the cue and the target). This would argue against sensory refractoriness being the main cause of the effect.

of the picture, feeding back into the same regions of the visual cortex that had been involved in the initial processing of the picture. Feedback towards the visual system was expected to influence the bottom-up processing of visually presented probe stimuli, resulting in early ERP (P1 - N1) attention effects for probes presented at the same retinotopic location as pictures.

Conditions with probes presented at the first latency (500 ms after word onset) showed no significant interaction between picture location, probe location, and picture - word matching. ERPs to same location probes presented at the later probe latency (1000 ms after word onset) did show effects of matching between the picture and the word. However, the ERPs showed no early influence on bottom-up visual processing of the probe within the latency range of the P1 and N1 components (100 ms - 200 ms after probe onset). The earliest significant ERP effect was in the latency of the P2 component, 250 ms - 280 ms after probe onset, showing a more positive amplitude at midline anterior recording sites, for same location match probes, as compared to the other three probe conditions. Following the effect on the P2, ERPs were more negative over midline occipital-parietal electrodes in the latency of the P3 (380 ms post probe onset).

The finding of specific ERP effects for same location probes presented in matching picture - word conditions is consistent with the idea that retinotopic levels of picture representation are somehow involved in the matching between pictures and words. However, we cannot argue that the semantic matching between the picture and the word actually fed back to and re-activated the retinotopic levels of picture representation within the visual system. Only the finding of effects on ERPs related to early visual processing of same location match probes would have allowed for such a conclusion. Although it is certainly not impossible that visual processing was also engaged in conditions with matching pictures and words, the coarse probing method that was used in the present paradigm may have failed to overlap with this process. Indeed, results suggest that probes mainly interacted with processes directed at establishing a relationship between unrelated picture - word pairs. Conditions with matching picture - word pairs may have resulted in less prolonged processing, since there is no obvious need for further search of memory when a positive match has been established.

How then may we explain the selective ERP effects for same location probes presented in conditions with matching picture - word pairs? The observed pattern of effects over frontal and occipital cortices is certainly not considered to be typical for the involvement of spatial attention, which is thought to operate on the bottom-up processing of visual stimuli by modulating the amplitude of early visual (P1 and N1) components in extrastriate visual areas (Mangun et al., 1993; Heinze et al., 1994; Mangun et al., 2000). Rather, the present results seem to be more characteristic of a top-down activation within the visual system (as opposed to a bottom-up influence on early visual processing that was predicted). Both the order of effects (an initial frontal effect followed by an effect over the visual cortex), and the latency of the effect over the visual cortex, are consistent with this idea.

We speculate that same location probes may have acted to attract attention towards the location at which the picture had been presented[4] which could have triggered the system into re-activating the memory trace of the previous episode (Fuster, 1999). The P2 and P3 ERP effects recorded to same location match probes show some resemblance to the ERP effects of visual object working memory which we investigated in a recent study. Object working memory (retain polygons of different complexity in short-term memory) was found to be reflected in a prolonged frontal positivity, together with a sustained posterior negativity. Although the ERP effects on the P2 and the P3 in the present experiment are only short-lived, the similarity to the ERP effects of visual object working memory does suggest that same location probes may have resulted in a temporary re-activation of the picture's representation within the visual object working memory system. That reactivation only occurs in conditions with matching pairs suggests that the semantic matching between the picture and the word put a strong emphasis on the retinotopic location of the picture. The earlier frontal effect to same location match probes in the latency of the P2 suggests that frontal areas may have retained a memory of the previous matching, while activity in posterior visual areas had already decayed (Fuster, 1999). Although ERP responses to probes were found to reflect the absence of attention at the location of the picture, frontal areas may have preserved a memory for the visual representation of the object, including the information about the retinotopic location of the picture. The exact mechanism via which same location probes may have connected with frontal memory is not clear. A possible answer may be found in the intimate relationship and mutual interdependence that exists between attention and memory (e.g. Desimone, 1996; Fuster, 1999). Both memory retrieval and attention rely on fast and automatic processes, that may be captured by the reflexive properties of peripherally presented probes. Retrieval of visual memory, indexed by the more negative P3 over the occipital cortex may operate via existing top-down pathways from frontal to visual cortical areas (Van Essen, 1985; Desimone & Ungerleider, 1989; Felleman & Van Essen, 1991).

4.5 Experiment 2

Experiment 2 was performed to extend our knowledge of the interactions between semantic and perceptual processes. Results of the previous experiment showed relationships between semantic and perceptual levels of representation. Unrelated picture - word pairs were observed to result in a search process that apparently involved active use of visual information within perceptual areas. In conditions with match-

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[4] Peripheral exogenous cueing has been consistently observed to reflexively attract spatial attention to the location of the cue (Jonides, 1981; Müller & Rabbitt, 1989).

ing picture - word pairs, ERPs to same location probes suggested that probes triggered the retrieval of the picture's representation via a short-term activation within object working memory. Both results are very interesting since they suggest the existence of a coupling between semantic and perceptual levels of representation. It is however possible that these results are very much dependent on the repetition manipulation. The frequent co-occurrence of matching picture - word pairs may have led subjects to use words in order to facilitate the recognition of pictures. Note that picture identification was fairly difficult since objects were presented within the parafoveal field, and subjects were not allowed to make eye movements. This may have introduced a visually oriented strategy in which each word is actively compared with the visual characteristics of pictures. In order to determine how much of the results of the previous experiment may be explained by subjects' usage of a visual strategy we conducted a second experiment using associated words instead of words that have the same meaning as pictures. Associated words have a semantic relationship with pictures but no explicit connection with the picture's visual characteristics.

4.6 Method

4.6.1 Subjects

A total of twenty-one subjects participated in the experiment. None of the subjects had been involved in experiment 1. One participant was excluded from analysis for making too many inappropriate eye movements. All remaining twenty subjects (8 male, 12 female, aged 18 - 33 (mean age of 21)) were right handed, healthy, and had normal or corrected-to-normal vision. Subjects were paid a standard fee for participation.

4.6.2 Materials

The set of 416 pictures that were presented in the previous experiment were used to elicit associations. A total of 35 participants sat in a classroom and noted their first association for each individual picture that was projected on a blank wall of the classroom. Each picture was presented for 7 seconds, and subjects were instructed to write down one-word associations. Subsequently, subjects' associations were analyzed for between subject agreement. A criterion of 50% association agreement across subjects resulted in the selection of 320 pictures and associations. Associations included 40 verbs, 150 nouns, and 19 adjectives. Since quite a few associations were elicited by more than one picture (e.g. 'music' in response to musical instruments) these do not add up to 320. For each individual association, we selected a word of the same type (verb / noun / adjective), word length, and comparable written frequency (from the CELEX data base (Burnage, 1990)), to be presented in unrelated picture -

word trials. This ensured that an equal number of recurrent words were presented in both associated and unrelated picture - word trials. Related and unrelated picture - word pairs were balanced across subjects. See the appendix for chapter 4 on page 148 for the associated and unrelated words for each picture used in this experiment.

As in the previous experiment, a total of 16 pseudo-pictures (obtained from Martin et al. (1995)), and 16 pseudowords were included for presentation. These were paired with 16 additional words and 16 line-drawings respectively which were selected only to be presented for the completion of trials containing pseudo-items.

4.6.3 Procedure

The procedure was similar to the previous experiment. Subjects were presented with line-drawings, words, and probe stimuli, and had to respond to occasional pseudo-drawings and pseudowords. The main difference from the previous experiment was 1) that we presented associated words instead of words with the same meaning as pictures, 2) we presented words in lower case as opposed to upper case for ease of reading, and 3) we restricted probes to be presented at the second probe latency (1000 ms post word onset) as the previous experiment only showed reliable effects to probes presented at this latency. An additional advantage of this limitation is that it compensated for the reduction in the number of line-drawings (320 instead of 416) which affects the number of trials per condition. Similar to the previous experiment we presented subjects with 8 consecutive blocks. Each block included 44 trials.

4.6.4 EEG recording and data analysis

The EEG recording setup was the same as in the previous experiment. Electrode resistance was kept below 5K-Ohm. A total of 8 stimulus categories were defined by three within subject factors: PICLOC (pictures presented in the UVF versus pictures presented in the LVF), ASSOC (words associated to the picture versus words that are unrelated to the picture), and PROBELOC (probes presented in the UVF versus probes presented in the LVF). The calculation of ERPs, artefact rejection, and blink correction was all done in a manner identical to the previous experiment. Statistical analysis was identical to the previous experiment, except for the removal of PROBELAT (probe latency) from the statistical design.

4.7 Results

4.7.1 Behavior

On average, subjects correctly responded to 62.8% of all pseudo-pictures being displayed. 37.2% remained undetected. The percentage of missed pseudo-pictures is noticeable higher than the percentage of missed pseudo-pictures reported in the previous experiment (18.1%). Analysis of the number of pseudo-pictures missed showed a non-significant ($F_{1,19}$ = 1.43; P = 0.247) advantage for pseudo-pictures presented in the UVF (33.8%) as compared to the LVF (41.9%). Reaction times showed no significant ($F_{1,9}$ = 0.03; P = 0.867) effect of visual field (UVF=1202 ms, LVF=1211 ms). Of all pseudowords 91.5% were detected correctly (8.5% misses). Analysis of reaction times and misses to pseudowords indicated no significant effects of picture location.

On trials which contained only genuine pictures and words, an average of 7.6% false alarms were registered (as opposed to 5% in the previous experiment). Response times of false alarms, however, were somewhat slower (1369 ms) in the current experiment, than in the previous experiment (1274 ms). It is difficult to determine whether false alarms were made in response to picture stimuli or to words, since responses could be made throughout the trial. Analysis of the number of false alarms showed that less false alarms were made ($F_{1,19}$ = 8.82; $P < 0.008$) in trials were pictures and words were associated (6.6%), as compared to trials containing unrelated picture and word stimuli (8.6%). No significant difference was observed in the reaction times to trials with associated and unrelated picture - word pairs ($F_{1,19}$ = 1.67; P = 0.219).

4.7.2 Event-related Potentials

Effects of picture - word matching

As expected, unrelated words generated a clear N400 effect, as compared to associated words ($F_{1,19}$ = 23.82; $P < 0.000$), with a maximum at around the Pz electrode. As in the previous experiment the N400 effect was followed by a slow wave negativity for unrelated picture - word pairs, as opposed to associated pairs. The topography of the slow wave effect, and the consecutive stages that were identified in the previous experiment were roughly replicated in the present experimental results. While in the previous experiment the first stage showed a left frontal maximum, in the present experiment a lateralization towards the left side of the scalp was observed. The distribution of this effect varied between maxima over left frontal and left posterior cortical areas. See Figure 4.7 on the following page for the average distribution of this effect at 620 ms post word onset. The second stage of the post N400 slow wave difference, which showed a right occipital maximum in the previous experiment, was found to display bilateral occipital maxima in the present experiment. In the third stage we again observed a central maximum, together with additional effects over left and right occipital cortices. In the previous experiment the distribution of the third stage was found to continue until the end of the recording epoch, but in the current experiment a fourth stage followed which showed a right frontal maximum, together with bilateral occipital maxima (from about 1360 ms post word onset until the end of the recording interval). Figure 4.7 on the next page displays

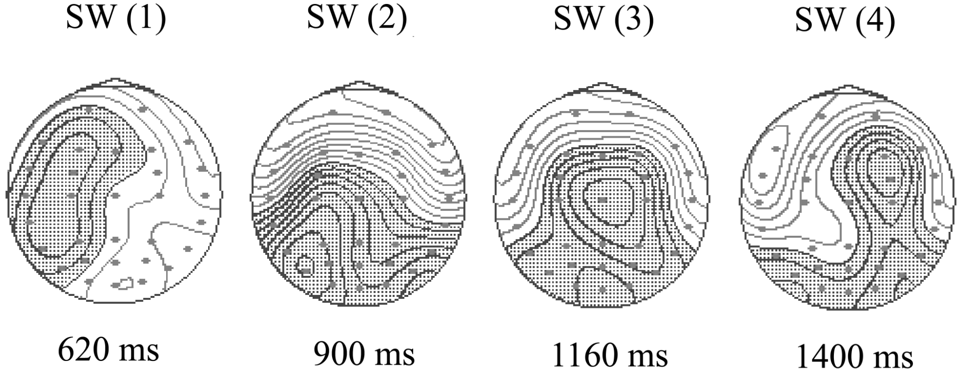


Figure 4.7: Topographic distribution of matching effects at four different latencies. Latencies are relative to word onset. The N400 effect to unrelated words (not depicted here) is followed by a negative slow wave (SW) with roughly four consecutive stages The distribution of these effects is seen from the top, looking down on the head (nose is pointing upwards). Gray areas reflect negative polarity, white areas indicate positive polarity. For the outer most left map, isopotential lines are separated by 0.4μV. Isopotential lines in the other three maps are separated by 0.2μV

the four topographic maps of the post N400 slow wave effect at time points which are typical of the distribution of the effect in the four consecutive stages.

Probes interfere with picture - word matching

As was the case in the previous experiment, probes were found to interfere with the post N400 slow wave pattern. The effect was stronger for UVF probes than for LVF probes. Analysis of midline electrodes found that the effect was significant from 160 ms - 490 ms, 510 ms - 750 ms, and 760 ms - 840 ms post probe (ASSOC by PROBELOC; $F_{1,19}$ = 18.23; $P < 0.000$). A similar pattern of results was observed in the analysis of lateral electrodes, showing significant interactions between ASSOC and PROBELOC from 170 ms - 200 ms, 250 ms - 380 ms, 390 ms - 480 ms, 510 ms - 730 ms, and 760 ms - 860 ms post probe onset ($F_{1,19}$ = 17.49; $P < 0.001$).

Retinotopic effects of picture - word matching

In the previous experiment, ERPs to same location probes presented in matching picture - word conditions were found to elicit an increased amplitude of the frontal P2 component, followed by a more negative amplitude of the P3 component over midline occipital areas, as compared to other probe conditions. Contrary to the previous experiment, same location probes presented in associated picture - word

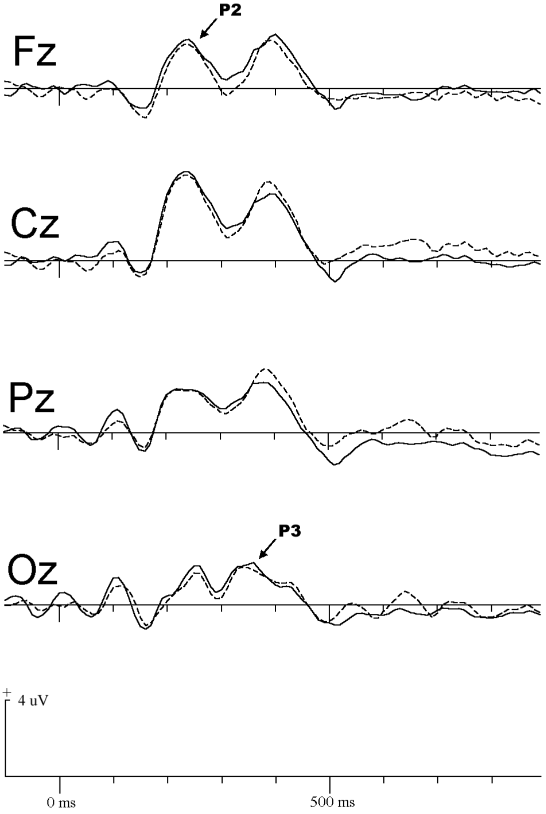


Figure 4.8: ERPs for probes presented at the same location of a previously presented picture. Solid lines show ERPs to same location probes presented in conditions with associated pictures and words (UVF probes and LVF probes pooled together). Dashed lines show ERPs to same location probes presented in conditions with unrelated pictures and words.

conditions did not result in any specific ERP effects, as compared to other probe conditions. Statistically, there was no significant interaction between PICLOC, ASSOC, and PROBELOC, either in the latency of the P2 ($F_{1,19}$ = 0.79; P = 0.514), or in the latency of the P3 ($F_{1,19}$ = 0.70; P = 0.564). See Figure 4.8 for the absence of a difference in the ERPs to same location probes presented in associated and unrelated picture - word conditions.

As was the case in experiment 1 there were no endogenous effects of attention on the P1 and N1 components to same location probes, either in the match or in the unrelated picture - word conditions. Just as was observed in the previous experiment, ERPs to same location probes showed a broadly distributed posterior negative difference as opposed to probes presented opposite to the location of the picture (exogenous cueing effect). Statistical analysis found the effect to be significant from 140 ms - 560 ms after probe onset (midline: PICLOC * PROBELOC; $F_{1,19} = 15.48$; $P < 0.001$; lateral: PICLOC * PROBELOC; $F_{1,19} = 7.17$; $P = 0.015$). Although the interaction between PICLOC and PROBELOC became significant in the latency range of the N1, this effect does not reflect a modulation of the N1 component. Rather, it appears that the negative difference becomes significant parallel to the onset of the probe's N1 response (for a similar pattern of results see Eimer, 1994). The absence of effects within the latency of the P1 further supports the conclusion that spatial attention was not directed at the location of the picture when probes were presented.

4.8 Discussion

The current experiment largely replicated the results of the first experiment. The word - picture relationship was found to result in a strong N400 effect, with more negative ERPs for unrelated than for associated words. The difference between the two categories of words continued and developed into a post N400 slow wave, as was also observed in the earlier experiment. The scalp distribution of the post N400 slow wave effect in the separate stages approximated the topography of the effect observed in experiment 1. Although there were some differences in the exact distribution (possibly due to the use of associated words instead of repetition words, or because of using a different group of subjects), the general trends in the first three stages of both experiments were very similar (SW 1: left hemisphere; SW 2: occipital cortex; SW 3: central and occipital areas). More importantly, the occipital distribution of the post N400 negativity suggests that subjects conducted an additional search for unrelated picture - word pairs, which involved processing within the visual system. As was the case in the previous experiment, this hypothesis is supported by the fact that probe stimuli interfered with the post N400 slow wave. The interference effect of probe stimuli was stronger when probes were presented in the UVF than in the LVF, with the attenuation becoming significant in the latency of the UVF probe's N1 response. The replication of these results suggests that the change of paradigm, from a repetition paradigm to picture - word association, did not change subjects' strategy in using visual processes in their attempt to relate verbal information to pictorial input.

While the previous experiment showed specific ERP effects for same location probe stimuli presented in conditions with matching picture - word pairs, these effects were absent in the ERP results of the present experiment. No significant interaction between picture location, probe location, and word-type (associated words versus unrelated words) was observed in the statistical analysis of ERPs recorded in experiment 2 for either the P2 or the P3. We cannot explain this result by hypothesizing that subjects used a less visually oriented strategy, since unrelated picture - word pairs elicited search processes which appear to include visual components. Rather, the pattern of results suggests that the retinotopic effects which were observed in the previous experiment depend on the usage of words that are identical in meaning to the pictures. Semantic relationship per se between the picture and the word does not seem to be responsible for the effects observed in the previous experiment, but rather the usage of words that carry a specific reference to the object's visual representation.

4.9 General Discussion

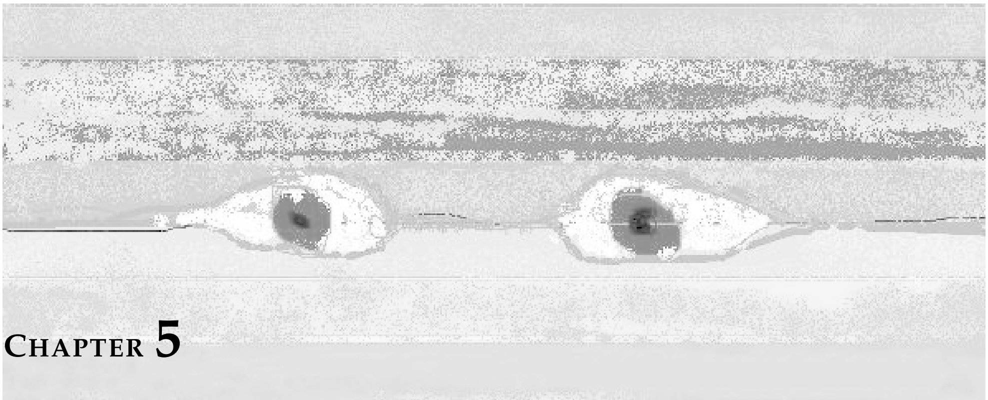
The goal of the present study was to increase our understanding of the relationship between semantic and perceptual levels of representation. A picture - word repetition paradigm was used in which we manipulated the semantic relationship between pictures and words. Experiment 1 involved two types of trials, one with words that had the same meaning as pictures, and one with words that were unrelated to pictures. In Experiment 2 we replaced words that were identical in meaning with words that are semantically associated to pictures.

In both experiments, visually presented probe stimuli were used to determine the presence of perceptual effects within the visual system, originating from the semantic interaction between words and pictures. In both experiments, conditions with unrelated picture - word pairs generated a search process following the N400 which included processing within the visual system. Probe stimuli were found to attenuate the amplitude of the search related negativity. The latency of the interaction which was significant at the time of the N1 response to the probe, suggested that the attempt to find a relationship between the picture and the word involved processing within extrastriate visual perceptual areas. As was argued in the discussion of experiment 1, the slow wave effect to unrelated picture - word pairs is unlikely to reflect attention directed at the (retinotopic) location of the picture. Rather, the stronger inhibitory effect of UVF probes was interpreted to be consistent with a more general visual search process that is biased to ventral visual areas.

While probes presented in unrelated picture - word conditions were found to interact with ongoing search related processing within the visual system, ERPs to probes presented in matching conditions did not show any ongoing processing within the visual perceptual cortex at the time of probe presentation. Note that we had predicted that matching words would re-activate the visual memory trace of previously presented pictures, including their location. Such a re-activation would be expected to lead to attentional effects on early visual processing (P1 and N1) for probes presented at the same location as pictures. Endogenous cueing of spatial attention has been extensively investigated within the left and right visual fields, showing consistent increases of the P1 and N1 amplitude for stimuli presented at the attended location (reviews can be found in Mangun & Hillyard, 1995; Wijers et al., 1996). Comparable effects of endogenous or symbolic cueing of spatial attention have been observed for stimuli presented in the upper and lower visual fields (Okita, Konishi, Takashi, & Tanaka, 1990; Mangun et al., 1993; Gunter, Wijers, Jackson, & Mulder, 1994). The absence of early ERP effects to same location match probes suggests that visual processing for conditions with matching picture - word stimuli may have finished at the time that probes were presented.

Although bottom-up effects of matching words on the early ERP components of same location probes were absent, interactions between picture location, match, and probe location in experiment 1 did prove significant for later ERP components. Same location probes presented in matching picture - word conditions generated a more positive frontal P2 component, followed by a more negative P3 over the occipital scalp, as compared to other probe conditions. These effects are not considered to be typical for the involvement of spatial attention. As argued in the discussion of experiment 1, a frontal positivity coupled with a posterior negativity may index the involvement of object working memory. We speculate that, although probes may have been presented too late to interact with initial processing in conditions with matching picture - word pairs, same location probes may result in a temporary re-activation of the previous episode via the visual object working memory system. Both the absence of (P2 and P3) effects for same location probes presented in unrelated picture - word conditions, and the failure to find similar effects using associated words, suggest that the effects for same location probes in experiment 1 specifically depended on the inclusion of words that direct attention to the pictures' visual representation. The capture of attention by a visual probe stimulus, redirecting attention towards the same retinotopic visual area, may have facilitated the re-activation of the object's representation within visual working memory, while not doing so when less visual priming is present.

In sum, the current study was successful in finding interactions between semantic and visual perceptual levels of representation. Conditions with unrelated picture - word pairs generated a semantically mediated search process following the N400 which was interpreted to involve processing within the (ventral) visual system. Furthermore, semantic interactions between pictures and words were found to have an effect on the ERPs to same location probes, which is consistent with the idea that retinotopic levels of object representation are temporary linked with the semantic level of object description. These results are important because they show that semantic processes do not operate in isolation but appear to be intimately related with processing in the visual system.



CHAPTER 5

Shared Neural Basis for Visual Object Working Memory and Visual Semantics: Evidence from Event-Related Potentials

Event-related potentials were used to investigate possible structural overlap between visual object working memory and concreteness effects in word processing. Subjects performed an object working memory task which involved 5 s retention of simple 4-angled polygons (load 1), complex 10-angled polygons (load 2), and a no-load baseline condition. During the polygon retention interval subjects were presented with a language decision task to auditory presented concrete (imageable) and abstract words. In one half of all blocks the language task required subjects to make a concrete-abstract decision to each word that was presented, and in the other half subjects were required to make a lexical decision. ERP results are consistent with the usage of object working memory for the visualization of concrete words. The current study supports a model of visual semantics in which visual semantic information relating to concrete words is first retrieved from long-term memory (indicated by a stronger anterior N400, and posterior occipital positivity to concrete as opposed to abstract words), and is subsequently visualized via the network for object working memory (reflected by a left frontal positive slow wave and a bilateral occipital slow wave negativity that was found to vary with both object working memory load and concreteness). Retrieval and visualization of concrete words may proceed automatically, as the clearest effects of concreteness were found in the lexical decision task. In the concrete-abstract decision task we found a somewhat different

pattern of results, which suggests that explicit visualization to concrete words may operate via (partly) different mechanisms.

5.1 Introduction

Generally, people find concrete words (e.g. lion) easier to understand and to remember than abstract words (e.g. idea). This phenomenon is known as the concreteness effect, and has yielded robust effects in a large variety of experimental studies (review in Paivio, 1991). The discussion on the origin of the concreteness effect is an old one, which is far from settled. We can distinguish between several theoretical perspectives which have been proposed to explain the effect.

On the behavioral level there remain two contenders: dual coding theory (Paivio, 1971) and context availability theory (Schwanenflugel & Shoben, 1983). Dual coding theory is perhaps the most widely known theory of the concreteness effect. According to this theory the fundamental difference between concrete and abstract words is that concrete words may be translated into a mental (visual) image, while abstract words can only activate a verbal or linguistic code of representation. Dual coding theory posits two systems, one verbal and one imagistic, that are functionally distinct, yet interconnected. Because concrete words are more imageable than abstract words, dual coding theory proposes that concrete words are processed by both the verbal (left hemisphere) and the imagery system (right hemisphere), as an account for the superiority of concrete words over abstract words.

Context availability theory, on the other hand, proposes the existence of a single amodal semantic system for word meanings. This theory argues that concrete words benefit from a more extensive propositional organization that may include additional perceptual properties or stronger contextual support for concrete items than for abstract items (e.g. Kieras, 1978). According to the context availability theory, abstract words presented in isolation need more contextual support than concrete words, because they are inherently more ambiguous or vague and therefore harder to process. Concrete words on the other hand are said to exhibit stronger or more extensive associative links in semantic memory.

Both dual coding theory and context availability are based on behavioral evidence. Others have sought to understand the organization of semantic memory by investigating neuropsychologically impaired patients (Breedin, Saffran, & Coslett, 1994; Saffran & Schwartz, 1994; Damasio et al., 1996; Tranel et al., 1997; Coltheart et al., 1998), and in vivo imaging of semantic processing in normal subjects (Martin, 1998; Pulvermüller, 1999a, 2001; Martin & Chao, 2001). Both lines of neurologically oriented research have converged on the perspective that the development of meaning for concrete objects such as plants, animals, and tools originates in everyday life experience with these objects. According to Pulvermüller (1999a), when the meaning of a concrete content word is being acquired, the learner may be exposed to sensory information via various modalities which becomes associated to the word. The same goes for action words which may become associated with the actions that are performed by the learner at the time that the word is learned. This process of co-activation results in the development of a functional unit or cell assembly that links the word's phonological features with visual and action properties in sensory and motor areas of the cortex. Allport's theory of conceptual memory (Allport, 1985) describes auto-associated activity patterns in different sensory and motor modalities that link phonological and orthographic representations of words to e.g. visual and motor attributes that describe accumulated knowledge of the visual and functional properties of objects. Damasio and co-workers (e.g. Damasio et al., 1996; Tranel et al., 1997) propose a similar theory in which a neural system in temporal and occipito-temporal cortices operates as a catalyst for the retrieval of multidimensional aspects of knowledge which are hypothesized to be distributed in various regions of the brain.

These neuropsychological theories may be classified as multi-code theories of semantic memory that are more similar to dual coding theory than to (single code) context availability theory. While dual coding theory puts a strong emphasis on the visual representation of concrete items, the neurological perspective provides a more general model on the multi-sensory organization of semantic knowledge and its development. Similar to the dual coding theory, however, the processing of concrete words is considered to result in a more extensive sensory representation, when compared with abstract words.

Although the distributed account of semantic memory seems promising, we feel that the approach is still very generally formulated. There is little known about the neurophysiological mechanisms which enable retrieval and activation of concrete semantic knowledge. The technique of event-related brain potentials (ERPs) may serve to answer some of the questions that are relevant in this respect. ERPs provide an on-line temporal view on the brain while information is being processed. The purpose of the present study is to investigate the retrieval of visual semantic information of concrete words, and to learn more about the functional mechanisms that may assist in this process.

One main candidate as a mechanism for the activation of visual semantic information from concrete words is visual working memory (Baddeley, 1986; Logie & Baddeley, 1990). Previous neuroimaging has distinguished between object working memory and spatial working memory (Owen, Milner, Petrides, & Evans, 1996; Smith & Jonides, 1997; Belger et al., 1998; Courtney, Petit, Haxby, & Ungerleider, 1998), showing a left hemisphere dominance for object working memory with emphasis on the ventro-lateral frontal cortex and inferior occipito-temporal lobe. Although neuroimaging research on working memory is still very much in progress, these results have typically been interpreted to reflect a cortical network for the retention of object-shape, with specialization for object recognition in inferior temporal regions (Ungerleider & Mishkin, 1982) extending into ventro-lateral frontal cortex that serves to maintain an active representation of the object after the stimulus has been removed from view (Ungerleider, Courtney, & Haxby, 1998) (see also Courtney et al., 1998; D'Eposito, Postle, & Lease, 1999, for a slightly different perspective on the organization of working memory in the frontal lobes). Similar results have been obtained in experiments where there is no external visual stimulus to be remembered, but rather require the internal visualization of stimuli, as is the case with mental imagery. Here too the evidence seems to point towards the importance of the left inferior occipito-temporal lobe (review in Farah, 1995). Consistent with these results is a large literature which has suggested that the left inferior frontal and left ventral occipito-temporal areas are important for semantic memory concerning concrete objects (Breedin et al., 1994; Damasio et al., 1996; Wiggs, Weisberg, & Martin, 1999; Martin & Chao, 2001).[1] The overall picture from these findings is that there is a cortical network specialized for object representation which is involved in object working memory, mental imagery and visual semantics for concrete objects.

In the current study we will investigate the cortical mechanisms that are involved in the activation of visual semantic information from concrete words. It is hypothesized that concrete words will activate their visual semantic meaning via the cortical network for object working memory. This hypothesis is investigated by presenting concrete (imageable) words and abstract (non-imageable) words in various conditions that differ in the amount of load that is put on the object working memory system. When words are presented in conditions where object working memory load is high, difficulty in the activation of visual semantic meaning is expected, as compared to words presented in conditions where there is no load on object working memory.

In a number of ERP studies Holcomb et al. (Kounios & Holcomb, 1994; Holcomb, Kounios, Anderson, & West, 1999; West & Holcomb, 2000) investigated ERP differences between concrete and abstract words. Kounios and Holcomb (1994) observed a larger N400 amplitude to concrete words than to abstract words. The N400 effect elicited by concrete words was larger over the right hemisphere than over the left hemisphere which was considered to be consistent with the dual coding theory which predicts imagistic processing to concrete words in the right hemisphere. Effects on the N400 over frontal sites were found to be larger in conditions that required a concrete-abstract decision to words, as opposed to conditions that required a lexical decision. The frontal distribution of the concreteness effect is difficult to reconcile with the proposed locus of mental imagery in the left occipito-temporal lobe (e.g. D'Eposito et al., 1997). In a later publication by West and Holcomb (2000) this led to an attempt to separate concreteness effects from imageability. While replicating the N400 effect of concreteness, imageability was found to be accommodated by a later posterior negativity that was larger over the left hemisphere. This effect

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[1] Notice that these results are inconsistent with the dual coding theory (Paivio, 1991) which proposes that imagistic processes are lateralized to the right hemisphere.

was marginal however, and was only observed when abstract imageable words were compared with abstract non-imageable words.

In the present study we aim to obtain a clearer perspective on the functional significance of the various ERP effects that have been reported in the previous studies. The main innovation made in the present design is that we compare directly the effects of concreteness to the effects of object working memory, and investigate the interference between these two cognitive processes. Second, we will record and analyze ERPs over a longer period of time than previous studies, since the ERP effects of object working memory and mental imagery have been found to result in slow wave effects that extend over several seconds (Farah, Peronnet, Weisberg, & Monheit, 1989; Mecklinger & Pfeifer, 1996; Ruchkin et al., 1997). Previous studies by Holcomb et al. restricted analysis to 1200 ms after word onset. Longer recording intervals may enable us to find effects of concreteness over posterior areas with a relatively late onset.

Similar to Kounios and Holcomb (1994) we will investigate the ERPs to concrete and abstract words in two language tasks, one that will require subjects to decide whether words are lexically valid (lexical decision task), and one in which subjects distinguish between concrete and abstract words (concrete-abstract decision task). The investigation of the concreteness effect in both language tasks is important for our understanding of the conditions under which visual information becomes active. Farah (1995) suggests that the activation of visual semantic or imagistic information is under voluntary control, and will only occur when relevant to the situation. 'Whereas we cannot look at a cat without activating our concept of a cat, we can think of a cat without generating a visual image of one' (Farah, 1995, (pg. 1459)). The opposite view is taken by Martin (1998) that 'In humans, semantic networks [including perceptual representations] are activated not only when objects are seen, but also when the object's name is read, heard, or retrieved in the service of writing and speech' (pg. 74) (see also Pulvermüller, 1999a). This point of view presupposes that visual semantic features associated with concrete words are automatically activated as the word is recognized at the lexical level (see also Deacon, Hewitt, Yang, & Nagata, 2000). With the current design we hope to address this issue. If the visual semantic representation of concrete words is automatically activated, then we may expect posterior effects of imageability to concrete words presented in both the lexical decision task and the concrete-abstract task. If however the imagistic representation of concrete words is only activated by voluntary control, then we expect the effects to be limited to conditions that require concrete-abstract decision.

5.2 Method

5.2.1 Subjects

A total of twenty-one subjects (10 male, 11 female) participated in the experiment. Most were students of the University of Groningen. Subjects' average age was 22 (SD 3.17). All were native speakers of the Dutch language, were right handed, healthy, and had normal or corrected-to-normal vision. Subjects were paid standard experimental fee for participation.

5.2.2 Stimuli and materials

Polygons

Object working memory load was manipulated by creating polygons (Attneave & Arnoult, 1956) with two levels of complexity: simple 4-angled polygons, and more complex 10-angled polygons that had to be retained in memory for a delayed matching to sample task. 4-angled polygons were created in a two axis coordinate system (see Figure 5.1 on the next page), with one axis running from the upper left to the lower right, and the other axis running from the lower left to the upper right, orthogonal to the first. The center of the polygon was defined by the intersection of the two axes. For each direction of the coordinate system (upper left, upper right, lower left, and lower right), a random number was chosen that defined the distance of an angular point to the polygon's center. The maximum distance between an angular point and the center of the polygon was set at 100 pixels. The minimal distance was chosen at 4 pixels. Polygons were realized by a line-drawing algorithm that connected the four resulting angular points with one another.

In order to be included as a stimulus in the experiment each polygon had to fulfill a number of requirements. To restrict inter polygon variability, each polygon's surface was kept between 500 and 1500 pixels. In addition, each of the polygon's angles were selected to be between 45-135 degrees, to ensure that every angle was clearly visible to the subjects. This resulted in 600 different 4-angled polygons.

10-angled polygons were created within a five axes coordinate system to afford polygons with ten angular points (see Figure 5.1 on the facing page). The procedure was similar to that of the 4-angled polygons. For each individual angular point of a polygon, a random distance between 4 and 100 pixels was chosen, which defined the outline of the polygon. 10-angled polygons had to meet the same requirements as the 4-angled polygons. In order to ensure accurate comparison between both types of polygons, 10-angled polygons were equated in size with 4-angled polygons. For each of the 600 simple polygons that had already been created, a 10-angled polygon was generated with the same size.

The maximum distance from the center of a polygon to its outline was 100 pixels. This corresponds to a maximum of 6.06 visual degrees on a 17 inch screen with a

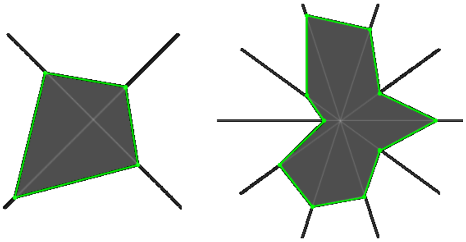

Figure 5.1: Example of stimuli used for the object working memory task. Depicted on the left side is a simple polygon with four angles, and on the right side is a complex polygon with 10 angles. The axes that are shown in the figure were not displayed in the experiment, as were the dots that define the vertexes of the polygons.

resolution of 640 by 480 pixels at a viewing distance of 50 cm. For each polygon we calculated the exact center of gravity and presented it on the fixation point. Polygons to be memorized (memory objects) were presented with a dark gray surface and a green outline, displayed on black background. Polygons which were used to test subjects' memory for objects (test objects) were displayed with a dark gray surface and a light grey outline. The different colors of the memory and test objects were used to emphasize the difference between the them, such that subjects were less likely to get confused.

Words

Concrete and abstract words were selected from a list generated by van Loon-Vervoorn (1985), which contains 4600 Dutch nouns, 1000 verbs and 500 adjectives, that were all tested on their image-ability. 300 abstract nouns were selected from the list having an imageability rating of 3.3 or lower on a seven point scale. Similarly, 300 concrete nouns were selected with an imageability rating of 6.6 or higher. In order to constrain word length variability, only one, or two syllable words were used. Abstract and concrete words were matched on number of syllables (concrete words: 1.61, abstract words: 1.74), number of phonemes (concrete words: 5.01, abstract words: 5.11), and on their written-frequency (concrete words: 694.4, abstract words: 696.6) in a 42 million word database (Burnage, 1990). In addition, we created a set of 300 pseudowords that were matched with abstract and concrete words for mean number of syllables and word length. See the appendix for chapter 5 on page 155 for the concrete words, abstract words, and pseudowords used in this experiment.

Words and pseudowords were then recorded as wave files (16 bits) with a sample frequency of 44.1 kHz, spoken by a female voice. A profile was made of the amount of noise for recorded words and pseudowords and noise reduction was carried out to minimize differences in noise level across conditions. Recordings were filtered to approximate natural speech. Individual words were selected and saved as separate wave files that were enveloped to ensure smooth onset and offset. A normalization of amplitude was performed to equate the volume of all wave files. The speed of articulation was then digitally altered to 115% of the original tempo. Resulting average file lengths were 643 ms (SD 115 ms) for concrete words, 683 ms (SD 116 ms) for abstract words, and 662 ms (SD 114 ms) for pseudowords.

5.2.3 Procedure

The experiment involved a dual task paradigm in which subjects were required to remember a visually presented polygon for a short period of time (5 seconds delayed match to sample). During object retention, a second task was administered, in which a spoken word was presented to subjects which required classification (see below). The object working memory task involved three levels of difficulty, or load. In the load 1 condition, subjects were presented with relatively easy 4-angled polygons that had to be maintained in short-term memory. The load 2 condition involved the retention of the more complex 10-angled polygons. In addition to the load 1 and load 2 conditions a third condition was used (load 0), which involved visual presentation of 4-angled and 10-angled polygons, but subjects were instructed not to carry out the object working memory task. The load 0 condition served as a control or baseline condition with which to compare effects of object working memory in the load 1 and load 2 conditions.

Two different word decision tasks were used. In the lexical decision task subjects had to distinguish words from pseudowords. In the concrete-abstract decision task subjects were required to classify each presented word as concrete or abstract. Half of all words were presented in the lexical decision task, and the other half was presented for concrete-abstract decision. Across subjects words were balanced over task conditions.

The three object working memory conditions (load 1, load 2, and load 0) were paired with the two language tasks (lexical decision and concrete-abstract decision), resulting in six possible combinations that were administered as separate experimental blocks. Block order was pseudo-randomized across subjects, with half of the subjects first receiving three lexical decision blocks (paired with the three object load conditions), and the other half of the subjects first receiving three concrete-abstract decision blocks (paired with object load conditions: load 0, load 1, and load 2). The order of load 0, load 1, and load 2 conditions within tasks was balanced across subjects. Each block that involved lexical decisions to words was presented in four consecutive experimental runs, of 50 trials each, taking about 6 minutes and 40 seconds per run. As there is no reason to present pseudowords in the concrete-abstract decision task, these were excluded from the list. As a result, concrete-abstract decision blocks were presented in three consecutive runs of 50 trials each, with each run again taking approximately 6 minutes and 40 seconds to complete. Both language tasks included a number of trials in which no word was presented (no-word percentage in lexical decision blocks = 25%; no-word percentage in concrete-abstract decision blocks = 33%). This was done in order to get a clean view on the single task effect of object working memory, without interruption from auditory presented words.

Before subjects began with the actual experiment they were allowed to practice until both the experimenter and the participant felt that the task was performed in a confident manner.[2] With every change in block, e.g. changing from 4-angled polygons to 10-angled polygons, subjects were allowed one practice run to familiarize themselves with the new stimulus properties or task instructions.

Subjects were seated in a dimly lit, sound attenuated, and electrically shielded cabin facing a computer screen at a distance of 50 cm with their head in a chin-rest. Chair and chin-rest were adjusted to fit individual demands. The index fingers of the subject's right and left hands rested on two touch-sensitive response boxes which recorded a response when one of the fingers was lifted (response hands were balanced across subjects). A Pentium computer controlled the presentation of visual and auditory stimuli, and the collection of behavioral responses. Sampling of the EEG was done on a separate machine.

Task

Trials presented to the subjects all had the same structure. The object working memory task involved two objects, a memory object (a dark grey polygon with a green outline) and test object (a second polygon with a light grey outline), that were presented on a computer screen (see Figure 5.2 on the next page). The participant was instructed to retain the shape of the memory object in short-term memory, and compare it with the test object. Subjects responded to both matching and non-matching test objects. During the polygon retention interval, intermediate between the memory object and the test object, a word was presented via headphones. In one condition subjects were required to distinguish between words and pseudowords (lexical decision responses to both words and pseudowords). In a second condition, subjects had to classify each word as either concrete or abstract. Response hands were balanced across subjects. Subjects were not allowed to respond immediately to words, but had to delay their response until the presentation of a beep on the headset. This was done because differences in reaction times to concrete and abstract words may cause differences in the ERPs to both word-types that may be confounded with the early ERP effects to abstract and concrete words. The delay of subjects' responses ensured a clean recording epoch, in which we can compare the ERPs to abstract and concrete words.

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[2] Subjects' practice was only concerned with the first condition that was administered (e.g. lexical decision with 4 angled polygons.

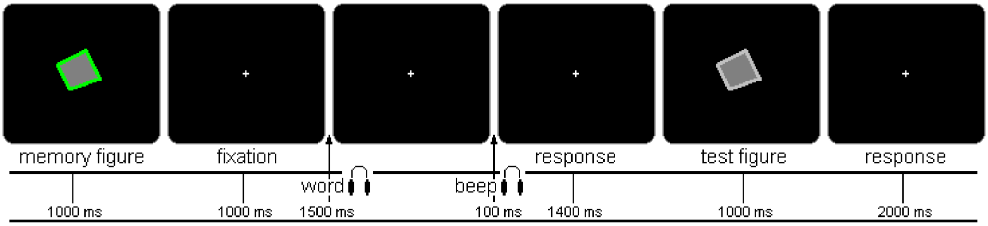

Figure 5.2: Example of a possible trial, showing the presentation of consecutive visual and auditory frames.

Timing of a stimuli was identical in all trials (see Figure 5.2). First a memory figure was presented for 1000 ms, followed by a single fixation point that remained on screen for 4000 ms. 1000 ms after offset of the memory figure (during the fixation interval), a word could be presented via the headphones (average word length: 663 ms). In some cases no word was presented. 1500 ms after onset of the word, a 100 ms beep was presented after which subjects could respond to the word. After the beep subjects had 1400 ms to respond. Following the response interval to words, a test figure was presented (see Figure 5.2), which was identical to the memory figure in half of the trials. In other cases, one of the polygon's angular points had been moved along the trajectory of one of the axes, either 50 pixels away, or 50 pixels towards the origin of the object.

5.2.4 EEG recordings

The electroencephalogram (EEG) was recorded with 37 Sn-electrodes placed in an electrocap (Electro-Cap international) at positions Fp1, Fp2, Fz, F3, F4, F7, F8, FC3, FC4, FC7, FC8, Cz, C3, C4, T7, T8, TP7, TP8, Pz, P3, P4, P7, P8, P9, P10, POz, PO3, PO4, PO7, PO8, PO9, PO10, Oz, O1, O2, O9, and O10 according to the revised 10-20 system as presented by Pivik et al. (1993). Electrodes were referred to the left and right (electronically averaged) mastoids. Horizontal EOG was recorded via two Sn-electrodes situated on the outer canti of the left and the right eye. Vertical EOG was recorded with two Sn-electrodes placed above and below the left eye, one on the cheekbone and one above the eyebrow. The ground electrode was on the sternum. Electrode resistance was kept below 2K-Ohm. EEG and EOG signals were amplified (EEG: 0.2 mV/V; EOG: 0.5 mV/V; time constant: 10 sec.), sampled at 1000 Hz, digitally lowpass filtered with a cutoff frequency of 30 Hz and reduced to a sample frequency of 100 Hz on-line.

5.2.5 Data Analysis

Behavioral analysis

Experimental trials involved two response intervals, one to record subject's behavior to words, and one to measure subjects performance to polygon matching. Responses to both stimuli were analyzed separately, with tests for significance (MANOVA repeated measurements) for reaction times, errors (wrong response), and misses (no response). Main analysis of behavior to abstract and concrete words included three within subject factors: task (lexical decision task versus concrete-abstract decision task), word-type (abstract versus concrete words), and load (load 0, load 1, and load 2). Main analysis of responses to polygons involved task (lexical decision task versus concrete-abstract decision task), word-type (abstract, concrete, and no-word conditions), and load (load 1 versus load 2) as within subject factors.

ERP analysis

Trials containing amplifier artefacts, and trials with incorrect responses were rejected from further analysis. The eye movement correction procedure of Gratton et al. (1983) was used to correct EEG for blinks and small saccades. Separate ERPs were calculated, synchronized to the onset of memory polygons and to the onset of words. In both cases, individual trials were aligned using a 100 ms pre-stimulus baseline interval. Separate averages per stimulus category (see below) were calculated for each individual participant. EEG analysis was done with the Brain Vision Analyser software package. ERPs to memory objects included most of the trial, running from 100 ms before onset of the memory figure until 100 ms before offset of the test figure, including a 6 second interval. ERPs to words covered 4 seconds, running from 100 ms before word onset until 100 ms before offset of the memory figure.

For both lexical decision blocks and the concrete-abstract decision blocks ERPs were pooled over conditions with matching and non-matching test polygons. ERPs recorded to the load 0 condition were pooled for 10-angled polygons and 4-angled polygons. For the lexical blocks, this resulted in a total of 12 stimulus categories, based on the combinations of object working memory load (load 0, load 1, and load 2), and word-type (abstract, concrete, pseudoword, no word). For the concrete-abstract decision blocks there were only 9 stimulus categories, since word-type did not include pseudowords. Statistical analysis excluded conditions with pseudowords, and conditions in which there was no word presented, resulting in total of 6 stimulus categories per task that were included for statistical testing.

Averaged ERPs to memory polygons and words were divided into intervals of 50 ms that were exported and tested for significance using MANOVA repeated measurements analysis in SPSS 7.5.2. Separate analyses were performed for midline electrodes (Fz, Cz, Pz, POz, and Oz), frontal electrodes (Fp1, Fp2, F3, F4, F7, and F8), central electrodes (FC3, FC4, FT7, FT8, C3, C4, T7, T8, TP7, and TP8), posterior electrodes (P3, P4, P7, P8, PO3, PO4, PO7, PO8, O1, and O2), and cerebellar electrodes (P9, P10, PO9, PO10, O9, and O10). To correct for chance capitalization (that is, correcting for the number of tests of significance being performed) only three consecutive significant intervals (α<.05) of 50 ms were accepted as truly significant. For both the analysis of ERPs to memory polygons and ERPs to words, within subject factors were: task (lexical decision versus concrete-abstract decision), load (load 0, load 1 and load 2), word-type (concrete versus abstract words), hemisphere (left versus right hemisphere) and electrode.

5.3 Results

5.3.1 Behavior

Behavior to words

Table 5.1 and Table 5.2 on the next page show the average response times, percentage of errors, and percentage of misses for lexical decisions and concrete-abstract decisions to words presented under different object load conditions.

Subject's responses to words showed a main effect of task, with faster ($F_{1,20}$ = 7.97; $P < 0.010$) and more accurate ($F_{1,20}$ = 5.83; $P < 0.025$) responses to words presented in the lexical decision task (RT = 404 ms; percentage of errors = 3.55%) than to words presented in the concrete-abstract decision task (RT = 468 ms; error percentage = 7.51%).

Although subjects had to hold their responses to words until the beep, this did not take away behavioral differences between abstract and concrete words. Subjects'

Table 5.1: Mean response times (standard deviations between brackets), percentage of errors, and percentage of misses for lexical decision responses to abstract words, concrete words, and pseudowords presented under different object load conditions.

	Load 0	Load 1	Load 2
Response times			
Abstract words	447 (176)	403 (139)	397 (119)
Concrete words	416 (197)	377 (151)	383 (124)
Pseudowords	470 (200)	416 (137)	427 (133)
Errors			
Abstract words	4.29	6.48	7.13
Concrete words	1.33	1.05	1.05
Pseudowords	3.04	2.95	2.95
Misses			
Abstract words	1.90	1.14	1.62
Concrete words	1.81	1.05	0.95
Pseudowords	2.86	2.38	3.24

Table 5.2: Mean response times (standard deviations between brackets), percentage of errors, and percentage of misses for concrete-abstract decisions to abstract words and concrete words presented under different object load conditions.

	Load 0	Load 1	Load 2
Response times			
Abstract words	540 (171)	482 (133)	489 (138)
Concrete words	492 (229)	407 (129)	396 (119)
Errors			
Abstract words	14.38	10.29	12.10
Concrete words	5.71	1.05	1.52
Misses			
Abstract words	4.86	2.67	2.86
Concrete words	1.62	1.05	0.95

responses were faster ($F_{1,20}$ = 30.55; $P < 0.000$), more accurate ($F_{1,20}$ = 46.98; $P < 0.000$), and showed less misses ($F_{1,20}$ = 8.87; $P < 0.007$) to concrete words (RT = 412 ms; percentage of errors = 1.95%; percentage of misses = 1.24%) than to abstract words (RT = 460 ms; percentage of errors = 9.11%; percentage of misses = 2.51%).

The advantage to concrete words, as compared to abstract words, was larger for words presented in the concrete-abstract decision task than for words presented in the lexical decision task (RT: -38 ms versus -24 ms (task by word-type interaction: $F_{1,20}$ = 7.84; $P < 0.011$); percentage of errors: -9.49% versus -4.83% (task by word-type: $F_{1,20}$ = 4.19; $P < 0.054$); percentage of misses: -2.25% versus -0.29% (task by word-type: $F_{1,20}$ = 8.70; $P < 0.008$)).

Object working memory load was reflected in the response times to words, showing faster responses ($F_{1,20}$ = 3.54; $P < 0.049$) when words had been presented in the object retention conditions (RT load 1 = 1917 ms, and RT load 2 = 1916 ms) as compared to words presented in the no-load condition (RT load 0 = 1974 ms). However, object load did not show selective effects for abstract or concrete words. No significant interactions were found between load and word-type.

Behavior to polygons

Table 5.3 on the following page and Table 5.4 on page 91 show the average response times, percentage of errors, and percentage of misses for the the polygon matching task, under conditions in which subjects made lexical decisions and concrete-abstract decisions to words.

The analysis of subjects' responses to polygons showed a main effect of load reflecting prolonged reaction times ($F_{1,20}$ = 3.33; $P < 0.083$) and more errors ($F_{1,20}$ = 53.23; $P < 0.000$) for the load 2 condition (RT = 923 ms; percentage of errors = 18.08%) than for the load 1 condition (RT = 884 ms; percentage of errors = 10.29%).

Table 5.3: Mean response times (standard deviations between brackets), percentage of errors, and percentage of misses for the the polygon matching task, under conditions in which subjects made lexical decisions to abstract words, concrete words, and pseudowords, or conditions in which no words were presented.

	Load 1	Load 2
Response times		
Abstract words	827 (241)	878 (273)
Concrete words	818 (262)	899 (296)
Pseudowords	888 (249)	933 (266)
No words	908 (250)	950 (266)
Errors		
Abstract words	10.57	18.67
Concrete words	8.86	18.95
Pseudowords	13.71	22.10
No words	8.48	15.62
Misses		
Abstract words	3.05	3.05
Concrete words	3.33	4.19
Pseudowords	1.90	2.57
No words	1.52	4.29

As already observed in the analysis of responses to words, dual task conditions resulted in faster response times than single task conditions. Trials with intervening words were accompanied by faster responses to polygons (886 ms) than trials in which no word was presented (941 ms). Furthermore, trials involving concrete words were associated with faster responses to polygons (869 ms) than trials that included abstract words (902 ms)(main effect of word-type: $F_{2,19} = 14.12$; $P < 0.000$). A similar pattern of results was found in the analysis of errors (main effect of word-type: $F_{2,19} = 10.22$; $P < 0.001$), reflecting more errors in the polygon matching task for trials that included abstract words (error percentage = 10.60%), as compared to trials that involved concrete words (error percentage = 8.63%), and trials in which no word was presented (error percentage = 8.49%).

The different performance to polygons for trials with abstract and concrete words was mainly brought about by blocks that involved concrete-abstract decisions to words. Both the response times and the percentage of errors to polygons paired with the concrete-abstract decision task showed faster responses and less errors when the intervening word was a concrete word (RT = 879 ms; error percentage = 12%), as opposed to an abstract word (RT = 950 ms; error percentage = 17.19%)(RT: task by word-type ($F_{2,19} = 14.10$; $P < 0.000$); errors: task by word-type ($F_{2,19} = 6.94$; $P < 0.005$)). Response times to polygons paired with the lexical decision task showed a less strong difference between trials with concrete words (RT = 859 ms; error percentage = 13.90%) and trials with abstract words (RT = 853 ms; error percentage = 14.62%).

Table 5.4: Mean response times (standard deviations between brackets), percentage of errors, and percentage of misses for the the polygon matching task, under conditions in which subjects made concrete-abstract decisions to abstract words, and concrete words, or conditions in which no words were presented.

	Load 1	Load 2
Response times		
Abstract words	952 (248)	947 (246)
Concrete words	858 (245)	910 (251)
No words	942 (245)	962 (244)
Errors		
Abstract words	14.67	19.71
Concrete words	9.90	14.10
No words	9.24	17.62
Misses		
Abstract words	2.86	2.38
Concrete words	3.62	1.90
No words	2.48	1.62

In addition to the more general effects of word-type on the performance of the object retention task described above, the analysis of reaction times to polygons showed a significant interaction between word-type and load ($F_{2,19} = 4.95$; $P < 0.019$). Although polygon matching times were found to be prolonged with more complex polygons (load 2 condition), as opposed to the simple polygons (load 1 condition) the size of the reaction time difference between the load 1 and the load 2 condition was significantly affected by the type of intervening word. Both abstract words and conditions in which no words were intervening showed a small reaction time difference between the load 1 and the load 2 condition (abstract words: 890 ms (load 1) versus 913 ms (load 2); no-word: 925 ms (load 1) versus 956 ms (load 2)). Inter-

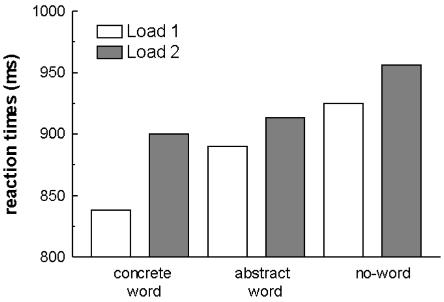

Figure 5.3: Reaction times to polygon matching for simple polygons (load 1) and complex polygons (load 2), separate for conditions with concrete words, abstract words, and no words intervening the memory interval.

vening of concrete words resulted in a larger difference between load 1 and load 2 conditions (concrete words: 838 ms (load 1) versus 900 ms (load 2)). See Figure 5.3 on the preceding page for the reaction times to load 1 and load 2 polygons, intervened by concrete words, abstract words, and conditions without words.

5.3.2 Event-related Potentials

The results section on event-related potentials involves two parts. In the first part the ERP effects of object working memory load will be identified. In the second part we will focus on the concreteness effects by describing the ERP differences between abstract and concrete words as recorded in the lexical decision and concrete-abstract decision tasks. In addition we will describe the influence of object working memory load on the processing of concrete words in the two language tasks.

ERP effects of object working memory

Figure 5.4 on the next page displays the ERPs recorded in the different object working memory load conditions. The figure depicts the entire 6 s trial interval, showing ERP components evoked by subsequent presentation of memory figures (onset at 0 s), auditory words (onset at 2 s), and test figures (onset at 5 s).

Manipulations of object working memory load were found to result in a clear pattern of slow wave effects over frontal, occipital and parietal areas. Over frontal areas, object working memory load was found to be accompanied by a positive slow wave that showed increased amplitude with increasing load. Over occipital areas the opposite pattern was found: a negative slow wave that increased in amplitude with increasing object load. Parietal areas showed a sustained positivity in object working memory load conditions (load 1 and load 2) as compared to the load 0 condition where no memory of polygons was required. Figure 5.5 on page 94 shows the distribution of the effects over frontal, occipital, and parietal areas at 1300 ms post onset of the memory figure. The distribution of the effects in time was found to be highly constant.[3]

Frontal effects of object working memory Over frontal areas, larger object working memory load was found to be accompanied by a positive slow wave that showed increased amplitude with increasing load. In the main analysis of frontal electrodes effects of load were found to be significant shortly (150 ms) after onset of the memory figure. The effect of load continued to be significant during most of the retention interval, up to 3000 ms after onset of the memory figure ($F_{2,19} = 29.78$; $P < 0.000$). See electrodes F7 and F8 of Figure 5.4 on the facing page. Pair-wise comparisons showed that all three load conditions differed significantly from one another over

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[3] There is one exception. The broad frontal positivity as displayed in the right panel of Figure 5.5 on page 94 was found to be more selectively distributed over fronto-central electrode sites at subsequent intervals.

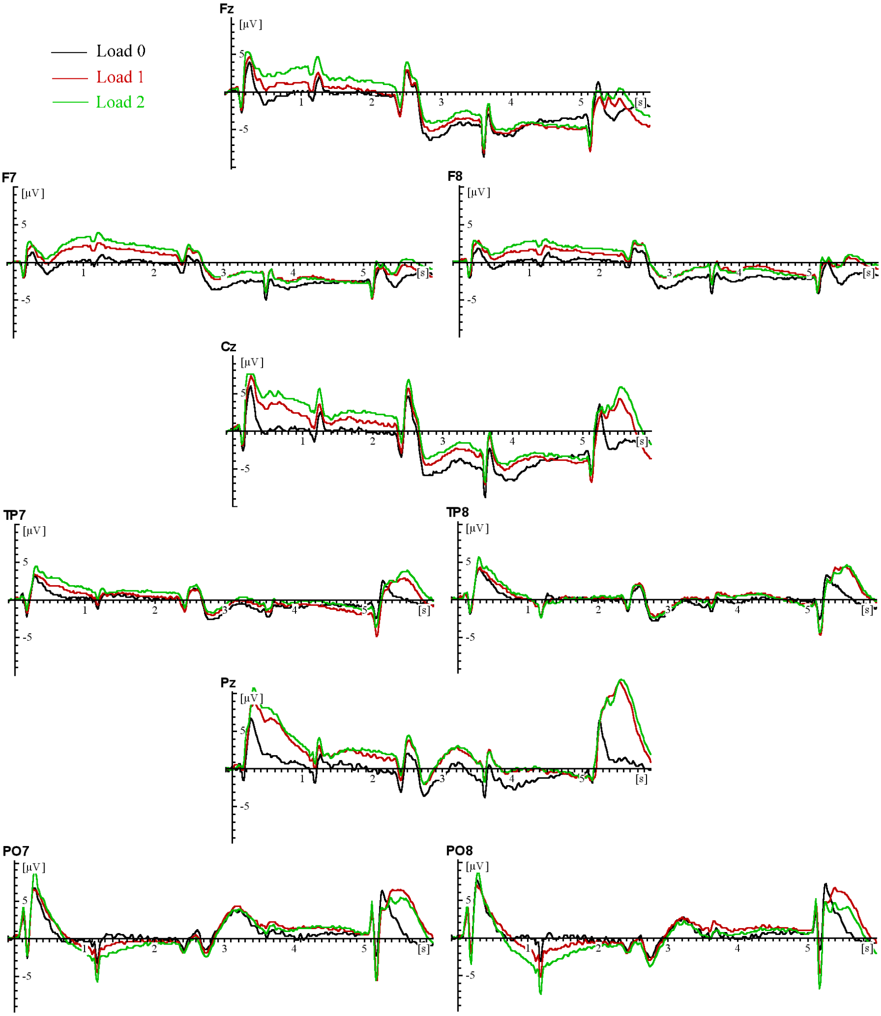

Figure 5.4: ERPs aligned to memory figures, showing the complete 6 s. trial interval. Red lines and green lines respectively show ERPs to the retention of simple 4-angle polygons (load 1), and complex 10-angle polygons (load 2). Black lines represent ERPs to memory figures (4-angle polygons and 10-angle polygons grouped together) that did not have to be remembered (load 0). Grand average ERPs in all three conditions are pooled together for trials which included abstract words, concrete words, and no-word presentation. Colored figure at http://www.ub.rug.nl/eldoc/dis/arts/h.t.van.schie/

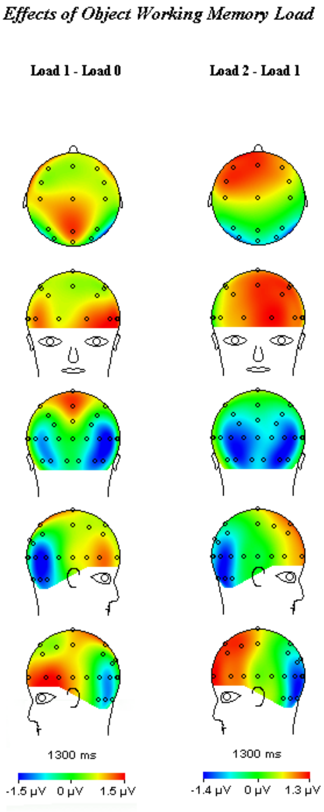

Figure 5.5: Topographic maps showing the distribution of the effects of object working memory. The left panel shows the topographic distribution of the ERP difference between load 1 (retain 4-angle polygon) and load 0 (no retention) object working memory conditions. The right panel shows the difference between retaining the more complex 10-angle polygons (load 2), and the less complex 4-angle polygons (load 1) at 1300 ms after polygon onset. Colored figure at http://www.ub.rug.nl/eldoc/dis/arts/h.t.van.schie/

frontal areas. Main analysis of frontal electrodes found that the frontal effect of load was shortly absent in the 2450 ms - 2700 ms interval, which is probably due to the presentation of words at that time.

From about 4350 ms, both load 1 and load 2 conditions generated a fronto-central negativity as compared to the load 0 condition (load by electrode: $F_{4,17} = 5.47$; $P < 0.005$), which probably reflects stronger anticipation (contingent negative variation or CNV) to the upcoming test stimulus. This effect is best seen at the Fz electrode in Figure 5.4 on the page before.

Following the onset of the test figure, both the load 1 and load 2 conditions generated a prominent P3 effect over parietal areas, that also showed significance over frontal electrodes ($F_{2,19}$ = 7.76; $P < 0.003$). Parallel to the selective P3 effect for the load 1 and load 2 conditions, a frontal slow wave difference between load 1 and load 2 emerged, that was similar to the slow wave effect during the retention interval. See the Fz and Cz electrodes in Figure 5.4 on page 93. Pair-wise comparisons between load 1 and 2 showed the frontal effect of load to be significant from 5450 ms - 6000 ms ($F_{2,19}$ = 9.61; $P < 0.006$). Although the distribution of the frontal effect is relatively similar to the topography of the load effect during the retention interval, the pair-wise comparison between load 1 and load 2 conditions found an additional interaction between load and hemisphere (5750 ms - 6000 ms; $F_{2,19}$ = 13.31; $P < 0.002$), showing a bias to the left hemisphere that was not observed in the retention interval.

Occipital effects of object working memory Over occipital areas object working memory was found to be reflected in a sustained negative slow wave that increased in amplitude with increasing object load. The negative slow wave started to develop in the latency of the P3 evoked by the memory figure, some 400 ms after onset of the figure, reaching a maximum negative difference at around 1100 ms - 1300 ms (load by electrode; $F_{8,13}$ = 15.52; $P < 0.000$). See electrodes PO7 and PO8 of Figure 5.4 on page 93. In addition, the main analysis of posterior electrodes, which included both occipital and parieto-occipital electrodes,[4] showed an interaction between load and hemisphere (800 ms - 1300 ms; $F_{2,19}$ = 5.38; $P < 0.014$), reflecting the presence of a larger slow wave negative difference over the right occipital lobe, than over the left (compare PO7 with PO8 in Figure 5.4 on page 93). After 1300 ms the occipital slow wave negativity gradually decreased, and had disappeared at the latency of 2200 ms. Although the main analysis of posterior electrodes continued to show significant interactions between load and electrode (reflecting the sustained positive slow wave over parietal areas: see below), the pair-wise comparison between load 1 and load 2 conditions only showed effects of load to be significant until 2200 ms.

Similar to effects observed over frontal electrodes, presentation of the test figure resulted in the re-emergence of a slow wave negative difference over posterior occipital electrodes. The pair-wise comparison of load 1 and load 2 conditions showed a significant interaction between load and electrode in the 5300 ms - 6000 ms interval ($F_{4,17}$ = 14.85; $P < 0.000$). Like the distribution of the slow wave negativity during the retention interval, the re-emerging occipital negativity was larger over the right occipital hemisphere (load by electrode by hemisphere; $F_{4,17}$ = 7.67; $P < 0.001$).

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[4] In the subsequent text we will refer to these as posterior or occipital sites

Parietal effects of object working memory The largest and most prolonged effect of load was found at the Pz electrode (see Figure 5.4 on page 93). The sustained positive slow wave over central parietal areas which was observed for the load 1 and load 2 conditions, as opposed to the load 0 condition, showed significance almost throughout the entire trial period (main analysis of midline electrodes: load by electrode; $F_{8,13} = 27.91$; $P < 0.000$). Whether we can classify this effect as a genuine effect of object working memory is questionable since there is no parietal difference between load 1 and load 2 conditions during the retention interval. Rather than signaling the amount of short-term memory load within object working memory, the effect seems to correlate with the presence of a task, as opposed to the load 0 conditions where there is no working memory task associated with polygons.

ERP effects of concreteness

N400 Figure 5.6 on the facing page displays the ERPs to abstract and concrete words as recorded in the context of the lexical decision task (upper panel), and the concrete-abstract decision task (lower panel). As is clear from Figure 5.6 on the next page, ERPs to concrete words differed from ERPs to abstract words. The earliest difference between concrete and abstract words was found on the N400. Concrete words generated a stronger N400 effect over anterior electrodes. The N400 effect is clearly visible at the Fz and Cz electrodes in Figure 5.6 on the facing page, and lasted from about 950 ms until 1600 ms post word onset.[5] The larger N400 to concrete words over frontal areas was significant. The analysis of word ERPs over frontal areas showed a main effect of word-type in the 950 ms - 1350 ms interval ($F_{1,20} = 66.96$; $P < 0.000$), along with an interaction between word-type and electrode in the 1200 ms - 1600 ms interval ($F_{2,19} = 26.70$; $P < 0.000$). The topographic distribution of the N400 effect to concrete words is presented in Figure 5.7 on page 98 and Figure 5.8 on page 99 (left panels).

The amplitude of the N400 effect to concrete versus abstract words was not influenced by the type of decision that subjects had to make (lexical decision or concrete-abstract decision). There were no significant interactions between task and word-type in the latency of the N400 (main analysis frontal electrodes: $F_{1,20} = 0.01$; $P = .914$).

The anterior N400 effect to concrete words, as compared with abstract words, was not influenced by the requirement to retain objects within visual memory. Both the lexical decision task and the concrete-abstract decision task showed similar N400

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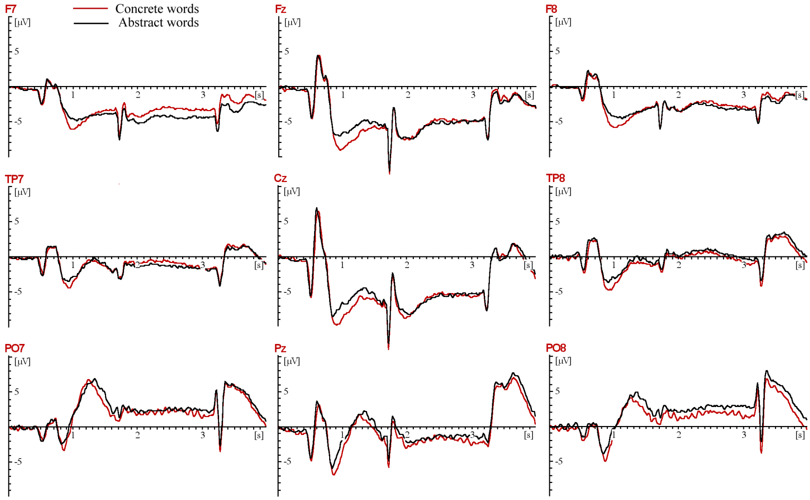
[5] Notice that with auditory word presentation, as compared to visually presented words, the relative timing of ERP components with respect to stimulus onset is delayed as auditory words cannot be presented at a single moment. While with visually presented words, the N400 effect reaches its maximum at around 400 ms after word onset, the N400 effect to auditory words in the present experiment was found to peak at 900 ms - 1000 ms after word onset. Notice however that the latency of the N400 component with respect to the auditory N1 component is within the normal range (the N400 reaches its maximum some 400 ms after the peak of the auditory N1)

Lexical Decision Task



Concrete-Abstract Decision Task

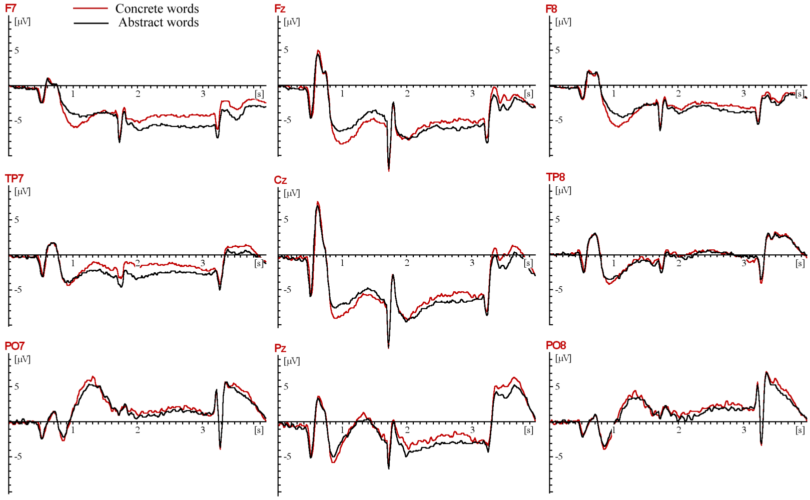


Figure 5.6: ERPs to words, showing the 4 second period from word onset to trial end. ERPs are aligned to a 100 ms pre-word baseline (not displayed). Red lines represent ERPs to concrete words, and black lines display ERPs to abstract words. The upper panel shows the ERPs to words recorded in the lexical decision task. The lower panel shows the ERPs to words presented in the concrete-abstract decision task. Colored figure at http://www.ub.rug.nl/eldoc/dis/arts/h.t.van.schie/

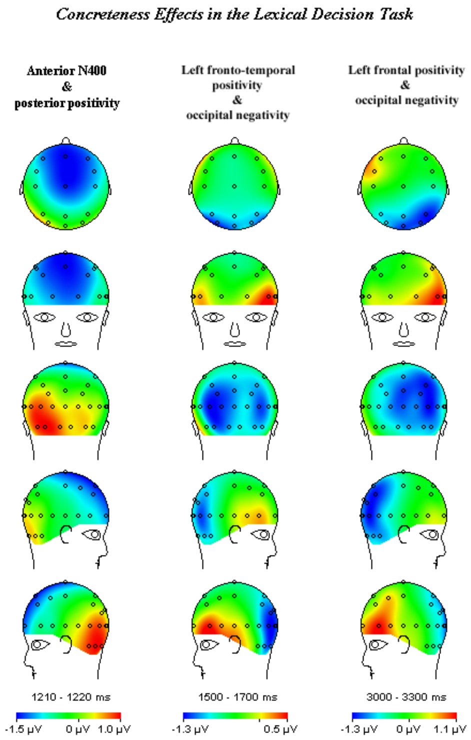


Figure 5.7: Topographic maps showing the distribution of the consecutive effects of concreteness as recorded in the lexical decision task. The left panel shows the topographic distribution of the anterior N400 effect to concrete words, as opposed to abstract words. The same panel shows the distribution of a posterior positivity that was found parallel to the N400 over anterior areas. The middle panel shows the topography of two subsequent effects of concreteness. Left fronto-temporal areas showed a prolonged slow wave positivity for concrete words as compared to abstract words, accompanied by a bilateral occipital negativity for concrete as opposed to abstract words. In the third panel the left fronto-temporal positivity has changed to a left frontal positivity for concrete as opposed to abstract words, again accompanied by a posterior negativity for concrete words. Colored figure at http://www.ub.rug.nl/eldoc/dis/arts/h.t.van.schie/

effects to concrete words in the three object load conditions. Main analysis of word ERPs over frontal electrodes showed no significant interactions between word-type and load ($F_{2,19}$ = .007; P = .993), and no interactions between word-type, load, and task ($F_{2,19}$ = .113; P = .893), in the interval of the N400.

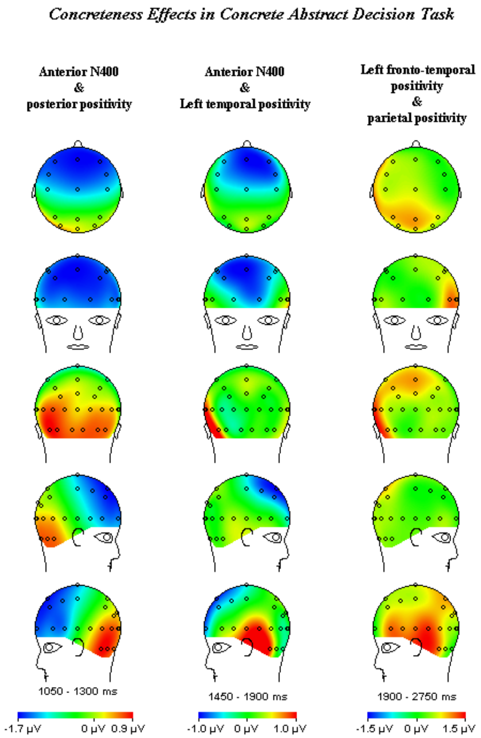


Figure 5.8: Topographic maps showing the distribution of the consecutive effects of concreteness as recorded in the concrete-abstract decision task. The left panel shows the topographic distribution of the anterior N400 effect to concrete words, as opposed to abstract words. The same panel shows the distribution of a posterior positivity that was found parallel to the N400 over anterior areas. The middle panel shows the anterior N400 together with the posterior slow wave positivity over left temporal areas. The third panel displays the effects of concreteness in the final stages of the ERP interval. Here the concreteness effect resulted in a fronto-temporal slow wave positivity over the left hemisphere. Partly coinciding with the fronto-temporal positivity a parietal slow wave positivity was observed over midline posterior areas. Colored figure at http://www.ub.rug.nl/eldoc/dis/arts/h.t.van.schie/

Posterior positivity Parallel to the N400 effect, a positivity was noted over the posterior cortex. Concrete words generated a positive wave as compared to abstract words. The effect was significant in the analysis of posterior electrodes from 1050 ms - 1300 ms post word (word by electrode; $F_{4,17}$ = 9.15; $P < 0.000$). At cerebellar electrodes we found the effect significant from 1150 ms - 1350 ms (main effect of word-type; $F_{4,17}$ = 9.15; $P < 0.000$). See Figure 5.7 on the preceding page and Figure 5.8 for the distribution of the posterior positivity as observed in the lexical decision task and the concrete-abstract decision task. Since the posterior positivity was strongest at the cerebellar electrodes it is difficult to see the effect in Figure 5.6 on page 97. Some of the effect may be seen at the PO7 electrode in the lower part of the figure (concrete-abstract decision task).

Although the posterior positivity to concrete words was somewhat stronger in the lexical decision task, this difference failed to reach significance. Neither the analysis of posterior electrodes, nor the analysis of cerebellar electrodes showed significant interactions between task and word-type in the 1050 ms - 1350 ms post word interval.

The posterior positivity did not interact with object working memory load. Neither in the analysis of posterior electrodes, nor in the analysis of cerebellar electrodes did we find a significant interaction between task and word-type in the interval of the positive slow wave.

Left frontal slow wave A third ERP effect of concreteness was found over the left inferior frontal cortex. In both the lexical decision task and the concrete-abstract decision task, concrete words generated a positive slow wave as compared to abstract words. The effect can be observed in Figure 5.6 on page 97 (electrode F7). As is clear from the figure, the left frontal slow wave set in shortly after the N400 effect, and lasted throughout most of the ERP interval. In the main analysis of frontal electrodes we found a word-type by hemisphere interaction from 2000 ms - 4000 ms ($F_{1,20}$ = 18.05; $P < .000$), and a word-type by electrode by hemisphere interaction from 1850 ms - 2650 ms, and from 2700 ms - 2850 ms ($F_{2,19}$ = 8.56; $P < .002$). Figure 5.7 on page 98 and Figure 5.8 on the preceding page show the distribution of the slow wave effect over the left frontal hemisphere.

As may be seen in Figure 5.6 on page 97, the size of the frontal slow wave effect is somewhat larger in the concrete-abstract decision task, as compared to the lexical decision task. However, the difference between both tasks was only significant for a short interval (task by word-type by electrode by hemisphere interaction in the main analysis of frontal electrodes, from 2400 ms - 2550 ms; $F_{2,19}$ = 4.92; $P < .019$).

The main analysis of frontal electrodes showed an interaction between word-type, load, electrode, and hemisphere from 2250 ms - 2400 ms post word ($F_{4,17}$ = 3.62; $P < .026$), which suggested the possibility that the left frontal effect of concreteness might have been influenced by object load. In both the lexical decision task and the concrete-abstract decision task the size of the frontal slow wave was somewhat smaller in the load 1 condition. However, pair-wise comparisons of effect in the three load conditions did not prove to be reliable.

Although no reliable interactions between word-type and load were observed over the frontal electrodes, we did find a strong influence of load on the slow wave effect of concreteness at the FT7 electrode which is located just posterior to the F7 electrode. Note that the FT7 electrode is part of the group of central electrodes, and was not included in the statistical analysis of frontal electrodes. At the FT7 electrode we found a significant reduction in the size of the frontal slow wave effect of con-

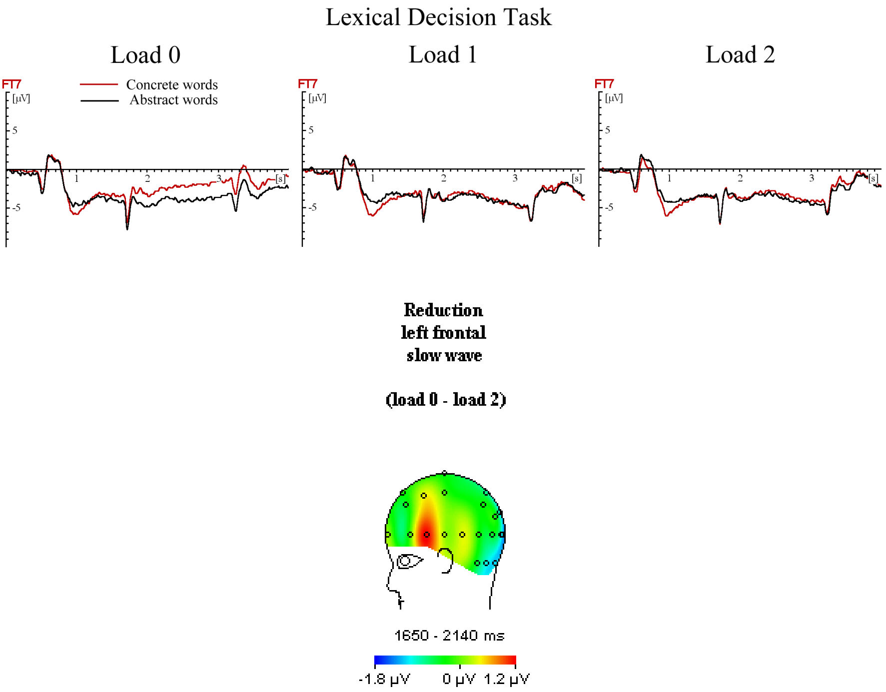


Figure 5.9: (Top) ERPs to words, recorded in the lexical decision task at the FT7 electrode. Red lines show ERPs to concrete words, and black lines display ERPs to abstract words. Left, right, and middle columns show ERPs recorded in load 0, load 1, and load 2 conditions respectively. (Bottom) Topographic map showing the reduction of the left frontal slow wave due to object working memory. The figure displays the difference between the concreteness effect in the load 0 condition as compared to the concreteness effect observed in the load 2 condition in the 1650 ms - 2140 ms interval post word onset. Colored figure at http://www.ub.rug.nl/eldoc/dis/arts/h.t.van.schie/

creteness in conditions that required object retention. This effect, however, was only observed in the lexical decision task, and not in the concrete-abstract decision task. See Figure 5.9 for the reduction of the concreteness effect at the FT7 electrode as observed in the lexical decision task. Statistically the suppression of the concreteness effect over the FT7 electrode is reflected in the main analysis of central electrodes, which showed an interaction between task, word-type, load, and hemisphere that was significant from 1900 ms - 2050 ms, 2200 ms - 2350 ms, and 2400 ms - 2650 ms post word onset ($F_{2,19} = 6.68$; $P < .006$). In addition we observed an interaction with electrode (task by word-type by load by hemisphere by electrode, which was significant from 1400 ms - 2150 ms ($F_{8,13} = 5.66$; $P < .003$). In a subsequent analysis restricted to the lexical decision task we observed an interaction between word-type, load, electrode, and hemisphere (from 1700 ms - 2050 ms; $F_{8,13} = 9.45$; $P < .000$)

which supported the effects observed in the main analysis. Figure 5.9 on the page before displays the topographic distribution of the left frontal slow wave effect in the load 0 condition, as compared to the effect in the load 2 condition.

Left temporal slow wave A fourth ERP effect of concreteness that was present in both the lexical decision task and the concrete-abstract decision task was found over the left posterior temporal cortex. Concrete words generated a more positive ERP than abstract words. The effect can be observed in Figure 5.6 on page 97 (electrode TP7). Clearly, there is a prominent difference between the effect of concreteness as observed in the lexical decision task and the concrete-abstract decision task. In the concrete-abstract decision task the temporal slow wave had an early onset (see middle panel of Figure 5.8 on page 99 for the distribution of the early temporal effect). Furthermore, the amplitude of the temporal slow wave effect is much larger in the concrete-abstract decision task than in the lexical decision task. Statistically, however, there were no clear differences between the temporal effects in the two language tasks. The analysis of central electrodes showed a strong interaction between word-type and hemisphere from 1850 ms - 4000 ms post word ($F_{1,20}$ = 31.67; $P < .000$). However, there was no interaction with task.

The temporal slow wave to concrete words as observed in the lexical decision task was not influenced by object load. Although the statistical analysis of the ERPs recorded to the central electrodes in the lexical decision task showed clear interactions between word-type, load, hemisphere, and electrode, these interactions reflect the reduction of the left frontal slow wave at the FT7 electrode which was discussed earlier (see previous paragraph 'Left frontal slow wave'). To be certain, we performed an additional analysis on the ERPs recorded to the TP7 and TP8 electrodes in the lexical decision task. No significant interactions were found between word-type, load, and hemisphere ($F_{2,19}$ = .439; $P = .651$).

In order to determine the possible effects of object working memory on the temporal slow waves recorded in the concrete-abstract decision task, an additional analysis was performed. The analysis, which was restricted to the ERPs at central electrodes recorded in the concrete-abstract decision task, showed an interaction between word-type, load, and hemisphere (1600 ms - 1800 ms; $F_{2,19}$ = 4.93; $P < .019$). In addition we found an interaction between word-type, load, hemisphere, and electrode (1450 ms - 1750 ms; $F_{8,13}$ = 6.08; $P < .002$). These interactions reflect the earlier onset of the temporal slow wave positivity in the load 2 condition, as compared to the onset of the temporal slow waves as recorded in the load 0 and load 1 conditions. There were, however, no significant effects of object working memory load on the amplitude of the temporal slow wave to concrete words in subsequent intervals.

Task specific ERP effects of concreteness

In the previous section we described effects of concreteness that were observed in both language tasks. However, results also showed task specific effects of concreteness, which were selectively found in either the lexical decision or the concrete-abstract decision task. In the following we will describe the task specific ERP effects of concreteness.

Occipital negative slow wave In the lexical decision task and the concrete-abstract decision tasks we observed different effects of concreteness over posterior electrodes. In the lexical decision task, concrete words generated a robust slow wave negative difference over occipital electrodes, as compared to abstract words. This effect is best seen at the PO7 electrode in the upper panel of Figure 5.6 on page 97. In the concrete-abstract decision task, on the other hand, concrete words were found to generate a posterior slow wave positivity over the parietal lobe (this effect will be discussed in the next section). The different effects of concreteness in the lexical decision task and the concrete-abstract decision task resulted in a task by word-type interaction in the main analysis of posterior electrodes (1400 ms - 1550 ms, 2250 ms - 2400 ms, and 3600 ms - 3900 ms; $F_{1,20} = 28.03$; $P < .000$). In order to discriminate between the posterior effects of concreteness in both language tasks we performed two additional analyses, one which was restricted to the lexical decision task, and a second which was restricted to posterior effects of concreteness in the concrete-abstract decision task. Here, we will focus on the effect of concreteness as observed in the lexical decision task.

In the lexical decision task, concrete words generated a robust slow wave negative difference, as compared to abstract words (see Figure 5.6 on page 97, upper panel). The effect set in at around 1300 ms, some 400 ms after the peak of the N400. After an initial bilateral distribution over the left and right occipital hemispheres, the slow wave negativity dominated over the right occipital lobe. See Figure 5.7 on page 98 for the distribution of the occipital slow wave negativity to concrete words in the early stages of the slow wave (middle panel), and the distribution of the effect at a later time (right panel). The analysis of posterior electrodes in the lexical decision task showed a main effect of word-type from 1400 ms - 1600 ms, and from 3050 ms - 3300 ms ($F_{1,20} = 12.19$; $P < .002$). In addition we found an interaction between word-type and hemisphere in the 3350 ms - 3550 ms interval post word ($F_{1,20} = 8.52$; $P < .008$).

No significant interactions were found between word-type and load, which suggests that the occipital slow wave effect of concreteness as observed in the lexical decision task was not influenced by object working memory load.

Parietal slow wave In the concrete-abstract decision task we found that concrete words generated a slow wave positivity over the posterior parietal lobe, as compared to the ERPs to abstract words. This effect is clearly different from the occipital slow wave negativity to concrete words that was observed in the lexical decision task (see above). See Figure 5.6 on page 97 (lower panel) for the difference between the ERPs to concrete and abstract words over the parietal lobe (Pz electrode). As is clear from the figure, the parietal slow wave positivity to concrete words started at around 1900 ms post word onset, lasting until 3000 ms, and than reappearing again during presentation of the test polygon (3500 ms - 3800 ms). See Figure 5.8 on page 99 for the distribution of the parietal slow wave in the 1900 ms - 2750 ms interval. Statistical analysis of the ERPs to posterior electrodes in the concrete-abstract decision task, resulted in a significant effect of word-type from 3550 ms - 3850 ms ($F_{1,20} = 9.22$; $P < .007$). No significant effect of word-type was found in the earlier interval (from 1900 ms - 3000 ms).

The previous paragraph shows that, although the parietal slow wave to concrete words was centered over the Pz electrode, its effects were also evident in the ERPs to posterior electrodes. The main analysis of midline electrodes (which included the Pz electrode) showed an interaction between task and word-type (3600 ms - 3750 ms; $F_{1,20} = 7.85$; $P < .011$). A subsequent analysis restricted to the concrete-abstract decision task showed a main effect of word-type from 2250 ms - 2400 ms, 2800 ms - 3100 ms, and from 3450 ms - 3750 ms ($F_{1,20} = 11.43$; $P < .003$). There was no interaction with electrode since slow wave effects to concrete words were not restricted to the Pz electrode. See Figure 5.6 on page 97 (lower panel) for the slow wave effects of concreteness at the Fz, Cz, and Pz electrodes. The Fz electrode is also sensitive to the effects of concrete words as observed over the left anterior lobe (see above). At the Cz electrode we find a spreading of the effect observed over the left posterior temporal lobe. Together the slow wave effects over the left frontal, left temporal, and parietal areas result in a main effect of word-type in the analysis of midline electrodes.

The parietal positive slow wave effect of concreteness that was selectively observed in the concrete-abstract decision task was not found to be influenced by the object working memory task. The analysis of ERPs to midline electrodes in the concrete-abstract decision task did not show significant interactions between word-type and load.

5.4 Discussion

In the current study we investigated the cortical mechanisms that are involved in the activation of visual semantic information from concrete words. It was hypothesized that concrete words will activate their visual semantic meaning via the cortical network for object working memory.

5.4.1 Behavior

On the behavioral level, responses to words and polygons were found to display the expected effects of concreteness and object working memory. Subjects' responses to polygons showed the expected effects of object working memory load, with prolonged reaction times and more errors to the visually complex polygons (load 2 condition), than to the more simple polygons (load 1 condition). Although the requirement of keeping a polygon in short-term memory was found to speed up the response times to words, the complexity of polygons did not affect the response times to words.

Concrete words showed faster reaction times, more accurate responses, and less misses than abstract words. Although the behavioral advantage to concrete words was observed in both language tasks, the effects were notably stronger in the concrete-abstract decision task. Concreteness effects were also significant in response to the polygon matching task, with faster and more accurate responses for trials that involved concrete words, as opposed to trials that included abstract words. Again, the effects of concreteness were strongest in conditions which required concrete-abstract decisions.

Although generally, behavior to polygons was more efficient and faster in trials which involved concrete words, we did find that the effect of object load was more strongly influenced by concrete words than by abstract words (see Figure 5.3 on page 91). This result is consistent with the hypothesis that object working memory and concrete words involve related cognitive processes.

5.4.2 ERPs

ERP effects of object working memory

ERP effects accompanying object working memory were found to display slow wave potentials over frontal, occipital and parietal areas. Both object load conditions involving the retention of simple and complex polygons generated a slow wave positivity over bilateral inferior frontal areas (electrodes F7 and F8), as compared to the load 0 condition where no memory for polygon shape was required. Retention of more complex polygons resulted in a pronounced slow wave with a broad medial frontal distribution (around Fz) as compared to the retention of simple polygons. Shortly after onset of the frontal slow wave, a bilateral occipital negative slow wave was observed that was found to grow in amplitude with increasing object load. The effect was larger over the right occipital lobe than over the left. At parietal sites object retention was accompanied by a positive slow wave (centered around the Pz electrode), as compared to conditions where no object retention was required. The slow wave effect over the parietal cortex was of similar size in the load 1 and load 2 conditions.

Previous work has found that processing in visual working memory is associated with negative slow wave waves over posterior areas. The requirement to maintain spatial materials or to transform (rotate) visual information generally results in maxima over the parietal cortex (e.g. Peronnet & Farah, 1989; Wijers, Mulder, Otten, Feenstra, & Mulder, 1989b; Rösler, Heil, Bajric, Pauls, & Hennighausen, 1995), while retention of visual object information is generally accompanied by a negative slow wave with a more posterior occipital maximum (Uhl et al., 1990; Ruchkin et al., 1992, 1994; Ruchkin, Canoune, Johnson Jr., & Ritter, 1995; Ruchkin et al., 1997). Although some studies have reported negative slow waves to object retention over frontal areas (Mecklinger & Muller, 1996; Löw et al., 1999), these studies used a different placement of the reference electrode, which may have affected the polarity of the frontal slow wave as compared to studies that used a non-cephalic reference.

In addition to the studies discussed above which reported negative slow waves to accompany processes within visual working memory, other studies have reported positive slow wave effects over frontal areas to operations within visual working memory. Berti, Geissler, Lachmann, and Mecklinger (2000) compared ERPs to simple and complex five-point patterns that had to be maintained in working memory. Retention of complex patterns over a 1500 ms interval resulted in a posterior negativity (peak around 350 ms), followed by a positive slow wave over fronto-central areas (500 ms - 1200 ms), as compared to the retention of simple patterns.[6] Klaver (1999a) investigated object storage in short-term memory. During the memorization interval (1850 ms retention delay), increasing memory load (retention of one versus two objects) resulted in two positive shifts over fronto-central electrode sites (200 ms - 300 ms, and 600 ms - 1000 ms) and a negative shift over posterior electrode sites (300 ms - 800 ms). Consistent with the involvement of a frontal positive slow wave in object working memory, Nielsen-Bohlman and Knight (1999) have observed a reduced frontal positivity for retention of line-drawings of familiar objects in patients with lesions in dorsolateral frontal cortex.

In sum, while spatial working memory is generally accompanied by a single negative slow wave, which is usually maximal over the parietal lobe, object working memory is probably associated with two slow wave effects, one with a negative polarity over occipital areas, and a second with a positive polarity over frontal areas.

The distribution of the slow wave effects over the frontal cortex is consistent with the existence of an object working memory system within ventro-lateral areas of both frontal hemispheres, which is biased towards the left frontal lobe for the representation of objects (Smith & Jonides, 1997). The finding of additional slow wave negativity over bilateral occipital cortices supports a frontal - posterior network for object representation, where the visual representations of objects are retained in the ventral temporo-occipital pathway.

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[6] Note that Berti et al. (2000) interpreted the latter effect as a negative slow wave to less complex patterns, based on the majority of studies that have reported slow wave negativities for retention in working memory.

Although the current effects over frontal and occipital areas are consistent with the existing literature, the parietal slow wave positivity that was recorded to the retention of both simple and complex polygons is not. Both the lack of earlier reports describing positive slow waves over the parietal cortex to visual working memory conditions, and the fact that the amplitude of the parietal slow wave was unaffected by the amount of object load, lead us to believe that the parietal slow wave is not a direct correlate of maintenance within object working memory.

ERP effects of concreteness

ERP correlates of concreteness consisted of slow wave effects over a variety of cortical areas. The earliest ERP effect of concreteness was found on the amplitude of the N400 over the frontal cortex (950 ms - 1600 ms after word onset). Parallel to the N400 effect over frontal areas, a posterior positivity was noted over posterior and cerebellar electrodes (1050 ms - 1300 ms). Subsequent to the effect on the N400, concreteness effects were found over left posterior temporal (1850 ms - 4000 ms) and left frontal areas (2000 ms - 4000 ms), showing a positive slow wave for concrete as opposed to abstract words. A task specific effect of concreteness was observed in the lexical decision task which showed a bilateral slow wave negativity over the occipital lobe. Following the initial bilateral distribution, which was significant from 1400 ms - 1600 ms, the effect shifted to the right hemisphere. In the concrete-abstract decision task there was no occipital slow wave effect of concreteness. Rather, concrete words generated a parietal slow wave which was more positive as compared to the ERPs to abstract words. The parietal effect, which was selectively found in the concrete-abstract decision task, was significant from 2250 ms - 2400 ms, and 3600 ms - 3900 ms.

N400 The present results successfully replicated the N400 effect of concreteness over frontal cortical areas as observed by Kounios and Holcomb (1994). However, Kounios and Holcomb (1994) found a larger N400 effect of concreteness in the concrete-abstract decision task, as compared to the lexical decision task. Our results showed no difference between the amplitude of the N400 effect in the lexical decision task and the concrete-abstract decision task. One difference between the current study and the study by Kounios and Holcomb (1994) is that the latter used different subjects for the lexical decision and the concrete-abstract decision tasks, while in the present study the same subjects performed in both language task conditions. This suggests the possibility that the larger N400 amplitude in the concrete-abstract decision experiment of Kounios and Holcomb (1994) occurred as a consequence of an accidental between group difference, rather than reflecting a task specific influence on the concreteness effect. Another difference between the present study and the study by Kounios and Holcomb (1994), is that Kounios and Holcomb found the N400 effect to concrete words to be lateralized to the right frontal lobe, while in the present results we found the effect on the N400 to be distributed centrally over the frontal cortex. As an explanation we note the possibility that the distribution of the N400 effect in the Kounios and Holcomb (1994) study may have shifted to the right anterior cortex due to positive slow wave effects over the left frontal lobe. Although the effect over the left frontal lobe, as observed in the current study was only significant after the N400 interval had finished, it is possible that the left frontal positivity may have had an earlier onset in the Kounios and Holcomb study, which may, as a result, have affected the distribution of the N400 negativity to concrete words.

Previous research has shown the existence of an N400-like ERP effect for pictures with a more anterior distribution as compared to the N400 effect to words which is generally found over the posterior parietal lobe (Barrett & Rugg, 1990; Ganis et al., 1996). Although the exact function, and cortical origin of the frontal negativity is still under debate (e.g. Schendan, 2002) it seems clear that the effect is involved in the processing of picture or object specific information. McPherson and Holcomb (1999) suggested that the anterior N400 may originate from the dorsolateral prefrontal cortex (cf. Kosslyn et al., 1994b) which, among other things, may act to look up stored properties of objects that are difficult to identify. A similar suggestion has been made by Schendan (2002) who proposed that "the frontal N350 reflects [...] searching for a stored description that matches the perceived image" (pg. 943), but they speculated on a neuroanatomical locus in the occipitotemporal and mid-fusiform regions, as these areas have been proposed to hold the structural descriptions of objects (see also Doninger et al., 2000). As discussed already, similar effects have also been found for the processing of concrete versus abstract words (e.g. Kounios & Holcomb, 1994), in conditions where no actual picture is being presented. In line with these studies we concur that the anterior negativity may index processes that are specifically associated with high-level analysis and retrieval of visual descriptive information about objects.

One important advance that is made in the current study, as compared to the previous studies, is that our results suggest that the anterior N400 to concrete words is not a direct measure of visual processing, but appears to be associated to pre-visual processing (possibly retrieval of high-level object information from long-term memory).

Posterior positivity Possibly, the occipital positivity that was found to concrete words as compared to abstract words, parallel to the N400 effect over frontal areas, is somehow related to the retrieval of concrete visual information from long-term memory.[7] A similar posterior effect, parallel to the anterior N400, was observed by McPherson (Mcpherson & Holcomb, 1992; McPherson & Holcomb, 1999), which was hypothesized to be associated with activation within an early visual buffer (in

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[7] Clearly, it is not the case that the posterior positivity and the anterior N400 effect are a manifestation of the same cortical source. The duration of the N400 effect is much longer than the posterior effect. Furthermore, we find that the posterior slow wave effect is lateralized to the left hemisphere, while there is no lateralization for the anterior effect on the N400.

areas 17 and 18), which is believed to be involved in the retention of mental images (Kosslyn et al., 1994b). In our view this is unlikely since mental imagery and visual working memory have consistently been associated with negative slow waves over the posterior cortex, and almost never with positive waves. Instead we propose that the posterior positivity over the occipital cortex is functionally related to the N400 effect over the anterior lobe, as both effects are consistently observed together. Possibly the posterior positivity is associated with the retrieval of structural descriptions of objects in the left occipito-temporal lobe. The lateralization of the effect overlying the left ventral hemisphere is consistent with this possibility.

Concreteness effects in the lexical decision task Although the present study successfully replicated the anterior N400 effect of concreteness, together with the posterior positivity which has been found in parallel to the N400, these effects are not considered as a direct manifestation of imageability. Rather, the present results seem to suggest that the activation of object information in the visual system is signaled by the slow wave effects which follow up upon the N400. Following the anterior N400, and posterior slow wave positivity, ERPs in the lexical decision task were found to generate a slow wave negativity over bilateral occipital cortices, shortly followed by the onset of a slow wave positivity over the left frontal cortex. These effects appear to be consistent with previous reports of object working memory and mental imagery, which have been observed to result in slow wave effects over several seconds (Farah et al., 1989; Mecklinger & Muller, 1996; Ruchkin et al., 1997). The obvious similarity between the effects of object working memory, as observed in the present study, and the slow wave effects to concreteness as recorded in the lexical decision task, suggest that concrete words activate their visual representation via the existing network for object representation. Slow wave effects over the left frontal cortex may signal activation of object representation in the left ventro-lateral frontal lobe (e.g. Smith & Jonides, 1997). The finding of additional slow wave negativity over bilateral occipital cortices supports a frontal - posterior network for object representation, where the visual representations of concrete words are activated in the ventral occipito-temporal pathway (cf. Ungerleider et al., 1998).

Since concreteness effects were hypothesized to use the same neural system as object working memory, we expected to find interactions between object load and effects of concreteness. Results showed that the requirement to maintain an object in working memory affected the amplitude of the left frontal slow wave to concrete words. This result is important because it is consistent with the hypothesis that object working memory and concreteness effects to words use overlapping neural structures. However, the reduction did not involve the entire distribution of the left frontal slow wave, but was restricted to two specific electrodes, FT7 and FC3. This suggests that only part of the left frontal slow wave is actively involved with object representation. A consequence of this observation is that the left frontal positivity may not just signal the activity of one functional process, but may reflect the combined activity of several processes.

Results did not show a significant influence of object working memory on the visual slow wave negativity to concrete words. Although both the retention of objects, and the processing of concrete words generated a slow wave negativity over the visual cortex, we did not find an interaction between them. A possible explanation for the absence of an interaction is that the occipital slow wave to the object retention task ended just before the presentation of words (see Figure 5.4 on page 93). Frontal effects of the object retention task, on the other hand, continued throughout the ERP interval for words. As a consequence, the interactions between object working memory and concreteness may have been confined to the frontal area.

Concreteness effects in the concrete-abstract decision task Similar to the lexical decision task, concrete words presented in the concrete-abstract decision task generated a positive slow wave over the left frontal cortex. In addition to the frontal effect, concrete words were found to result in a strong positive slow wave over the left posterior temporal cortex. Opposite to the effects of concreteness as observed in the lexical decision task, concrete words did not lead to a slow wave negativity over the occipital lobe. Rather, concrete words were found to generate a positive slow wave that was maximal over the parietal lobe.

While the concreteness effects in the lexical decision task were found to be highly similar to the slow wave effects of object retention, this was less so for ERPs to concrete words presented in the concrete-abstract decision task. Although concrete words did result in a slow wave positivity over the left frontal lobe, which is similar to the frontal effect to object retention, we did not find an interaction between the effects of concreteness and object working memory. Both the absence of an interaction between object working memory and the effect of concreteness, and the absence of a negative slow wave over the occipital lobe, suggest that concrete words presented in the concrete-abstract decision task do not put emphasis on the system for object working memory.

Although this conclusion seems to be straightforward, we cannot be entirely sure if it is valid. We had suggested that the instruction to discriminate between concrete and abstract words might put a stronger emphasis on the visualization of concrete words as compared to the condition which requires only lexical decision. However, the absence of a negative slow wave over occipital lobe in the concrete-abstract decision task does not necessarily mean that subjects did not visualize. It may be that an occipital effect was present, but was overshadowed by the parietal positivity to concrete words. Also, the observation of a positive slow wave over ventral parts of the left frontal cortex does suggest that visual working memory was used in the concrete-abstract decision task. However it is difficult to explain why there was no interaction with the polygon retention task.

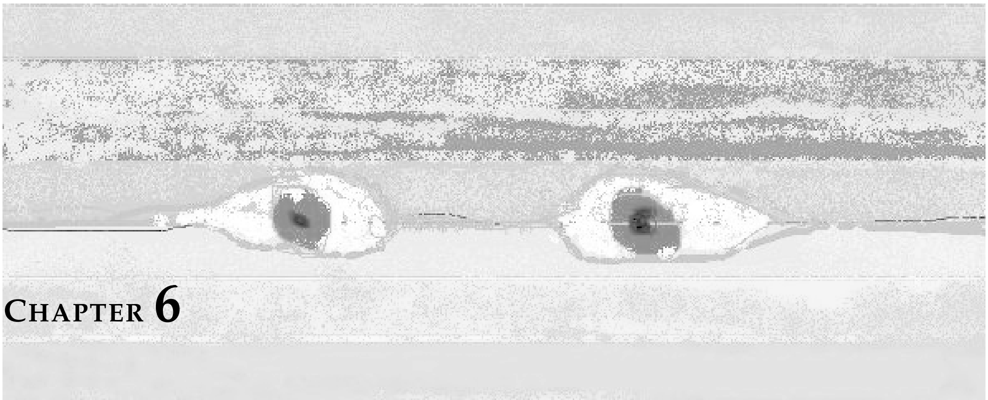
Although we cannot be certain that object working memory was not involved in the concrete-abstract decision condition, it is clear that task instructions to subjects had a large influence on the processing of concrete and abstract words. The different results in the two language tasks suggest that there are additional processes involved when subjects are consciously deciding on the concreteness of words. The larger concreteness effect over the left posterior temporal lobe in the concrete-abstract decision task may be associated with the retrieval of additional semantic knowledge to concrete lexical items as has been suggested by Damasio et al. (1996), and Tranel et al. (1997). The absence of a left temporal positivity in the ERPs to the polygon retention task is consistent with this interpretation, as polygons do not have a lexical representation.

The parietal slow wave effect of concreteness as observed in the concrete-abstract decision task may be associated with attentional mechanisms which assist visualization to concrete words (cf. Kosslyn, 1994a). Smith and Jonides (1997) suggested that the parietal lobe may be especially important for the control of visual selective attention. Furthermore, ERP effects accompanying the control of spatial attention often include effects over the parietal lobe (e.g. Harter, Miller, Price, Lalonde, & Keyes, 1989; Mangun, 1994). Interestingly, we also observed a parietal slow wave for the object retention task. The parietal slow wave did not differ for the retention of simple and complex polygons. This suggests that the size of the parietal effect is no estimate of the amount of information that has to be retained in working memory. Rather it suggests that the parietal effect is involved with the control of visual information in working memory. The same interpretation may be upheld for the parietal slow wave that was observed in the concrete-abstract decision task. Task conditions which require active or conscious use of visual information in working memory may be assisted by attentional control processes in the parietal lobe (cf. Kosslyn, 1994a).

Further research will have to clarify some of the effects that were observed in the concrete-abstract decision task. For both the left temporal slow wave and the parietal slow wave effects to concreteness it is still unclear what exact functional process they are reflecting. Furthermore, the question is still open whether concrete-abstract decision does involve processing within object working memory, or whether these effects are only found in conditions which require lexical decision.

5.5 Conclusion

In conclusion, we feel that the current study supports a model of visual semantics in which visual semantic information of concrete words is first retrieved from long-term memory (indexed by the anterior N400, and the posterior positivity), and is subsequently visualized via the existing network for object working memory (reflected by the left frontal positive slow wave and the bilateral occipital slow wave negativity). Retrieval and visualization of concrete words may proceed relatively automatic, as is clear from the effects as observed in the lexical decision task. Further research will have to clarify the concreteness effects that were found in the concrete-abstract decision task, and investigate the question whether concrete-abstract decisions also involve processes within object working memory, or engage a different neural system.



CHAPTER 6

Summary and General Discussion

6.1 Summary

The nature of meaning has intrigued generations of psychologists, philosophers, and linguists who have tried to understand how meaning is represented in our minds and brains. Some have proposed that semantic memory for words is represented in an amodal propositional or symbolic form, which is separate from sensory or perceptual representations (e.g. Anderson, 1976; Schwanenflugel & Shoben, 1983). Others have suggested that the meaning of concrete words is represented somewhere in the sensory areas of our brain (e.g. Paivio, 1971; Warrington, 1975; Allport, 1985; Pulvermüller, 1999a). Although there is a growing interest among cognitive scientists in investigating the organization of semantic memory, little is known yet about the neurophysiological mechanisms which enable retrieval and activation of concrete semantic knowledge.

A central issue in the present thesis concerned the possible role of objects and their representations as part of semantic memory for concrete words. Several experiments were discussed which investigated the different properties of visual semantic memory and its relationship to object representations in the visual system. Chapter 2 focused on functional mechanisms for visual search and object recognition, and investigated whether visual mechanisms for object identification are affected by the visual semantic representations of concrete words. Chapter 3 was concerned with the distribution of semantic memory for concrete words in the dorsal and ventral visual streams, and investigated the possibility that visual semantics follows the organization of perceptual function in the brain. Chapter 4 investigated the hypothesis that objects are represented via a temporary association between sensory, perceptual, and semantic levels of object description. Chapter 5 focused on the cortical mechanisms which are involved in the activation of visual semantic information from concrete words. It was hypothesized that concrete words will activate visual semantic meaning via the cortical network for object working memory.

6.1.1 Chapter 2

Semantic knowledge about visual properties of objects is believed to be particular important for the recognition and search for visual objects. Chapter 2 concentrated on functional mechanisms for visual search and object recognition, and investigated whether visual mechanisms for object identification are affected by the visual semantic representations of concrete words.

One of the mechanisms that is considered to play key role in visual search is inhibition of return (IOR). IOR refers to a bias not to return attention to objects or locations which have been recently attended, thereby favoring novel and yet unexplored objects and portions of the visual field. IOR is closely associated with the system for saccadic eye movements which has been claimed to be biased towards visual search and object recognition in the upper visual field (Previc, 1990). Based on the proposed advantage for saccadic eye movements towards the upper visual field it was expected that IOR would be stronger for objects presented in the upper visual field. Previous studies have shown that IOR is closely tied to specific objects or parts of objects (Tipper, 1991; Ro & Rafal, 1999) which suggests that IOR is not simply a subcortical (saccade related) process but is associated with the cortical representations of objects. Chasteen and Pratt (1999) have found that IOR affects the lexical access of words, and Fuentes et al. (1999b) showed that IOR may be evoked by the onset of words, and that the inhibitory effect of IOR may extend to or interact with the semantic properties of words (see also Fuentes et al., 1999a). This suggests that the effects of IOR may transfer up to lexical and semantic representations of objects. Although bottom-up effects of IOR may spread to higher cognitive functions, it is unclear whether the reverse is also true, that is, whether it possible for higher cognitive functions to modulate the behavior of IOR. In order to investigate this hypothesis the experimental design included words which could either be semantically identical to the object, or unrelated to the object. Semantic priming effects from words were expected to modify the strength of IOR towards objects.

Results of experiment 1 showed a clear difference between IOR in the upper and the lower visual fields. It was argued that the stronger effect of IOR in the UVF is consistent with the advantage for saccadic eye movements and object recognition in the UVF, as proposed by Previc (1990). However, the UVF effect for IOR might have been due to basic differences in sensitivity to stimuli presented in the upper and lower visual fields. This hypothesis was investigated in experiment 2 which involved a standard peripheral cueing design with uninformative cues (instead of objects) and subsequent detection of visual probes in the upper and lower visual hemifields. Results of experiment 2 showed comparable effects of IOR in the upper and lower visual fields. This supported the hypothesis that the inclusion of task relevant objects in experiment 1 had caused the bias for IOR to the UVF.

It is particularly relevant to the present thesis whether the object-based properties of IOR are associated with the visual semantic representations of concrete objects. This hypothesis was investigated by the inclusion of words which were presented shortly after the object had disappeared from the screen (experiment 1). In half of the cases the word had the same meaning as the picture, while in the other cases a word was presented which was unrelated to the object. In this situation both IOR and semantic priming are directed at the same object. If there is a reciprocal relationship between IOR and the semantic system then we might expect an influence of matching words on IOR. Contrary to our predictions, however, the inclusion of words did not modify the magnitude of IOR in an interesting way. This suggests that IOR is not very sensitive to semantic factors. If we had found an influence of semantic priming on the UVF effect of IOR then we might have concluded that the UVF advantage of IOR is associated with cortical mechanisms for object representation in the ventral stream. However, as this is not the case, a more probable explanation for the UVF bias of IOR is that there is a stronger tendency to use saccadic eye movements for the identification of objects in the UVF, as compared to the identification of objects presented in the LVF. This result suggests that shifts of covert visual attention to the identification of objects presented in the UVF are accompanied by saccadic planning, and that this tendency is less strong for the identification of LVF objects.

As the paradigm used in chapter 4 is very similar to the experimental setup in chapter 2, a logical step would have been to compare the behavioral results of chapter 2 with the electrophysiological measurements of chapter 4. It would be especially interesting to see whether the UVF advantage for IOR which was found in chapter 2 is associated with stronger ERP effects to probes presented in the UVF. Unfortunately, this was not possible because of a baseline problem. Pictures presented in the upper visual field resulted in a large positive ERP response which took approximately the entire trial period to return to baseline. The opposite was observed for LVF pictures, which generated a strong negativity that was persistent throughout most of the trial. In most cases there is no problem with this, because if we pool ERPs over conditions with pictures in the UVF and pictures in the LVF, these effects will average out. However, if we want the calculate the ERP effects of IOR in the upper or lower visual field we need to subtract the conditions with upper and lower visual field pictures. Although we were able to determine ERP effects of IOR by pooling over the upper and lower visual fields, we could not reliably ascertain the effects of IOR in the separate vertical hemifields.

6.1.2 Chapter 3

Chapter 3 was concerned with the distribution of semantic memory in the dorsal and ventral visual streams, and investigated the possibility that visual semantic memory follows the organization of perceptual function in the brain (cf. Martin et al., 1995). The ventral stream is characteristically involved in object recognition (e.g. representing the shape and color of objects) (e.g. Haxby et al., 1991), while the dorsal stream is believed to subserve processing of actions directed at those objects (e.g. Goodale, 1996; Jeannerod, 1997). Most studies which have investigated differences between the ventral and dorsal visual streams have focused on the processing of manipulable and nonmanipulable objects (e.g. tools versus animals) (e.g. Martin et al., 1996; Chao & Martin, 2000). However, using objects as stimuli makes it impossible to disentangle perceptual or visual specialization in one or the other pathway from semantic specialization. Words, on the other hand, have the advantage that they only activate the semantic representation of an object. The present study investigated semantic specialization in the dorsal and ventral visual stream by presenting words referring to manipulable and nonmanipulable objects to the upper and lower visual fields. Four sets of experimental words were used: (1) words referring to manipulable objects generally found in the UVF (e.g. 'clothesline'), (2) words referring to manipulable objects generally found in the lower visual field (LVF) (e.g. 'keyboard'), (3) words referring to nonmanipulable objects generally found in the UVF (e.g. 'chimney'), and (4) words referring to nonmanipulable objects generally found in the LVF (e.g. 'railway'). Under the hypothesis that visually presented words are able to connect to their semantic representations directly, a relative advantage was expected for manipulable words when presented to the LVF (which is connected to the dorsal visual stream). Words referring to nonmanipulable objects were expected to show an advantage when presented to the UVF (which connects to the ventral visual stream). Notice that the logic involved here is similar to divided field experiments which are directed at investigating left and right hemispheric differences in language function. Verbal materials (words or sentences of different sorts) are presented to the left and right visual fields in order to study language function in the respective contralateral hemispheres (review in Chiarello, 1988). In our case we made use of the crossed organization of visual information which directs visual input from the LVF to the dorsal occipital cortex, and visual input from the UVF to ventral occipital cortex (e.g. Previc, 1990; Danckert & Goodale, 2001).

Results showed that there were differences between the four experimental sets of words. Both words denoting manipulable objects biased towards the LVF (e.g. 'keyboard'), and words referring to nonmanipulable objects with a bias towards the UVF (e.g. 'chimney'), were responded to faster and more accurately, as compared to the other two word categories denoting manipulable objects with an UVF bias (e.g. 'clothesline'), and nonmanipulable objects with a LVF bias (e.g.'railway'). Possibly, manipulable objects with a LVF bias, and nonmanipulable objects with an UVF bias are more representative of the natural organization of elements in the visual world

(Hayes-Roth & Hayes-Roth, 1977; Previc, 1990), which gives them an advantage over objects with a less typical position (Das-Smaal, 1990).

An unexpected additional finding was a prominent advantage for words presented to the LVF, as compared to words presented to the UVF. Field effects were approximately twice as strong for words than for pseudowords, suggesting an advantage for language materials being presented in the LVF.

Consistent with our expectations, behavioral analysis of responses to manipulable and nonmanipulable words showed that manipulable words were processed more accurately (fewer errors) when presented to the LVF. Nonmanipulable words on the other hand were more accurately responded to when presented in the UVF. An important fact, however, is that this pattern of results was only found for repeated target words when the same word, presented as a prime, had been in the LVF. We speculated that stronger priming effects from words presented in the LVF may have provided the necessary conditions for this effect to occur. Priming may be necessary to (pre-)activate the relevant features of manipulable and nonmanipulable words for them to be directly activated by the presentation of the word within the appropriate visual field.

6.1.3 Chapter 4

An important question with respect to the organization of meaningful information in the brain is how objects are represented. Chapter 4 investigated the hypothesis that objects are represented via a temporary association between sensory, perceptual, and semantic levels of object description. A consequence of such a temporary association may be that a change at one level of the object representation (e.g. at the semantic level) will automatically affect the other levels of the representation (e.g. the perceptual representation of the object). In order to investigate this question, a picture - word repetition paradigm was used in which the semantic relationship between pictures and words was manipulated. Experiment 1 involved two types of trials, one with words that had the same meaning as pictures (matching words), and one with words that were unrelated to pictures (unrelated words). Matching words were expected to connect with the semantic representation of pictures, and, as a result, reinforce the object representation. If perceptual features are linked to the object's semantic representation, we should expect to find effects of matching words feeding back to the perceptual level. Visually presented probes were used to study these potential effects of semantic matching at the perceptual level.

ERPs to unrelated words resulted in a strong N400 effect which is generally found for stimuli for which there is no obvious semantic relationship (Kutas & Hillyard, 1980, 1984). The general conception of the N400 effect is that it reflects an attempt for semantic integration of unrelated items. Following the effect on the N400, nonrelated words were found to generate a prolonged negativity over visual and frontal cortical areas. Part of the post N400 negativity appeared to reflect additional visual processing (possibly involved with further visual-based search for a potential relationship between the picture and the word) as it was strongly affected by the presentation of visual probe stimuli. Especially UVF probes resulted in a strong attenuation of the effect. These results are interesting because they suggest that visual processes may be invoked by or are included as part of (extended) semantic processing.

Under the hypothesis that the object's visual representation and its semantic representation are temporarily linked, we expected that matching words would strengthen the object representation in perceptual areas. As a consequence, matching words were expected to modify the early visual bottom-up process for probe stimuli presented at the same location as the picture. More specifically we expected that a semantic match between the picture and the word would re-direct visual attention to the original retinal location of the picture stimulus, and enhance the early visual (P1 and N1) ERP components to probes presented at that location. As expected, matching words did affect the ERP responses to same location probes. However, the earliest significant ERP effect was found in the latency of the P2 component, 250 ms - 280 ms after probe onset, showing a more positive amplitude at midline anterior recording sites for same location match probes, as compared to the other three probe conditions. Clearly, the latency of the effect on the P2 is well behind the latency of the P1 and N1 which are believed to signal visual processing in extrastriate areas[1] (e.g. Mangun et al., 2000). Following the effect on the P2 over frontal areas, ERPs were more negative over midline occipital electrodes in the latency of the P3 (380 ms post probe onset). This pattern of results is more characteristic of a top-down process and is distinctly different from the bottom-up effect which we had predicted.

Clearly, the finding of ERP effects to same location match probes is consistent with the idea that perceptual levels of object representation are somehow temporarily linked to the semantic representations of objects. However, we can only speculate about the functional mechanisms that are involved. The P2 and P3 ERP effects recorded to same location match probes show some resemblance to the ERP effects of visual object working memory which were investigated in chapter 5. Possibly, these effects signal the retrieval of the object representation in working memory. However, further study is necessary to investigate this possibility.

A second experiment was performed to examine if we could replicate these effects by using associated words instead of matching words. Possibly, the effects observed in the previous experiment are dependent on the frequent co-occurrence of matching picture - word pairs, which may have led subjects to adopt a visual strategy in which words are actively used to facilitate the recognition of objects.

As in experiment 1, unrelated words generated a stronger N400 negativity than related words, followed by an additional negativity over frontal and occipital areas. The probe ERPs again interfered with the post N400 negativity, showing stronger attenuation of the effect in conditions where probes had been presented in the UVF. Unlike experiment 1, however, same location probes presented in associated picture

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[1] Generally, the visual P1 and N1 components appear between 100 ms - 200 ms after stimulus onset.

- word conditions were not accompanied by effects on the P2 and P3 components. We cannot explain this result by hypothesizing that subjects used a less visually oriented strategy, since unrelated picture - word pairs elicited search processes which appeared to include visual components, as in experiment 1. Rather it seems to be the case that associations between semantic and perceptual levels of object representation may only become evident with words that specifically refer to the object's visual representation.

At first glance, these results are in opposition with the Hebbian perspective (e.g. Pulvermüller, 1999a). The idea that a change at one level of the object representation (e.g. semantic level) will automatically affect other levels of the object representation (e.g. the perceptual level) is not supported by the current results. Although ERPs in both experiments showed clear effects of the semantic relationship between the picture and the word, the difference in ERP effects to same location probes suggest that only matching words may have established a connection with the objects' visual retinotopic level of representation. Associated words may lack strength of semantic association or have no direct reference to objects' visual representations. However, the evidence for such a conclusion is only indirect. We did not directly investigate the spreading of activation in response to word presentation. Visual probes may only provide us with an indirect measure of the state of the perceptual system at the time of probe onset. Although the pattern of results is more consistent with the possibility of partial activation within the multilevel object representation (as opposed to full activation of all levels) this interpretation has to be taken with the appropriate reservations.

6.1.4 Chapter 5

Chapter 5 investigated the cortical mechanisms that are involved in the activation of visual semantic information from concrete words. It was hypothesized that concrete words will activate visual semantic meaning via the cortical network for object working memory. This hypothesis was investigated by presenting concrete (imageable) words and abstract (non-imageable) words under various amounts of load on object working memory. When words are presented in conditions where object working memory load is high, difficulty in the activation of visual semantic meaning was expected, as compared to words presented in conditions where there is no load on object working memory.

ERPs to concrete and abstract words were recorded in two language tasks, one in which subjects had to decide whether words are lexically valid (lexical decision task), and one in which subjects had to distinguish between concrete and abstract words (concrete-abstract decision task). The investigation of the concreteness effect in both language tasks is important for our understanding of the conditions under which visual information becomes active. Farah (1995) suggests that the activation of visual semantic or imagistic information is under voluntary control, and will only occur when relevant to the situation. The opposite view is taken by Martin (1998) that visual semantic or imagistic information is automatically activated when a concrete word is read, heard, or retrieved in the service of writing and speech. With the current design we hoped to address this issue.

ERP results were consistent with the hypothesis that object working memory is used for the visualization of concrete words. This study supports a model of visual semantics in which visual semantic information relating to concrete words is first retrieved from long-term memory (indexed by a stronger anterior N400, and posterior occipital positivity to concrete as opposed to abstract words), and is subsequently visualized via the network for object working memory (indicated by a left frontal positive slow wave and a bilateral occipital slow wave negativity that were found to reflect both object working memory and concreteness effects). Retrieval and visualization of concrete words may proceed relatively automatically, as the clearest effects of concreteness were found in the lexical decision task. In the concrete-abstract decision task we found a somewhat different pattern of results which suggests that explicit visualization to concrete words may operate via (partly) different mechanisms.

6.2 General Discussion

6.2.1 The Investigation of Dorsal and Ventral Pathways with Stimuli Presented in the Upper and Lower Visual Fields

A prominent part of this thesis is concerned with the properties of the dorsal and ventral pathways. Five out of six experiments that were discussed involved presentation of stimuli in the upper and lower visual fields (chapters 2 - 4). Although psychological research on language has extensively focused on word processing in the left and right visual fields (Coltheart, 1987), the upper and lower visual fields have been largely neglected. However, the same technique which is used to examine language processing in the left and right hemispheres may be used in the investigation of dorsal and ventral areas. A basic assumption of this approach is that stimuli which are presented in the UVF will be processed more easily in the ventral pathway, while stimuli presented in the LVF are more easily processed by dorsal visual areas.

Studies which have tried this approach generally observed clear-cut differences between the processing of information in the upper and lower visual fields (see review in Previc, 1990). However, although there may be qualitative differences for perception in the upper and lower visual fields, this does not necessarily mean that these differences are dependent on functional specialization of dorsal and ventral areas. Although there is a fair amount of evidence which suggests that upper and lower field differences depend on functional properties of the dorsal and ventral visual pathways (e.g. Danckert & Goodale, 2001), this relationship has yet to be proven.

According to Previc (1990) the organization of the perceptual system seems to have an evolutionary basis that has adapted to consistencies which are present in our visual surroundings. The fact that our hands generally manipulate objects in the lower part of our visual field may have led to a specialization for object manipulation in the dorsal visual stream. Similarly, the recognition and search for objects that are outside our reach is biased towards the UVF, which may have led to the development of a system for object recognition in the ventral visual stream.

As the ventral stream is most sensitive to the center of the retina (Baizer et al., 1991), it may require close cooperation with the saccadic eye movement system in order to bring objects to the fovea. Results of chapter 2 are consistent with the hypothesis that the identification of objects in the UVF is strongly associated with the saccadic eye movement system. The strength of IOR which is believed to be a reflection of saccadic preparation was notably stronger when objects had to be identified in the UVF, as compared to the LVF.

Results of chapter 4, which involved a paradigm similar to that which was used in chapter 2, suggested an association between visual processing of objects and the UVF. We found that conditions with unrelated picture-word pairs were accompanied a slow wave negativity over occipital and frontal lobes. Part of the effect appeared to reflect additional visual processing, possibly involved with further visual-based search for a potential relationship between the picture and the word. Interestingly, the presentation of visual probe stimuli interfered with this slow wave negativity, especially if probes were presented in the UVF. This interaction supports the idea that visual semantic processing is biased towards the ventral pathway.

As suggested by Previc (1990) the ventral pathway may have specialized for object identification in the UVF. Consistent with this idea, the detection of pseudopictures (chapter 4, experiment 1) was found to be better for the UVF than for the LVF.

In chapter 3 we found an unexpected advantage for words presented to the LVF, as compared to words presented to the UVF. Field effects were approximately twice as strong for words than for pseudowords, suggesting an advantage for language materials being presented in the LVF. Although there have been some investigations of visual field asymmetries for words presented in the upper and lower visual fields, the results of these studies were either inconclusive, or yielded opposite results. Although it appears to be possible to find differences with respect to word processing in the upper and lower visual fields, further research is necessary to investigate under which conditions these asymmetries occur, and whether there is a relationship to the organization of function in the ventral and visual pathways.

Results of chapter 3 furthermore supported the hypothesis that semantic properties for manipulable objects are associated with the dorsal stream, while semantic features for nonmanipulable objects appear to be associated with ventral areas of the visual cortex. Manipulable words were processed more accurately (less errors) when presented to the LVF. Nonmanipulable words on the other hand were more accurately responded to when presented in the UVF. An important fact, however, is that this pattern of results was only found for repeated target words when the same word, presented as a prime, had been in the LVF. We speculated that stronger priming effects from words presented in the LVF may have provided the necessary conditions for this effect to occur. Priming may be necessary to (pre-)activate the relevant features of manipulable and nonmanipulable words for them to be directly activated by the presentation of the word within the appropriate visual field.

In sum, these results support the idea that the divided visual field technique may be confidently used in the investigation of the dorsal and ventral visual areas. The results obtained with experiments that made us of this technique are consistent with earlier reports about the properties of ventral and dorsal visual streams. However, as most people do not know that the connectivity of the visual system from upper and lower parts of the visual field to ventral and dorsal areas is very similar to the organization of the left and right hemispheres with respect to the lateral parts of the visual field, this approach has played only a minor part in experimental psychology. For the future there is still much to be gained by applying this technique to the study of dorsal and ventral pathways.

6.2.2 Visual Processes are included in Semantic Function

Another central question in this thesis is whether semantic processes are associated with visual processes, or operate in isolation. This inquiry is valuable because it may inform us about the nature of visual semantic representation. Furthermore, the possibility that semantic and visual processes cooperate systematically is interesting because it may provide a more general perspective on the role of semantic function in cognition.

ERP studies reported in chapter 4 and chapter 5 found evidence which suggested that visual processes may be invoked by or are included as part of semantic processes. In chapter 4 results suggested that semantic processes which are directed at finding a meaningful relationship between a word and a picture may invoke processing within visual perceptual areas. The effect, which was found for unrelated picture - word pairs, showed a negative slow wave, part of which was overlying the occipital lobe. Previous work has found that processing in visual areas is associated with negative slow waves over posterior occipital areas (e.g. Uhl et al., 1990; Ruchkin et al., 1997). A similar negative slow wave effect was found in chapter 5 which investigated the processing of concrete imageable words as compared to abstract words. The effect, which was only observed in the lexical decision task, showed a marked similarity to the ERP effect which was found to be associated with the retention of polygons.

These results suggest that semantic processes are not isolated but operate in close cooperation with the visual system. Even in conditions in which there is no visual object present, as was the case in chapter 5, semantic processes may automatically evoke the activation of representations within the visual system.

The idea that there is a strong association between semantic and visual levels of representation agrees with the perspective that the development of semantic memory originates in everyday life experience with concrete objects (e.g. Martin et al., 1995). It is important to note that even when subject's task did not encourage visualization, evidence was found for visual processing. In chapter 4, subjects were presented with pictures and words, but the task performed by subjects was not explicitly directed at this relationship (subjects were instructed to respond to occasional pseudo-pictures and pseudowords). In chapter 5 subjects were required to determine whether words are lexically valid or not.

Although this suggests that use of visual processing may have occurred automatically we cannot be entirely sure that subjects did not adopt an active or conscious strategy to use visual processing. Notice that in chapter 4 the frequent co-occurrence of matching picture - word pairs may have led subjects to use words in order to facilitate the recognition of pictures. However, similar effects were found in experiment 2 in which pictures were paired with associated instead of matching words. With respect to the lexical decision task which was used in chapter 5, it may be that subjects actively tried to visualize each word, as the visual semantic information may strengthen subjects' trust in the correctness of the lexical decision. However, concreteness effects as observed in the lexical decision task were found to be different from the effects of concreteness as observed in the explicit concrete-abstract decision task. Since the concrete-abstract decision task is believed to demand active visualization, it appears unlikely that subjects were also consciously visualizing each word in the lexical decision task. Further research is necessary to determine whether these effects indeed occur automatically and without effort, or that these effects reflect the use of a voluntary controlled strategy to visualize.

6.2.3 Objects as Basic Representations for Semantic Memory

A third issue in the present thesis concerns the possible role of objects and their representations as part of semantic memory for concrete words. Although this issue is evident in all four experimental chapters, the use of object representation in semantic memory was only explicitly investigated in the two final chapters. Chapter 4 investigated the hypothesis that objects are represented via a temporary association between sensory, perceptual, and semantic levels of object description. Chapter 5 focused on the cortical mechanisms which are involved in the activation of visual semantic information by concrete words. It was hypothesized that concrete words will activate visual semantic meaning via the cortical network for object working memory.

Results from both chapters are consistent with the hypothesis that objects play an important role in the representation of concrete semantic information. Results were interpreted as being consistent with the hypothesis that visual semantic representation may be expressed via object working memory. The strongest argument for this conclusion is found in chapter 5. Here results showed that lexical decisions to concrete words generated a pattern of slow wave effects which were markedly similar to the effects of object working memory. Furthermore, concreteness effects to words were found to interact with the retention of polygons in object working memory. In chapter 4 matching words did affect the ERP responses to same location probes which is consistent with the idea that perceptual object representations are somehow temporarily linked to semantic representations. The ERP effects recorded to same location match probes show some resemblance to the ERP effects of visual object working memory which were found in chapter 5. Possibly, these effects signal the retrieval of the object representation in working memory. However, further study is necessary to validate this hypothesis.

6.3 General Conclusion

The main conclusion of the present thesis is that semantic processes are not isolated but are closely linked to visual processes. Results of chapter 3 suggest that semantic organization follows the specialization for object processing in the dorsal and ventral visual streams as proposed by Martin et al. (1995). Semantic information about manipulable objects appears to be processed in the dorsal stream which is believed to have specialized for reaching and manipulation of objects in the lower visual field (LVF). Semantic knowledge, describing the properties of nonmanipulable objects, on the other hand, is probably processed in the ventral stream which is thought to have specialized for visual search and recognition of objects in the upper visual field (UVF). Both perceptual function and visual semantic knowledge about objects seem to be organized with respect to the properties of our visual surroundings. The fact that our hands are generally manipulating objects in the lower part of our visual field may have led to a specialization for object manipulation in the dorsal visual stream. Similarly, the recognition and search for objects that are outside our reach may have led to the development of a system for object recognition in the ventral visual stream, which is associated with a bias for saccadic eye movements to the UVF.

The results of the present thesis are in accord with the view that semantic memory for concrete objects develops in close relationship with the perceptual experience of those objects. Results of chapter 5 suggest that the visual meaning of a concrete word is automatically activated whenever the word is recognized. Results suggested a model of visual semantics in which visual descriptive information about concrete words is first retrieved from long-term memory, and is subsequently visualized via the system for object working memory. In general it seems that object working memory plays an important role in both language and vision. Object working memory may become activated by visually perceived objects, but also by concrete linguistic expressions. Results of chapter 4 suggest that object working memory may be especially important for establishing a connection between verbal and pictorial information.

In conclusion I feel that the present thesis provides an interesting perspective on the relationship between semantic and visual processes. Results are consistent with the idea that semantic memory for concrete words is intimately linked to the visual system. Although there is an increasing amount of research being directed at the relationship between semantic processes and visual function (mostly research with a neuropsychological background), this relationship is still largely neglected within psycholinguistics. Partly this is because vision research and linguistic research are generally considered as separate areas of investigation. The present thesis suggests that there is strong interdependence between semantic processes and visual function. As such it may provide an incentive to others to direct their attention towards this developing field. The combined interest in language and vision may prove particularly rewarding, and is expected to extend the potential of both areas of investigation.

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Appendices

Appendix Chapter 2

Matching words used in Chapter 2 (experiment 1) and Chapter 4 (experiment 1)

001	aal	002	aap	003	aardappel
004	aardbei	005	accordeon	006	afwasmachine
007	ananas	008	anker	009	appel
010	arm	011	artisjok	012	asbak
013	asperge	014	auto	015	autoband
016	bal	017	ballon	018	banaan
019	bank	020	barbecue	021	bed
022	been	023	beer	024	beitel
025	berg	026	bever	027	bezem
028	bijl	029	bizon	030	blad
031	blik	032	blouse	033	boek
034	bolderkar	035	boog	036	boom
037	boon	038	boormachine	039	bord
040	borstel	041	boter	042	brievenbus
043	bril	044	broek	045	brood
046	broodrooster	047	bureau	048	bureaustoel
049	bus	050	cactus	051	cadeau
052	citroen	053	clown	054	dartpijl
055	deegroller	056	deur	057	deurknop
058	dinosaurus	059	doedelzak	060	dolfijn
061	doos	062	douche	063	druiven
064	duif	065	duikbril	066	duim
067	dwarsfluit	068	eekhoorn	069	eend
070	eikel	071	eland	072	envelop
073	ezel	074	fiets	075	flamingo
076	fluitje	077	föhn	078	fornuis
079	fototoestel	080	frituurpan	081	gans
082	garenklosje	083	geit	084	gier
085	gieter	086	gillet	087	giraffe
088	gitaar	089	glas	090	globe
091	gloeilamp	092	gorilla	093	grasmaaier
094	gum	095	haai	096	haan
097	haar	098	hagedis	099	halsketting
100	hamburger	101	hamer	102	hand
103	handschoen	104	hangslot	105	hark
106	harp	107	hart	108	hek
109	helikopter	110	helm	111	hersenen
112	hert	113	hoed	114	hoefijzer
115	hond	116	hondenhok	117	honkbalknuppel
118	horloge	119	huis	120	hyena
121	iglo	122	ijscoupe	123	inktvis

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124	jas	125	jasje	126	jojo
127	jurk	128	kaars	129	kaas
130	kalkoen	131	kam	132	kameel
133	kan	134	kangoeroe	135	kanon
136	kast	137	kat	138	kerk
139	kersen	140	ketel	141	ketting
142	keukentrap	143	kikker	144	kinderwagen
145	kip	146	kist	147	klarinet
148	kleerhanger	149	kleerkast	150	klok
151	klomp	152	kluis	153	knoop
154	koalaberen	155	koe	156	koekenpan
157	koelkast	158	koffer	159	kompas
160	konijn	161	kopje	162	koptelefoon
163	kraan	164	krab	165	krakeling
166	kreeft	167	krokodil	168	kroon
169	kruiwagen	170	kruk	171	kwal
172	kwast	173	laars	174	ladder
175	ladekast	176	lammetje	177	leeuw
178	lepel	179	libelle	180	liniaal
181	lippenstift	182	longen	183	luciferdoosje
184	luipaard	185	maan	186	magnetron
187	maïskolf	188	mand	189	meetlat
190	meeuw	191	meloen	192	mes
193	microfoon	194	microscoop	195	mier
196	miereneter	197	mixer	198	moer
199	molen	200	mond	201	mondharmonica
202	motor	203	muis	204	mus
205	naaimachine	206	naald	207	narcis
208	net	209	neus	210	neushoorn
211	nijlpaard	212	nijptang	213	olielamp
214	olifant	215	oog	216	oor
217	openhaard	218	overall	219	paard
220	paardebloem	221	paddestoel	222	palmboom
223	pan	224	papegaai	225	paperclip
226	paprika	227	parachute	228	paraplu
229	passer	230	pauw	231	peer
232	pelikaan	233	pen	234	penseel
235	perzik	236	pijl	237	pijp
238	pinda	239	pinguïn	240	piramide
241	pistool	242	plant	243	platenspeler
244	politiepet	245	pompoen	246	poort
247	pop	248	pot	249	potlood
250	prei	251	propeller	252	put
253	raam	254	radiator	255	radio
256	raket	257	rat	258	reiger
259	rekenmachine	260	reuzenrad	261	riem
262	ring	263	rits	264	rog
265	rok	266	rolschaats	267	roos
268	rups	269	sambaballen	270	sandwich
271	saxofoon	272	schaap	273	schaar
274	schakelaar	275	schedel	276	scheerapparaat
277	schelp	278	schemerlamp	279	schep
280	schepje	281	schilderij	282	schildpad
283	schoen	284	schoffel	285	schommel
286	schommelstoel	287	schorpioen	288	schroef
289	schroevendraaier	290	sigaar	291	sigaret
292	sinaasappel	293	sjaal	294	skelet
295	skilift	296	sla	297	slak

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298	slang	299	slee	300	sleutel
301	sneeuwpop	302	snijplank	303	sok
304	spijker	305	spin	306	spinnenweb
307	spinnewiel	308	sprinkhaan	309	spuit
310	steeksleutel	311	steelpan	312	ster
313	stethoscoop	314	stoel	315	stofzuiger
316	stoplicht	317	strijkijzer	318	strijkplank
319	strik	320	stropdas	321	struisvogel
322	taart	323	tafel	324	tamboerijn
325	tandenborstel	326	tang	327	tapijt
328	tas	329	telefoon	330	telescoop
331	televisie	332	tennisracket	333	tent
334	theepot	335	thermometer	336	tijger
337	tol	338	tomaat	339	ton
340	tor	341	totempaal	342	touw
343	tractor	344	trechter	345	trein
346	triangel	347	trommel	348	trompet
349	trui	350	tulp	351	ui
352	uil	353	vaas	354	varen
355	varken	356	veer	357	vergiet
358	verrekijker	359	vijl	360	vingerhoed
361	viool	362	vis	363	vishaak
364	viskom	365	vissenstaart	366	vlag
367	vleermuis	368	vleugel	369	vlieg
370	vlieger	371	vliegtuig	372	vlinder
373	voet	374	voetbalschoen	375	vogelhuisje
376	vogelkooi	377	vork	378	vos
379	vrachtwagen	380	vuilnisvat	381	vulpen
382	waaier	383	walrus	384	walvis
385	want	386	wasbak	387	wasknijper
388	wasmachine	389	weegschaal	390	wiel
391	wigwam	392	wijnfles	393	wijnglas
394	wijsvinger	395	windwijzer	396	wolf
397	wolk	398	worm	399	worst
400	wortel	401	zaag	402	zadel
403	zaklamp	404	zakmes	405	zebra
406	zeehond	407	zeepaard	408	zeester
409	zeilboot	410	zeppelin	411	zon
412	zonnebloem	413	zoutvat	414	zwaan
415	zwaardvis	416	zweep		

Unrelated words used in Chapter 2 (experiment 1) and Chapter 4 (experiment 1)

001	aas	002	aktetas	003	antenne
004	appartement	005	aquarium	006	badpak
007	basketbal	008	beeld	009	betonblok
010	bikini	011	bliksem	012	bodem
013	boer	014	boord	015	bouquet
016	bovenlip	017	brand	018	breinaald
019	broche	020	brochure	021	broekzak
022	caravan	023	cassette	024	cent
025	chalet	026	cheque	027	chip
028	chocola	029	dagboek	030	dansvloer
031	deurpost	032	dirigent	033	discus
034	distel	035	dobbelsteen	036	dobber

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037	drank	038	drempel	039	druppel
040	dubbeltje	041	duikboot	042	eettafel
043	emmer	044	etalagepop	045	etiket
046	fakkel	047	fiche	048	fietstas
049	folder	050	formulier	051	fossiel
052	foto	053	garde	054	glimlach
055	gong	056	gootsteen	057	grasveld
058	gulp	059	hakblok	060	handboek
061	hangmat	062	haven	063	heg
064	heup	065	heuvel	066	huifkar
067	ijzerdraad	068	jager	069	kaak
070	kabel	071	kalender	072	kanaal
073	kaviaar	074	kerktoren	075	keu
076	klooster	077	knikker	078	kogel
079	kraal	080	kring	081	kroonkurk
082	kroost	083	krultang	084	kudde
085	kuil	086	kussen	087	kwartje
088	laken	089	lampion	090	landkaart
091	lawine	092	lelie	093	lens
094	leuning	095	lift	096	ligstoel
097	limonade	098	luik	099	mantel
100	markt	101	mast	102	matras
103	medaille	104	meetlint	105	megafoon
106	metro	107	mondhoek	108	monitor
109	nest	110	oever	111	onkruid
112	orkaan	113	orkest	114	pannenkoek
115	parel	116	paspoort	117	peddel
118	pilaar	119	pink	120	pion
121	planeet	122	plank	123	poef
124	portier	125	postbode	126	publiek
127	puntmuts	128	pyjama	129	rammelaar
130	ravijn	131	regenjas	132	reisbureau
133	rekening	134	rijtuig	135	robot
136	roe	137	roeiboot	138	room
139	rugzak	140	ruiter	141	ruitenwisser
142	rupsband	143	sandaal	144	schaakbord
145	schoenlepel	146	schooltas	147	schuurpapier
148	sirene	149	skippybal	150	slagboom
151	sloot	152	snoer	153	snor
154	soep	155	soldaat	156	spaghetti
157	speen	158	speer	159	spek
160	speld	161	splinter	162	spook
163	spoorlijn	164	staf	165	stam
166	stapelbed	167	station	168	steeg
169	steen	170	stoep	171	stokje
172	strohoed	173	stuiver	174	tabak
175	tand	176	telefooncel	177	toast
178	tobbe	179	tong	180	tortilla
181	traan	182	tram	183	vel
184	vijver	185	villa	186	vlecht
187	vloeitje	188	vloerkleed	189	voetbal
190	voetpad	191	vogel	192	vuist
193	vulkaan	194	vuurtoren	195	wandelstok
196	wapen	197	waslijn	198	waterval
199	wekker	200	whisky	201	wimpel
202	wok	203	wrak	204	xylofoon
205	zandbak	206	zandloper	207	zetel
208	zuurstok				

Appendix Chapter 3

Words referring to manipulable objects with an UVF bias.

001	achteruitkijkspiegel	002	afzuigkap
003	bagagerek	004	basket
005	boksbal	006	bureaulamp
007	capuchon	008	dakraam
009	deltavlieger	010	douchekop
011	filmprojector	012	gordijnrails
013	hoed	014	imperiaal
015	kam	016	kapstok
017	klimmuur	018	klimrek
019	klimtouw	020	kuif
021	ladder	022	luxaflex
023	medicijnkastje	024	muts
025	parasol	026	pet
027	prikbord	028	pruik
029	rekstok	030	rolgordijn
031	schoolbord	032	slingers
033	speer	034	toorts
035	touwladder	036	valhelm
037	waslijn	038	zolderluik
039	zonneklep	040	zonnescherm

Words referring to manipulable objects with a LVF bias.

001	afstandsbediening	002	beker
003	biljartkeu	004	blikopener
005	cassetterecorder	006	deeg
007	deurkruk	008	dobbelsteen
009	elastiekje	010	emmer
011	fietspomp	012	garde
013	klei	014	knijpkat
015	knikker	016	koffiemolen
017	koffiezetapparaat	018	kurkentrekker
019	luik	020	pincet
021	plakband	022	priem
023	rietje	024	scheermesje
025	schuurpapier	026	spatel
027	stempel	028	step
029	stopwatch	030	stuur
031	theedoek	032	thermoskan
033	toetsenbord	034	ventiel
035	veter	036	walnoot
037	washandje	038	wekker
039	zeef	040	zeep

Words referring to nonmanipulable objects with an UVF bias.

001	afdakje	002	altaar
003	bergtop	004	circustent
005	dakgoot	006	dakpan
007	filmdoek	008	flatgebouw
009	gevel	010	graansilo
011	kerkklok	012	kerkorgel
013	komeet	014	lichtmast
015	luchtballon	016	meteoriet
017	nestkastje	018	pilaar
019	podium	020	poster
021	raket	022	regenboog
023	rookmelder	024	schoorsteen
025	spaceshuttle	026	ster
027	stoplicht	028	straaljager
029	straatnaambordje	030	tribune
031	uithangbord	032	verkeersbord
033	viaduct	034	vlaggenmast
035	vuurtoren	036	wimpel
037	wolk	038	wolkenkrabber
039	zeppelin	040	zuil

Words referring to nonmanipulable objects with a LVF bias.

001	afvoerbuis	002	akker
003	boomstronk	004	dansvloer
005	fossiel	006	fundering
007	grafsteen	008	greppel
009	grind	010	heg
011	heide	012	hondenhok
013	kuil	014	landingsbaan
015	meer	016	modderpoel
017	moeras	018	mos
019	nummerbord	020	paaltje
021	pijpleiding	022	putdeksel
023	reflector	024	remspoor
025	riolering	026	sierbestrating
027	sloot	028	spatlap
029	spoorlijn	030	stoeptegel
031	struikgewas	032	tafelpoot
033	tuinpad	034	uitlaat
035	vangrail	036	vensterbank
037	vijver	038	vloerbedekking
039	weide	040	zebrapad

Filler words

001	aanhangwagen	002	aanmaakhout	003	aanplakbiljet
004	aanplakbord	005	aanrecht	006	aanslagbiljet
007	aardolie	008	accu	009	achtbaan
010	afrastering	011	afvalcontainer	012	afwaskwast

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013	aggregaat	014	alpenweide	015	amandel
016	ambulance	017	amfibievoertuig	018	antenne
019	appartement	020	appelboor	021	aquarium
022	ark	023	atelier	024	atoom
025	autobaan	026	autogordel	027	automaat
028	avondkleding	029	baard	030	babyfoon
031	badpak	032	baggerschuit	033	bakblik
034	balkon	035	banjo	036	basterdsuiker
037	batterij	038	beddengoed	039	beerput
040	bergketen	041	berkenblad	042	beschuit
043	bestelbon	044	betaalautomaat	045	beton
046	bezem	047	bibliotheek	048	biefstuk
049	bikini	050	biljartbal	051	binnenband
052	bioscoop	053	bloembak	054	boeg
055	boksbeugel	056	bom	057	bonbon
058	bouwkeet	059	branding	060	bretels
061	brommer	062	broodtrommel	063	bult
064	bungalow	065	cafetaria	066	cel
067	cement	068	champagne	069	chocolaatje
070	cilinder	071	cirkelzaag	072	colonne
073	container	074	creditcard	075	dam
076	damesfiets	077	dampkring	078	damspel
079	damsteen	080	degen	081	dekzeil
082	diadeem	083	diamant	084	dieselmotor
085	dijk	086	diskette	087	doekje
088	doelpaal	089	draaikolk	090	draaiorgel
091	drempel	092	drijfzand	093	droogbloem
094	droogtrommel	095	dropje	096	duikboot
097	eelt	098	eethoek	099	erts
100	etalagepop	101	fabriek	102	fietsbel
103	flipperkast	104	fontein	105	galjoen
106	galsteen	107	gangkast	108	garagedeur
109	gaslamp	110	gasleiding	111	gehaktbal
112	gehoorapparaat	113	geitenkaas	114	geluidswal
115	gember	116	gewei	117	gierkar
118	gokkast	119	golfplaat	120	gootsteen
121	granaat	122	grasspriet	123	grenspost
124	grot	125	gummiknuppel	126	gymnastiekzaal
127	haaientand	128	haarlak	129	hagel
130	halsband	131	halster	132	halvarine
133	handgranaat	134	handvat	135	haven
136	heipaal	137	helmgras	138	herdersstaf
139	heuvel	140	hockeystick	141	hoogslaper
142	hoogwerker	143	hooi	144	ijsblokje
145	ijspegel	146	ijzerdraad	147	inktpot
148	jam	149	jeugdherberg	150	kaak
151	kaart	152	kabel	153	kabelbaan
154	kapel	155	kassa	156	katoenbaal
157	kattenluik	158	kauwgom	159	kegelbal
160	kei	161	klaslokaal	162	kleiduif
163	klittenband	164	kluif	165	knakworst
166	knalpot	167	kneedbom	168	knipperlicht
169	knuffeldier	170	koeienvlaai	171	kofferbak
172	kolenschop	173	kombuis	174	kontzak
175	kopieerapparaat	176	koplamp	177	koraal
178	kraag	179	kraanleertje	180	kribbe
181	kristal	182	kroket	183	kroon
184	kruipolie	185	kruiser	186	kruk

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187	krultang	188	kubus	189	kunstgebit
190	kunstijsbaan	191	kurk	192	kussensloop
193	kust	194	kwarktaart	195	kwartje
196	laadbak	197	laars	198	landbouwbedrijf
199	lans	200	lasbril	201	lasso
202	lava	203	lectuurbak	204	leslokaal
205	leuning	206	lijkwagen	207	lijmpot
208	lont	209	loopgraaf	210	machinegeweer
211	mantelpak	212	megafoon	213	mengpaneel
214	mitella	215	moker	216	moskee
217	mouw	218	naaigaren	219	naaldhak
220	nachthemd	221	neonreclame	222	noordwester
223	oliebol	224	oorbel	225	opblaasboot
226	pannenkoek	227	parketvloer	228	pauwenveer
229	pepernoot	230	perron	231	perskaart
232	perzikpit	233	piste	234	plank
235	platenhoes	236	plunjezak	237	pofbroek
238	ponskaart	239	poolkap	240	popcorn
241	potgrond	242	raceauto	243	rasp
244	reclamefolder	245	regenpak	246	schacht
247	schacht	248	scharrelei	249	scheepsdek
250	scheerzeep	251	schild	252	schoolgebouw
253	schuifdeur	254	sikkel	255	sirene
256	sirene	257	skelter	258	sloep
259	snaar	260	sneeuwbal	261	snoeischaar
262	soep	263	spandoek	264	speelhal
265	speldenkussen	266	spiegelei	267	spons
268	stadspoort	269	stapelbed	270	stembus
271	stencil	272	stikker	273	stiletto
274	stoomfluit	275	stuurhut	276	suikerklontje
277	tandpasta	278	tankstation	279	tegelwand
280	tekening	281	telelens	282	telescoophengel
283	terp	284	terras	285	tombe
286	toverstaf	287	trapeze	288	trapper
289	tuinstoel	290	urn	291	vacht
292	verkeersplein	293	vetvlek	294	vliegdekschip
295	vliegenvanger	296	vod	297	voelspriet
298	vossenhol	299	vredespijp	300	waakvlam
301	wachthuisje	302	wak	303	walkman
304	wandelpad	305	wandelstok	306	wandkleed
307	wastobbe	308	waterdruppel	309	waterfiets
310	waterkanon	311	waterleiding	312	weefgetouw
313	wenskaart	314	winkelstraat	315	woonboot
316	zaal	317	zakdoek	318	zandbak
319	zonnebril	320	zwachtel		

Pseudowords

001	aarvet	002	absortroop	003	afferstoop
004	akkelaar	005	alibol	006	alkerasp
007	amaroeng	008	amilas	009	andersteep
010	annerlan	011	aptiepreddel	012	aquadrocht
013	araboon	014	aram	015	arbeklonk
016	argenoom	017	aska	018	audir
019	baakbazzelaar	020	bachje	021	bakketspelter

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022	bangelspode	023	bant	024	bapkaaps
025	bedaker	026	bening	027	berftanke
028	bevrangstig	029	bezaanranpraal	030	bidomuskeet
031	biel	032	bielkenane	033	biggasmader
034	bing	035	biomaan	036	birang
037	blamdop	038	bleigerremmel	039	bliefkeek
040	blier	041	blinderpral	042	blokvertuim
043	blundaar	044	bodenpreller	045	bog
046	bomerwas	047	bonan	048	bopperdaar
049	bra	050	bradergoddel	051	brandostron
052	brankte	053	bred	054	breggedoren
055	breiversteep	056	brenk	057	bressietrakeze
058	brondelan	059	broppernaarf	060	bruimel
061	buinverstik	062	buraank	063	buwaartreper
064	daalnat	065	dadestraak	066	daggeprekt
067	damintieduskette	068	damverleer	069	dandebrin
070	degentekel	071	delirod	072	deppersknoof
073	diaatprammator	074	diora	075	dirreknevel
076	distaar	077	dollerstenne	078	doterband
079	draagbakkelaar	080	draam	081	drechband
082	dreednavel	083	dremelst	084	dribbe
085	drompeltemper	086	duiperskraap	087	duipert
088	duktrokker	089	dumtspander	090	dusebunkel
091	eerk	092	eftieng	093	eidemlaar
094	ema	095	emangaffelaar	096	emin
097	enktrik	098	eppa	099	etomovraat
100	etut	101	flaar	102	flasker
103	fol	104	fren	105	friezeram
106	frit	107	fronk	108	frontiel
109	fundat	110	gaalmut	111	gader
112	gamowonnera	113	gandstoor	114	gastenstrem
115	genendraak	116	gerdeuler	117	gewederip
118	giem	119	glak	120	glarenbrakkeer
121	glate	122	glind	123	gliveer
124	gloenik	125	gotolaarde	126	gouz
127	grabbelstronk	128	graddelkatta	129	gramvader
130	grei	131	grindpap	132	groppenazer
133	grotebracht	134	gummakloop	135	hager
136	halekaralaan	137	harnbeslaf	138	hazerdoksel
139	heftongblazoen	140	hegelaariskoopladdel	141	hezelam
142	hielokar	143	hilk	144	hipraas
145	hogebraan	146	hokertip	147	honpago
148	honsprookapper	149	hontol	150	horv
151	hoverbukaraatstef	152	huip	153	huiperntrek
154	ijsbeschaaf	155	iki	156	imdoeld
157	inkvaar	158	iradoor	159	irkerra
160	javeknappel	161	jige	162	joburtbeslogmore
163	joegder	164	jogelkar	165	jollideern
166	joperak	167	jumber	168	junteer
169	juzewiep	170	kabersterm	171	kahoen
172	kalamaar	173	karapraan	174	kaspesnoper
175	kederparl	176	keg	177	kerpelonde
178	kijnreufel	179	kladerbestrend	180	klagstoon
181	klarrepreel	182	kleber	183	klee
184	kletsebokstier	185	klettervern	186	kliemeldong
187	klijvan	188	klint	189	klisser
190	klitmus	191	klobol	192	kluinnaap
193	knaffevreel	194	kniller	195	koevenoom

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196	kogenzevel	197	koggeree	198	kokra
199	kolonstreet	200	kolp	201	komaringbaar
202	komolar	203	konofore	204	konternier
205	kooiedralk	206	kopperverstadiginger	207	kostella
208	kovenklor	209	krabbervesp	210	krakbodier
211	kraldie	212	kramat	213	kramersveerd
214	kramervicht	215	kraunt	216	kreeper
217	kreld	218	krikkel	219	kroeker
220	kroepel	221	kroft	222	krontebreng
223	kroolpase	224	kuikert	225	kwanteblor
226	kwarrebot	227	kwarv	228	kwijpsteef
229	lagboon	230	lamotor	231	lank
232	lapogen	233	lappel	234	larenak
235	laverdonkmas	236	likvraad	237	limokaan
238	limpulo	239	loorkefaat	240	maarsekamper
241	malp	242	malpervaar	243	mampepoter
244	manrel	245	masmunde	246	maton
247	meerdemonaag	248	meiverkracht	249	mekobijzer
250	merme	251	mesdonor	252	mezitroopbanzijn
253	milar	254	moek	255	molartiep
256	moorster	257	morraz	258	motezip
259	naarterlocht	260	naster	261	nessep
262	neverp	263	nieprachter	264	nijtar
265	nissermop	266	noderik	267	noese
268	nofferkan	269	noggebroek	270	nokkel
271	nolt	272	noodsop	273	nubbertadel
274	nuis	275	oekenberren	276	offel
277	okkerzeel	278	olki	279	olpengang
280	opertrochtig	281	opperbalt	282	osk
283	ostelmave	284	otenschoer	285	palier
286	paloetaam	287	pantirober	288	parakluunder
289	parca	290	passelflenk	291	pectier
292	peddelnout	293	peletien	294	peperdwaar
295	pessicum	296	peterklier	297	piedomist
298	pild	299	pitamarakien	300	plabberhomp
301	plark	302	plen	303	plentemoog
304	pliz	305	plokervaas	306	plompkap
307	plonker	308	ploppedaler	309	pneuroflaam
310	poekenspravister	311	poekentor	312	ponkstup
313	porreltank	314	pos	315	praankaver
316	praktur	317	preen	318	priekel
319	priep	320	prinnik	321	proeskroossneder
322	proliam	323	prommel	324	prottelier
325	puite	326	pun	327	pupperslam
328	quapron	329	radager	330	ran
331	raviomeiper	332	rechtaaf	333	reddelka
334	redelvraat	335	redvaller	336	reerdak
337	reit	338	rekkeldos	339	rekwammer
340	remertakel	341	revelsped	342	riel
343	rijfgar	344	rineg	345	roeghalma
346	roonka	347	roorvem	348	ropenvacht
349	ruimelter	350	ruivert	351	runbe
352	rusmevede	353	ruub	354	sabool
355	safrienschoelder	356	san	357	scheddem
358	schemen	359	schenner	360	sches
361	schierken	362	schijspar	363	scho
364	schoederenpelonne	365	schoep	366	schorm
367	schuigertangeland	368	schulaar	369	schuller

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370	skal	371	skilk	372	sokbas
373	soperaal	374	speigerke	375	spir
376	spoderwam	377	spraatmeguurthuik	378	spreefkul
379	spunk	380	stabbewis	381	stadeel
382	stas	383	stedev	384	steelkwad
385	steelrap	386	stegel	387	stimp
388	stimpa	389	stir	390	stoderekel
391	stoekenlar	392	stolte	393	stoopkleb
394	stor	395	straaf	396	stremener
397	strindpar	398	strome	399	stromenaar
400	stronner	401	struimper	402	subert
403	subsa	404	sulfo	405	tanfoor
406	tarrebeer	407	tarrepot	408	teddevide
409	tedenpaai	410	teerpij	411	theeskabus
412	tieleston	413	tiepo	414	tillat
415	tipoon	416	tixis	417	toddedrul
418	toender	419	togenste	420	tongbrel
421	toorder	422	trak	423	tranep
424	trannerd	425	tredderd	426	treider
427	trific	428	troeg	429	trover
430	truunsat	431	tuikelslom	432	tuip
433	uivenzamp	434	uptuun	435	vaalp
436	vaktor	437	vamotuig	438	vantplop
439	vekse	440	velterkrat	441	verredraanstepper
442	vielbeert	443	vlarmandel	444	voderist
445	volpad	446	vottestor	447	vraambrook
448	vritterip	449	vront	450	vroumel
451	vruulkidde	452	vulpenslo	453	walliepon
454	walpregger	455	wap	456	waperstuf
457	wapert	458	wastert	459	wedelkank
460	wekelbras	461	wensvroonbeklavinger	462	wijlpaner
463	wijterhif	464	wilaar	465	wilbe
466	wilkestan	467	witma	468	wramer
469	wregelman	470	wreng	471	wrikkeda
472	wuurstron	473	zaalderbo	474	zaalgot
475	zakelron	476	zeelag	477	zijbesnak
478	zinpoonhijsknaarp	479	zobeek	480	zodiboor

Appendix Chapter 4

Matching words used in Chapter 4 (experiment 1)

See Appendix Chapter 2, table starting on page 137

Unrelated words used in Chapter 4 (experiment 1)

See Appendix Chapter 2, table starting on page 139

Materials used in experiment 2

	Picture	Association	Unrelated
001	pinda	aap	bad
002	worm	aarde	drank
003	globe	aardrijkskunde	persoonlijkheid
004	olifant	afrika	whisky
005	kast	antiek	sirene
006	kangoeroe	australië	resultaat
007	koalaberen	australië	resultaat
008	autoband	auto	vest
009	scheerapparaat	baard	grond
010	kinderwagen	baby	tram
011	koekenpan	bakken	zoeken
012	krakeling	bakker	zuster
013	telefoon	bellen	bouwen
014	skelet	biologie	cassette
015	microscoop	biologie	cassette
016	hark	bladeren	aquarium
017	hond	blaffen	bepalen
018	hart	bloed	toast
019	vaas	bloemen	systeem
020	tractor	boer	lift
021	klomp	boer	lift
022	schaap	boerderij	bedoeling
023	pijl	boog	mens
024	boom	bos	aas
025	eekhoorn	bos	keu
026	hert	bos	pet
027	vos	bos	keu
028	riem	broek	vraag
029	broodrooster	brood	haven
030	snijplank	brood	haven
031	bureaustoel	bureau	folder
032	waaier	china	keuze
033	clown	circus	vijver

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	Picture	Association	Unrelated
034	dartpijl	darten	wekken
035	deegroller	deeg	nood
036	deurknop	deur	snor
037	stethoscoop	dokter	cheque
038	spuit	dokter	cheque
039	ezel	dom	nat
040	gier	dood	leeg
041	schedel	dood	best
042	pistool	dood	even
043	naald	draad	kring
044	tol	draaien	sluiten
045	duikbril	duiken	merken
046	piramide	egypte	zweet
047	kip	ei	la
048	iglo	eskimo	etiket
049	koelkast	eten	paar
050	pan	eten	gang
051	sandwich	eten	gang
052	vork	eten	gang
053	paprika	eten	dame
054	fototoestel	foto	stam
055	banaan	geel	ruim
056	kluis	geld	eeuw
057	kerk	geloof	dekbed
058	steeksleutel	gereedschap	dobbelsteen
059	slang	gevaar	manier
060	krokodil	gevaarlijk	behoorlijk
061	vijl	gevangenis	vloerkleed
062	openhaard	gezellig	compleet
063	sla	gezond	actief
064	grasmaaier	gras	kans
065	kam	haar	room
066	borstel	haar	room
067	föhn	haar	room
068	pompoen	halloween	schrijver
069	spijker	hamer	leger
070	worst	hema	zorg
071	eikel	herfst	heuvel
072	paddestoel	herfst	pyjama
073	blad	herfst	pyjama
074	hondenhok	hond	idee
075	honkbalknuppel	honkbal	kaviaar
076	oor	horen	kapen
077	zaag	hout	jaar
078	bijl	hout	jaar
079	ui	huilen	zakken
080	wolf	huilen	praten
081	sleutel	huis	kurk
082	raam	huis	kurk
083	pinguïn	ijs	dag
084	wigwam	indiaan	dagboek
085	totempaal	indianen	klooster
086	inktvis	inkt	cent
087	muis	kaas	werk
088	plant	kamer	vuist
089	tent	kamperen	bereiken

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	Picture	Association	Unrelated
090	haar	kapper	orkaan
091	poort	kasteel	bouquet
092	reuzenrad	kermis	bikini
093	kalkoen	kerst	wapen
094	jojo	kind	doel
095	ballon	kind	doel
096	pauw	kinderboerderij	besluitvorming
097	bolderkar	kinderen	schouder
098	haan	kip	gom
099	wasmachine	kleren	dobber
100	kleerkast	kleren	heuvel
101	kleerhanger	kleren	heuvel
102	bever	knagen	vormen
103	schaar	knippen	zwijgen
104	steelpan	koken	ijken
105	fornuis	koken	ijken
106	kroon	koning	stokje
107	sjaal	kou	mol
108	handschoen	koud	boos
109	giraffe	lang	leeg
110	schildpad	langzaam	dankbaar
111	slak	langzaam	dankbaar
112	narcis	lente	zetel
113	tulp	lente	zetel
114	lammetje	lente	zetel
115	bureau	leren	mixen
116	boek	lezen	lopen
117	zaklamp	licht	groep
118	gloeilamp	licht	jager
119	schemerlamp	licht	jager
120	schakelaar	licht	stijl
121	olielamp	licht	hoofd
122	roos	liefde	kanaal
123	lippenstift	lippen	fakkel
124	zeppelin	lucht	ruzie
125	longen	lucht	ruzie
126	broek	man	wok
127	hamburger	mcdonalds	oplossing
128	strik	meisje	aantal
129	koe	melk	week
130	liniaal	meten	laten
131	meetlat	meten	laten
132	kat	miauw	knots
133	miereneter	mieren	plaats
134	varken	modder	minuut
135	helm	motor	traan
136	vleugel	muziek	dobber
137	trommel	muziek	heuvel
138	sambaballen	muziek	heuvel
139	dwarsfluit	muziek	dobber
140	viool	muziek	heuvel
141	accordeon	muziek	hoepel
142	radio	muziek	heuvel
143	platenspeler	muziek	heuvel
144	harp	muziek	heuvel
145	saxofoon	muziek	heuvel

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	Picture	Association	Unrelated
146	koptelefoon	muziek	heuvel
147	mondharmonica	muziek	heuvel
148	tamboerijn	muziek	heuvel
149	triangel	muziek	heuvel
150	gitaar	muziek	heuvel
151	trompet	muziek	heuvel
152	klarinet	muziek	pyjama
153	vingerhoed	naaien	slepen
154	garenklosje	naaien	slepen
155	naaimachine	naaien	slepen
156	uil	nacht	leger
157	vleermuis	nacht	leger
158	maan	nacht	tempo
159	vlag	nederland	hoofdstuk
160	stropdas	netjes	bitter
161	blouse	netjes	bitter
162	kompas	noorden	stadium
163	duim	oké	rand
164	schommelstoel	oma	keu
165	kanon	oorlog	matras
166	doos	opbergen	proberen
167	deur	open	leuk
168	wortel	oranje	extern
169	hoefijzer	paard	zweet
170	zadel	paard	snoer
171	bord	pap	nek
172	paperclip	papier	ruiter
173	frituurpan	patat	groep
174	zoutvat	peper	tobbe
175	mand	picknick	dirigent
176	boog	pijl	zeep
177	gieter	planten	gezicht
178	politiepet	politie	bliksem
179	brievenbus	post	lens
180	envelop	post	plek
181	gum	potlood	terrein
182	dinosaurus	prehistorie	beoordeling
183	ton	regen	kudde
184	paraplu	regen	jager
185	jas	regen	kudde
186	wolk	regen	jager
187	koffer	reizen	praten
188	trein	reizen	zakken
189	paard	rijden	hangen
190	asbak	roken	slaan
191	tomaat	rood	leeg
192	sigaar	rook	lens
193	sigaret	rook	lens
194	pijp	rook	plek
195	flamingo	roze	fout
196	neus	ruiken	kunnen
197	kist	schat	groep
198	fluitje	scheidsrechter	omstandigheden
199	trechter	scheikunde	etalagepop
200	anker	schip	laken
201	sok	schoen	wereld

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	Picture	Association	Unrelated
202	bus	school	hoepel
203	tas	school	heuvel
204	douche	schoon	stevig
205	doedelzak	schotland	zekerheid
206	pen	schrijven	ontdekken
207	vulpen	schrijven	ontdekken
208	moer	schroef	parasol
209	schroevendraaier	schroef	parasol
210	schroef	schroevendraaier	aandelenkapitaal
211	skilift	skiën	mogen
212	vergiet	sla	tak
213	bed	slapen	helpen
214	hangslot	sleutel	druppel
215	boter	smelten	bewegen
216	slee	sneeuw	pilaar
217	berg	sneeuw	pilaar
218	motor	snel	echt
219	magnetron	snel	echt
220	mes	snijden	leveren
221	lepel	soep	lijn
222	pop	spelen	gieten
223	bal	spelen	helpen
224	nijptang	spijker	leuning
225	hamer	spijker	antenne
226	spinnenweb	spin	stad
227	arm	sterk	meest
228	telescoop	sterren	onkruid
229	tafel	stoel	geluk
230	blik	stof	stem
231	bezem	stof	stem
232	stofzuiger	stof	stem
233	palmboom	strand	kroost
234	zebra	strepen	antenne
235	strijkplank	strijken	gebeuren
236	tandenborstel	tandpasta	formulier
237	potlood	tekenen	blijven
238	thermometer	temperatuur	telefooncel
239	tennisracket	tennis	ravijn
240	ketel	thee	fase
241	theepot	thee	fase
242	kopje	thee	fase
243	klok	tijd	dame
244	horloge	tijd	vest
245	ring	trouwen	beweren
246	hek	tuin	pink
247	schoffel	tuin	tand
248	maïskolf	veld	dank
249	kwast	verf	muts
250	penseel	verf	muts
251	taart	verjaardag	reisbureau
252	cadeau	verjaardag	reisbureau
253	stoplicht	verkeer	zwembad
254	vissenstaart	vis	heg
255	reiger	vis	rug
256	viskom	vis	heg
257	pelikaan	vis	heg

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	Picture	Association	Unrelated
258	net	vis	keu
259	vishaak	vissen	zeggen
260	helikopter	vliegen	geloven
261	propeller	vliegtuig	pannenkoek
262	rups	vlinder	stuiver
263	voetbalschoen	voetbal	vulkaan
264	vogelkooi	vogel	zweet
265	vogelhuisje	vogel	snoer
266	veer	vogel	vlecht
267	rok	vrouw	opzet
268	jurk	vrouw	opzet
269	vuilnisvat	vuilnis	rijtuig
270	luciferdoosje	vuur	plan
271	wiel	wagen	kabel
272	zon	warm	half
273	radiator	warmte	agenda
274	wasknijper	was	wet
275	put	water	kudde
276	kraan	water	groep
277	vis	water	kudde
278	wasbak	water	groep
279	kan	water	kudde
280	glas	water	kudde
281	spin	web	pet
282	overall	werken	tergen
283	wijnfles	wijn	zeep
284	wijnglas	wijn	orde
285	wijsvinger	wijzen	lachen
286	molen	wind	gang
287	zeilboot	wind	dame
288	vlieger	wind	dame
289	windwijzer	wind	gang
290	sneeuwpop	winter	biljet
291	trui	winter	biljet
292	want	winter	biljet
293	rekenmachine	wiskunde	grasveld
294	passer	wiskunde	grasveld
295	cactus	woestijn	medaille
296	kameel	woestijn	medaille
297	huis	wonen	racen
298	konijn	wortel	badpak
299	schepje	zand	tand
300	kruiwagen	zand	nood
301	schelp	zee	heg
302	rog	zee	pet
303	dolfijn	zee	heg
304	zeehond	zee	pet
305	haai	zee	heg
306	krab	zee	heg
307	zeepaard	zee	heg
308	zeester	zee	heg
309	walvis	zee	pet
310	kwal	zee	heg
311	oog	zien	gaan
312	bril	zien	gaan
313	microfoon	zingen	steken

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	Picture	Association	Unrelated
314	stoel	zitten	kiezen
315	kruk	zitten	kiezen
316	mond	zoenen	treden
317	zonnebloem	zomer	plank
318	ijscoupe	zomer	plank
319	citroen	zuur	mild
320	eend	zwemmen	streven

Appendix Chapter 5

Concrete words

001	aap	002	aardbei	003	aarde
004	akker	005	anker	006	appel
007	arend	008	augurk	009	baard
010	baby	011	badjas	012	badkuip
013	badmuts	014	baksteen	015	ballon
016	balpen	017	banaan	018	bed
019	beitel	020	berk	021	bezem
022	biefstuk	023	bijl	024	bil
025	bliksem	026	bloembol	027	bloempot
028	boek	029	bok	030	boomstam
031	braadpan	032	brancard	033	brandkast
034	breinaald	035	brief	036	broek
037	brommer	038	brood	039	citroen
040	colbert	041	dakpan	042	deur
043	deurknop	044	deurmat	045	dij
046	dolfijn	047	druppel	048	duif
049	duim	050	dweil	051	eekhoorn
052	eend	053	egel	054	eik
055	emmer	056	etui	057	ezel
058	fakkel	059	fiets	060	fietsband
061	fietsbel	062	fles	063	framboos
064	fruitschaal	065	galg	066	gans
067	garnaal	068	gebit	069	geit
070	geweer	071	gewei	072	glas
073	globe	074	gloeilamp	075	gootsteen
076	goudvis	077	graan	078	grapefruit
079	grasspriet	080	gulden	081	haan
082	haas	083	hamer	084	hamster
085	haring	086	hart	087	heftruck
088	heg	089	hemd	090	hert
091	hoofd	092	hooiberg	093	iglo
094	ijsbeer	095	inktpot	096	inktvis
097	jeep	098	kaars	099	kaas
100	kaasschaaf	101	kalf	102	kam
103	kameel	104	kan	105	kano
106	kanon	107	kei	108	kerstboom
109	kikker	110	kip	111	kladblok
112	klaproos	113	klokhuis	114	knijper
115	knuppel	116	koe	117	koelkast
118	kopje	119	kraai	120	krab
121	kreeft	122	krijt	123	kroepoek
124	kroket	125	krokus	126	kroon
127	kuif	128	kuiken	129	kurk
130	kwal	131	kwartje	132	kwast
133	ladder	134	lasso	135	leeuw
136	lippen	137	loep	138	luipaard
139	maan	140	maïs	141	meeuw
142	melkfles	143	meloen	144	merel
145	mes	146	mijter	147	molen
148	mond	149	monnik	150	mossel
151	muis	152	mummie	153	muur
154	naald	155	narcis	156	neushoorn
157	nijptang	158	non	159	ober

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160	oester	161	olijf	162	oog
163	oor	164	oorbel	165	paard
166	paling	167	palm	168	panter
169	parel	170	parkiet	171	paspoort
172	patat	173	paus	174	pauw
175	peer	176	penseel	177	perzik
178	pet	179	peuk	180	pinda
181	pinguïn	182	pink	183	pistool
184	pizza	185	plafond	186	pleister
187	po	188	poedel	189	poes
190	pony	191	potlood	192	prei
193	pruim	194	radijs	195	rails
196	rat	197	reiger	198	rijst
199	rits	200	roeiboot	201	roltrap
202	roos	203	rotje	204	rozijn
205	rugzak	206	sandwich	207	schaal
208	schaap	209	schaar	210	schepnet
211	schildpad	212	schoffel	213	schoolbord
214	schooltas	215	schoorsteen	216	schroef
217	scooter	218	servet	219	sigaar
220	skelet	221	slaapzak	222	slak
223	sneeuwpop	224	snor	225	soepkop
226	sok	227	sorbet	228	speen
229	spijker	230	spons	231	springtouw
232	sprinkhaan	233	spuit	234	stam
235	steelpan	236	stekker	237	stier
238	stoeprand	239	stoplicht	240	strijkplank
241	stropdas	242	stuiver	243	tandem
244	teil	245	tekkel	246	tepel
247	theedoek	248	theepot	249	tientje
250	tijger	251	tomaat	252	ton
253	tor	254	tractor	255	tram
256	trechter	257	trein	258	trompet
259	tulband	260	uil	261	varken
262	veter	263	veulen	264	viltstift
265	viool	266	vlag	267	vlakgom
268	vlam	269	vleermuis	270	vlieg
271	vlieger	272	vlinder	273	voet
274	voetbal	275	vork	276	vos
277	vuist	278	vulkaan	279	vulpen
280	vuurpijl	281	walvis	282	wenkbrauw
283	wesp	284	wijnglas	285	wolf
286	worm	287	zaag	288	zebra
289	zee	290	zeehond	291	zeeleeuw
292	zeep	293	zeilboot	294	zeis
295	zon	296	zwaan	297	zwaard
298	zwaluw	299	zweep	300	zwijn

Abstract words

001	aanbod	002	aanbreng	003	aanklacht
004	aanleg	005	aanpak	006	aanzien
007	aard	008	advies	009	afgunst
010	afkeer	011	afkomst	012	afloop
013	aftrek	014	afzet	015	ambt

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016	baat	017	ban	018	bard
019	bedrog	020	beheer	021	behoud
022	bekomst	023	benul	024	beraad
025	bereik	026	berouw	027	beschik
028	besef	029	betoog	030	beurt
031	bewijs	032	bewind	033	bezit
034	bijnaam	035	blaam	036	blijk
037	bluf	038	bond	039	bons
040	borg	041	bres	042	brik
043	buffer	044	censuur	045	christen
046	cyclus	047	dagtaak	048	denkbeeld
049	deugd	050	devies	051	ding
052	doem	053	draai	054	drang
055	dreiging	056	drom	057	durf
058	dwang	059	eendracht	060	eenheid
061	eenvoud	062	eer	063	effect
064	ere	065	ernst	066	ether
067	euvel	068	faam	069	fantast
070	fatsoen	071	foefje	072	fonds
073	frats	074	gave	075	geding
076	gedoe	077	geheim	078	geintje
079	gelag	080	geloof	081	gemak
082	gemis	083	geraas	084	gerucht
085	geschil	086	gever	087	gewest
088	gratie	089	grol	090	grootheid
091	grootte	092	gros	093	gruwel
094	gunst	095	heden	096	heffing
097	heiden	098	heil	099	heim
100	heimwee	101	hekel	102	herkomst
103	hiaat	104	idee	105	iets
106	ijver	107	impuls	108	inbreng
109	inhoud	110	inspraak	111	instinct
112	inteelt	113	inval	114	inzet
115	jargon	116	kader	117	kaf
118	kalmte	119	kanjer	120	kanker
121	kapjaar	122	kaste	123	kenner
124	keuze	125	kijk	126	klasse
127	klemtoon	128	klier	129	klimaat
130	kwarts	131	laster	132	lef
133	lener	134	lering	135	leugen
136	linie	137	list	138	loeder
139	maatstaf	140	maling	141	melding
142	mening	143	misbruik	144	moeite
145	moraal	146	motie	147	motto
148	mystiek	149	mythe	150	nadeel
151	nazaat	152	nep	153	noodlot
154	nut	155	omgang	156	omvang
157	omzet	158	onheil	159	onrecht
160	onrust	161	onschuld	162	ontzet
163	onwil	164	onzin	165	oordeel
166	oorzaak	167	opbouw	168	opzet
169	pacht	170	plan	171	pleidooi
172	plof	173	poging	174	pressie
175	profijt	176	pronk	177	pulp
178	raadsel	179	rang	180	ranglijst
181	reces	182	record	183	rede
184	regie	185	rente	186	rest
187	richtlijn	188	rijkdom	189	ritme

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190	ronde	191	rotzak	192	rubriek
193	rune	194	rustdag	195	scène
196	schaamte	197	schandaal	198	schande
199	schatting	200	schema	201	schennis
202	schepping	203	scherts	204	schorsing
205	schroom	206	score	207	serie
208	sleur	209	smoes	210	spijt
211	spraak	212	spreiding	213	spul
214	status	215	sterkte	216	steun
217	stijging	218	stijl	219	stilstand
220	stoornis	221	storing	222	subject
223	symbool	224	taboe	225	tact
226	tactiek	227	tal	228	talent
229	talg	230	tarief	231	tekort
232	tel	233	tempo	234	terts
235	thema	236	tijdje	237	tip
238	toeval	239	toorn	240	torn
241	totaal	242	trant	243	tred
244	triomf	245	trouw	246	truc
247	tucht	248	uiting	249	uitkomst
250	uitleg	251	uitslag	252	uitstel
253	uitval	254	uitvoer	255	uitweg
256	vakbond	257	veelheid	258	verbond
259	verhoor	260	verraad	261	vers
262	versie	263	verval	264	vervolg
265	verwijt	266	vete	267	viering
268	visie	269	voorgrond	270	voorproef
271	voorrecht	272	voorschrift	273	voorspel
274	voortgang	275	voorval	276	vrees
277	vuilak	278	waan	279	waar
280	waarde	281	wanhoop	282	weelde
283	weemoed	284	weerklank	285	welzijn
286	wending	287	werkje	288	wezen
289	wijsheid	290	wil	291	wilskracht
292	wreedheid	293	wrok	294	zede
295	zending	296	ziel	297	zonde
298	zone	299	zwakte	300	zwenk

Pseudowords

001	aarvet	002	absort	003	araboon
004	aram	005	aska	006	audir
007	bachje	008	bangel	009	bant
010	bapkaaps	011	bedaker	012	bening
013	biel	014	bielkeen	015	bing
016	birang	017	blamdop	018	bliefkeek
019	blier	020	blundaar	021	bog
022	bonan	023	bopperd	024	bra
025	brankte	026	bred	027	brenk
028	bruimel	029	buraank	030	daalnat
031	dadet	032	dagpek	033	degek
034	delirod	035	diora	036	distaar
037	draam	038	drechband	039	dreednaf
040	dremelst	041	dribbe	042	duilker
043	duipert	044	duktrok	045	eerk

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046	eftieng	047	ema	048	emin
049	enktrik	050	eppa	051	etut
052	etvraat	053	flaar	054	flasker
055	fol	056	fren	057	frit
058	fronk	059	frontiel	060	fundat
061	gaalmut	062	gader	063	gandstoor
064	genne	065	giem	066	giemmal
067	glak	068	glate	069	glind
070	gliveer	071	gloenik	072	golaard
073	gouz	074	grei	075	grindpap
076	hager	077	harnbeg	078	hilk
079	hipraas	080	honpago	081	hontol
082	horv	083	huip	084	iki
085	imdoeld	086	inkvaar	087	iradoor
088	jige	089	joegder	090	joldeern
091	joperak	092	jumber	093	junteer
094	kahoen	095	kapsterm	096	keg
097	kerplon	098	kijnreuf	099	klagstoon
100	kleber	101	klee	102	klijvan
103	klint	104	klisser	105	klitmus
106	klobol	107	kluinnaap	108	kniller
109	kobijz	110	kogzeem	111	kokra
112	kolp	113	komolar	114	konner
115	koofdralk	116	krabod	117	kraldie
118	kramat	119	kraunt	120	kreeper
121	kreld	122	krikkel	123	kroeker
124	kroepel	125	kroft	126	kuikert
127	kwarv	128	kwieblor	129	kwijpsteef
130	lagboon	131	lank	132	lappel
133	loorfaat	134	malp	135	malvaar
136	mampoet	137	manrel	138	maton
139	merme	140	milar	141	moek
142	morraz	143	naster	144	nessep
145	neverp	146	nijtar	147	noese
148	nogbree	149	nokkel	150	nolt
151	noodsop	152	nuis	153	offel
154	olki	155	osk	156	otschoer
157	palier	158	panber	159	parca
160	pectier	161	peenout	162	pepeld
163	perkluur	164	pild	165	plark
166	plen	167	plentmoog	168	pliz
169	plokvoes	170	plompkap	171	plonker
172	ponkstup	173	portink	174	pos
175	praktur	176	prankaf	177	preen
178	priekel	179	priep	180	prinnik
181	proliam	182	prommel	183	protlier
184	puite	185	pun	186	pupslam
187	quapron	188	radager	189	ran
190	rechtaaf	191	reelvriet	192	reerdak
193	reit	194	remtadel	195	riel
196	rijfgar	197	rineg	198	roenvacht
199	roonka	200	roorvem	201	ruivert
202	runbe	203	ruub	204	sabool
205	san	206	scheddem	207	schemen
208	sches	209	schierken	210	schijspar
211	scho	212	schoep	213	schorm
214	schulaar	215	schuller	216	skal
217	skilk	218	sokbas	219	soperaal

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220	spir	221	spreefkul	222	spunk
223	stadeel	224	stanwis	225	stas
226	stedev	227	steelkwad	228	steelrap
229	stegel	230	stimp	231	stimpa
232	stir	233	stoef	234	stoeklar
235	stolte	236	stoopkleb	237	stor
238	straaf	239	strement	240	strindpar
241	strome	242	stronaar	243	stronner
244	struimper	245	subert	246	subsa
247	sulfo	248	tanfoor	249	tedvide
250	teerpij	251	theegbas	252	tielston
253	tiepo	254	tillat	255	tipoon
256	tixis	257	toender	258	toorder
259	trak	260	tranep	261	trannerd
262	tredderd	263	treider	264	trific
265	troeg	266	trover	267	truunsat
268	tuikslom	269	tuip	270	uifzamp
271	uptuun	272	vaalp	273	vaktor
274	vantplop	275	vekse	276	velter
277	vielbeert	278	vlarmel	279	volpad
280	vraambrook	281	vreelkim	282	vront
283	vroumel	284	vulslo	285	walpreg
286	wap	287	wapert	288	wapstuuf
289	wastert	290	wilaar	291	wilbe
292	witma	293	wramer	294	wreng
295	wrikked	296	wuurstron	297	zaalgot
298	zaalrbo	299	zeelag	300	zobeek

Nederlandse Samenvatting

Inleiding

De betekenis van taal is een veelzijdig en intrigerend fenomeen. Generaties psychologen, filosofen en taalkundigen hebben zich bezig gehouden met de vraag hoe de betekenis van taal gerepresenteerd is in ons hoofd. Het verleden heeft aangetoond dat deze vraag niet eenvoudig is te beantwoorden. In de afgelopen decennia zijn nieuwe technieken ontwikkeld die wetenschappers in staat stellen om activiteit zoals zich die in de hersenen voordoet zichtbaar te maken. Hoewel deze technieken hebben geleid tot nieuwe inzichten kan men zeggen dat de wetenschap nog slechts in de kinderschoenen staat als het gaat om inzicht in de wijze waarop de betekenis van taal georganiseerd is in onze hersenen.

In algemene zin is men het er over eens dat veel betekenisaspecten van taal opgeslagen liggen in het semantische geheugen. Het semantische geheugen is het systeem dat betrokken is bij het verwerken, opslaan en ophalen van informatie over de betekenis van woorden, concepten en feiten (Warrington, 1975). Het semantische geheugen stelt ons in staat om betekenis te geven aan onze sensorische ervaringen (Hodges et al., 1992), de objecten die we zien en de woorden die we lezen of horen (Humphreys & Forde, 2001). Men denkt dat de ontwikkeling van het semantische geheugen ontstaat in de dagelijkse ervaring met concrete objecten zoals planten, dieren en gereedschappen (bijv. Pulvermüller, 1999a). Op het moment dat de betekenis van een concreet woord geleerd wordt, wordt de persoon geconfronteerd met prikkels uit de diverse zintuigen. Ook kan het zijn dat de persoon acties uitvoert met het object waar het woord aan refereert. Zowel de visuele als motorische ervaring die de persoon opdoet worden geassocieerd met de naam van het object (Allport, 1985). Visuele semantiek verwijst naar dat gedeelte van het semantische geheugen dat betrekking heeft op kennis van visuele elementen in de wereld om ons heen. Aangezien mensen in hoge mate visueel zijn ingesteld denkt men dat de betekenis van concrete woorden sterk gekoppeld is aan de visuele waarneming (Martin, 1998). Martin et al. (1995) stelden voor dat de semantische kennis van objecten ligt opgeslagen bij gebieden die betrokken zijn bij de perceptuele verwerking van die objecten. Ook stelden zij voor dat de organisatie van semantische kennis in het brein parallel loopt met de organisatie van perceptuele functies. Van perceptuele functies is bekend dat deze zijn onderverdeeld in verschillende gebieden, waarbij elk gebied is gespecialiseerd in een specifieke perceptuele eigenschap (bijv. analyse van vorm, kleur, beweging, positie, etc.)(Felleman & Van Essen, 1991). Dit voorstel doet een sterke voorspelling over de structurele relatie tussen visuele semantiek en perceptuele functie.

Nog niet zo lang geleden was men de mening toegedaan dat taal voor het merendeel een autonoom cognitief proces is met zijn eigen neurale processen en verantwoordelijke hersengebieden (bijv. Geschwind, 1965), waarbij het gebied van Broca en het gebied van Wernicke als belangrijkste werden gezien. Echter, zowel het onderzoek met patiënten die als gevolg van hersenbeschadiging problemen ondervinden met het begrijpen van taal, alsook de uitkomsten van neuroimaging-onderzoek[2] hebben bijgedragen aan het beeld dat de betekenis van taal in sterke mate gedistribueerd is en een beroep doet op verschillende sensorische en motorische gebieden van de hersenen.

Een populaire neuroimaging-techniek is het gebruik van het electroencephalogram (EEG) dat de mogelijkheid biedt om op nauwkeurige wijze neurale hersenactiviteit in de tijd te beschrijven. Het EEG wordt gemeten met elektroden die zijn aangebracht op de scalp waarmee de elektrische activiteit van de hersenen over de tijd wordt geregistreerd. Wanneer we het in de praktijk over EEG-onderzoek hebben betekent dit meestal dat het gaat om ERP-onderzoek. Event-related potentials (ERPs) geven het gemiddelde EEG-signaal weer in relatie tot een bepaalde gebeurtenis of event (bijvoorbeeld het verschijnen van een woord op een computermonitor). Psycholinguïstisch ERP-onderzoek naar semantiek heeft zich in hoge mate beziggehouden met de N400, een negatief elektrisch signaal dat ongeveer 400 milliseconden na aanbieding van een woord gemeten wordt. De N400 is gevoelig voor de semantische relatie tussen woorden, maar wordt ook gevonden met niet talige stimuli zoals lijntekeningen (bijv. Holcomb & McPherson, 1994) en gezichten (bijv Barrett & Rugg, 1990), wat doet vermoeden dat de N400 een algemene maat is voor de verwerking van betekenisvolle stimuli. De N400 is veelal gebruikt als middel tot onderzoek, om bijvoorbeeld de relatie te onderzoeken tussen semantische en grammaticale analyse van zinnen. Ook is de N400 gebruikt om de vraag te beantwoorden of er sprake is van een uniform semantisch geheugen ofwel een onderverdeling in semantische modules (bijvoorbeeld aparte modules voor talige en visuele semantiek). Echter er is nog steeds weinig bekend over de neurale bron van de N400 en belangrijker, hoe semantische informatie in de hersenen gerepresenteerd wordt en verwerkt. Hoewel ERP-onderzoek juist in staat zou moeten zijn om op een accurate wijze verslag te doen van de manier waarop betekenis in de hersenen wordt verwerkt, heeft een te sterke focus op de N400 (als zijnde 'de semantische component') ertoe geleid dat deze potentie onvoldoende is benut. Vooral de gedachte dat semantische betekenis van taal in sterke mate beroep doet op niet talige cognitieve processen en ERP-componenten (bijvoorbeeld visuele of motorische representaties) is onvoldoende onderzocht.

Naast het gebruik van neuroimaging technieken zoals ERPs bestaan er minder ingewikkelde technieken waarmee men interacties tussen semantische en visuele processen kan onderzoeken. De meest frequent gebruikte methode in psychologisch onderzoek is het reactietijdparadigma waarbij men op grond van de snelheid en accuraatheid waarmee proefpersonen reageren interne cognitieve processen tracht te

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[2] m.b.v. neuroimaging wordt een beeld gevormd van neurale processen

doorgronden. In één bepaald paradigma dat van grote waarde is gebleken worden stimuli aangeboden in verschillende delen van het visuele veld. Deze methode wordt vaak gebruikt om de talige eigenschappen van de linker en rechter hersenhelft te onderzoeken. Een typisch resultaat is dat woorden in het rechter visuele veld sneller en beter worden verwerkt dan woorden aangeboden in het linker visuele veld. Dit is omdat woorden in het rechter visuele veld rechtstreeks verwerkt worden door de linker hersenhelft die dominant is voor taal.

Eenzelfde organisatie zoals die bestaat voor het linker en rechter visuele veld is gevonden voor het bovenste en onderste visuele veld. Informatie aangeboden in het bovenste visuele veld komt terecht onderin de visuele hersenen (ventraal), terwijl het onderste visuele veld rechtstreeks verbonden is met het bovenste deel van de visuele cortex (dorsaal). Net als tussen de linker en rechter hemisfeer bestaan er interessante functionele verschillen tussen ventrale en dorsale gedeelten van het brein. De ventrale projectie is vooral belangrijk voor het herkennen en identificeren van objecten, terwijl het dorsale pad van belang lijkt te zijn voor het uitvoeren van acties met objecten (bijv. Creem & Proffitt, 2001). Ook semantische kennis lijkt dezelfde organisatie in de visuele hersenen te volgen. Patiënten met beschadigingen van het onderste (ventrale) deel van het visuele systeem lijken vooral problemen te ondervinden met het ophalen van visueel-semantische kennis van objecten (bijvoorbeeld kennis over de vorm, kleur, of grootte van objecten), terwijl patiënten met een dorsale laesie eerder moeite hebben met het gebruik van objecten (samenvattingen in Gainotti et al., 1995; Humphreys & Forde, 2001). Door betekenisvolle stimuli (woorden of plaatjes) aan te bieden in het bovenste en onderste visuele veld en de reacties van proefpersonen te meten zijn we in staat om de semantische eigenschappen in de dorsale en ventrale gedeelten van de visuele cortex te onderzoeken.

Samenvatting van de Experimentele Hoofdstukken

Het proefschrift is opgedeeld in twee delen. Het eerste deel (hoofdstukken 2 en 3) beschrijft een aantal gedragsexperimenten waarin getracht wordt de semantische eigenschappen te onderzoeken van ventrale en dorsale delen van de visuele cortex. Hierbij is gebruik gemaakt van de gekruiste organisatie in het visuele systeem. In het tweede deel (hoofdstukken 4 en 5) worden ERP-experimenten beschreven die er op gericht zijn een completer beeld te vormen van de functionele relatie tussen semantische en visuele processen in het brein.

Inhibition of Return en Semantische Priming voor Objecten in het Bovenste en Onderste Visuele Veld

Hoofdstuk 2 richt zich op de relatie tussen de semantische kennis van objecten en aandachtsmechanismen die een rol vervullen in visueel zoeken. Het efficiënt zoeken in de visuele omgeving is afhankelijk van de semantische kennis die we hebben over objecten en maakt gebruik van aandachtsmechanismen die het gedrag van onze ogen in de visuele ruimte controleren. Het idee bestaat dat er een sterke samenwerking is tussen de neurale mechanismen voor visuele semantiek en het systeem dat onze aandacht controleert.

Eén van de functionele mechanismen die een belangrijke rol speelt in visueel zoeken is 'inhibition of return' (IOR). IOR is gekoppeld aan het systeem voor saccadische oogsprongen.[3] Het mechanisme houdt bij welke objecten of posities bezocht zijn door de ogen en onderdrukt iedere volgende aandachtsverplaatsing naar dat object of die positie. Het gevolg is dat nog niet onderzochte objecten bevoordeeld worden.

(Previc, 1990) stelde voor dat er kwalitatieve verschillen bestaan tussen het bovenste en onderste visuele veld. Het bovenste visuele veld is gespecialiseerd in visueel zoeken en objectherkenning waarbij er een voordeel lijkt te bestaan voor het maken van saccadische oogsprongen. Het onderste visuele veld echter lijkt vooral gespecialiseerd in oog-handcoördinatie waarbij er een voordeel is voor oogbewegingen die het object volgen in de ruimte. Aangezien IOR gekoppeld is aan het systeem voor saccadische oogsprongen verwachten we een voordeel te vinden voor IOR in het bovenste visuele veld.

In experiment 1 werden plaatjes van objecten aangeboden in het onderste en bovenste visuele veld. De verwachting was dat objecten beter herkend zouden worden in het bovenste visuele veld. Ook het richten van de aandacht zou efficiënter zijn voor objecten in het bovenste visuele veld. Proefpersonen kregen de instructie om objecten te identificeren en vervolgens te reageren op het verschijnen van visuele probes. Deze probes zijn visuele prikkels met een zeer korte aanbiedingstijd, welke ofwel op de positie van het eerder aangeboden object werden getoond, ofwel op de tegenoverliggende positie op het scherm. De reactiesnelheid van proefpersonen op deze probes is vertraagd wanneer probes op dezelfde positie als het object worden aangeboden. Deze vertraging wordt gezien als het effect van IOR dat ontstaat a.g.v. het herhaaldelijk verplaatsen van de aandacht naar een bepaalde positie. De resultaten van dit experiment lieten zien dat het effect van IOR ongeveer twee maal zo sterk is in het bovenste visuele veld dan in het onderste visuele veld. Het sterkere effect van IOR in het bovenste visuele veld komt overeen met het voordeel voor saccadische oogsprongen in datzelfde gedeelte van het visuele veld.

In een tweede experiment werd onderzocht of de sterkere effecten van IOR in het bovenste visuele veld het gevolg zijn van de objecten die daar werden aangeboden, of dat dit effect het gevolg is van een sterkere gevoeligheid voor plotselinge visuele veranderingen in dit deel van het visuele veld. In dit tweede experiment werden in plaats van echte objecten, kortstondig visuele flitsen aangeboden. Proefpersonen kregen de instructie om deze flitsen te negeren. Dit resulteerde erin dat het eerder gevonden verschil tussen het bovenste en onderste visuele veld verdween. Dit resultaat ondersteunt de hypothese dat het identificeren en attenderen van objecten in het bovenste visuele veld gepaard gaat met een sterke mate van saccade preparatie. Vooral voor objecten aangeboden in het bovenste visuele veld lijkt er een sterke geneigdheid te bestaan tot het maken van oogsprongen om het object te identificeren.

Een van de actuele vragen met betrekking tot IOR is op welk niveau de inhibitie van IOR zich manifesteert. Over het algemeen wordt er van uit gegaan dat IOR

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[3] lees abrupte verplaatsingen van de ogen. Dit i.t.t. bijvoorbeeld volgbewegingen van ogen waarbij de ogen zich geleidelijk van de ene naar de andere positie verplaatsen.

een reflectie is van de mate van saccade preparatie in subcorticale gebieden van de hersenen. Echter het is mogelijk dat de effecten van IOR zich niet beperken tot subcorticale gebieden, maar tevens een rol spelen in de cortex. Resultaten van eerder onderzoek lieten zien dat de effecten van IOR sterk gekoppeld zijn aan objecten en delen van objecten (bijv. Tipper, 1991; Ro & Rafal, 1999) wat doet vermoeden dat IOR een corticale basis heeft en is geassocieerd met de corticale representaties van deze objecten. Chasteen en Pratt (1999) vonden dat IOR het lezen van woorden beïnvloed en resultaten van Fuentes et al. (1999a) lieten zien dat de effecten van IOR ook op semantisch niveau tot inhibitie kunnen leiden.

Een belangrijke vraag die zich aandient is dan ook of semantiek een invloed kan hebben op reflexieve aandachtsmechanimen zoals IOR. Door het aanbieden van woorden die ofwel gerelateerd of niet gerelateerd zijn aan objecten is getracht het effect van IOR te beïnvloeden. Hoewel zowel IOR als de semantische relatie tussen het woord en het object een effect lieten zien in de reactietijden op visuele probes vonden we geen invloed van de semantische relatie op IOR. Dit suggereert dat het effect van IOR voornamelijk subcorticaal gerepresenteerd is en dat, hoewel IOR een sterke invloed lijkt te hebben op hogere cognitieve processen, de omgekeerde invloed vanuit de semantiek naar IOR minder vanzelfsprekend is.

Semantische Specialisatie voor Manipuleerbare en Niet-manipuleerbare Objecten

Hoofdstuk 3 richt zich op de organisatie van het semantische geheugen in visuele hersengebieden. De visuele hersenen bestaan uit twee belangrijke paden, het dorsale en het ventrale pad, die elk specifieke functies bezitten. Het ventrale pad is betrokken bij het herkennen van objecten, terwijl het dorsale pad het mogelijk maakt om acties uit te voeren met objecten. Eenzelfde functionele organisatie is voorgesteld voor het semantische geheugen, waarbij de ventrale route semantische kennis bevat over de visuele eigenschappen van objecten en de dorsale route semantische kennis bevat over het type acties behorende bij objecten. Dit suggereert dat de organisatie van het semantische geheugen parallel loopt aan de perceptuele specialisatie voor objecten in het dorsale en ventrale pad.

Er werden twee typen woorden aangeboden: woorden die refereren aan manipuleerbare objecten (bijv. 'pen') en woorden die verwijzen naar niet-manipuleerbare objecten (bijv. 'schoorsteen'). De verwachting was dat woorden die refereren naar manipuleerbare objecten in het voordeel zijn wanneer deze aangeboden worden in het onderste visuele veld (het onderste visuele veld heeft een directe verbinding met het dorsale pad dat van belang zou zijn voor de functionele eigenschappen van objecten). Woorden die refereren naar niet-manipuleerbare objecten zouden in een voordeel moeten resulteren wanneer aangeboden in het bovenste visuele veld (het bovenste visuele veld heeft een directe verbinding met het ventrale pad dat voornamelijk kennis lijkt te bevatten over de visuele kenmerken van objecten). Proefpersonen dienden voor elk woord aan te geven of het een bestaand woord betrof, of een niet bestaand (pseudo) woord. De resultaten van deze lexicale-beslissingtaak lieten een voordeel zien voor manipuleerbare objecten in het onderste visuele veld en niet-manipuleerbare objecten in het bovenste visuele veld. Echter, dit patroon was alleen zichtbaar bij herhaalde aanbieding van woorden. Dit suggereert dat priming noodzakelijk is om met behulp van woorden de distributie van semantische eigenschappen in dorsale en ventrale gebieden in kaart te kunnen brengen.

Daarnaast lieten de resultaten een sterk voordeel zien wanneer woorden werden aangeboden in het onderste visuele veld. Het voordeel voor aanbieding in het onderste visuele veld was ongeveer twee maal zo groot voor echte woorden dan voor pseudowoorden. Dit lijkt te wijzen op een voordeel voor de verwerking van talige informatie in de dorsale gebieden.

De Relatie tussen Semantische en Perceptuele Representatie

Een belangrijke vraag die verband houdt met de organisatie van betekenis in het brein betreft de wijze waarop objecten zijn gerepresenteerd. Hoofdstuk 4 onderzoekt de hypothese dat objecten zijn gerepresenteerd via een tijdelijke verbinding tussen sensorische, perceptuele en semantische niveaus van objectbeschrijving. Het gevolg van een dergelijke tijdelijke verbinding zou kunnen zijn dat een verandering op één van deze niveaus (bijvoorbeeld het semantische niveau) automatisch leidt tot verandering op andere niveaus (bijvoorbeeld de perceptuele representatie van het object). Deze vraag is onderzocht met een plaatje - woord repetitieparadigma waarin de semantische relatie tussen het plaatje en het woord is gemanipuleerd. In experiment 1 werden plaatjes aangeboden gevolgd door een woord dat ofwel de naam van het object betrof (gerelateerd woord), ofwel gevolgd door een woord dat niet gerelateerd was aan het object. De verwachting was dat gerelateerde woorden de objectrepresentatie zouden versterken en dat dit effect tevens waarneembaar zou zijn op het perceptuele niveau. Door het aanbieden van visuele probe stimuli en het meten van de ERP-response op deze stimuli zijn we in staat eventuele feedback vanuit het semantische niveau naar het perceptuele niveau zichtbaar te maken. De redenering is dat toegenomen activatie in perceptuele gebieden de verwerking (ERPs) van visuele probes beïnvloed.

Niet-gerelateerde woorden genereerden een sterke N400, gemeten boven de pariëtale hersengebieden. De N400 is een afspiegeling van semantische integratie. Hoe groter het effect, des te moeilijker is het voor proefpersonen om het woord en het plaatje aan elkaar te relateren. Vanuit het effect op N400 ontstond een langdurige negatieve golf voor ongerelateerde woorden. Deze golf was onder andere maximaal boven visuele hersengebieden en weerspiegelt waarschijnlijk additionele visuele zoekprocessen die betrokken zijn bij het vinden van een semantische relatie tussen het plaatje en het woord. Interessant is dat dit zoekproces beïnvloed werd door het aanbieden van probes. ERPs op probe stimuli lieten zien dat probes al heel snel na hun aanbieding resulteerden in een onderdrukking van deze langdurige negatieve golf. Deze onderdrukking was een stuk sterker wanneer probes werden aangeboden in het bovenste visuele veld. Een mogelijke verklaring voor dit resultaat is dat het bovenste visuele veld een directe verbinding heeft met het ventrale pad dat een belangrijke rol lijkt te spelen in visueel zoeken en objectrepresentatie.

Zoals gezegd werden ERPs van visuele probe stimuli gebruikt om te onderzoeken of de semantische relatie tussen het woord en het plaatje effecten had op het perceptuele niveau. Zoals verwacht vonden we dat gerelateerde woorden invloed hadden op de verwerking van probes en voornamelijk wanneer deze probes werden aangeboden op de positie van het plaatje. Echter, de latentie van het effect op deze probes was vrij laat (250 - 280 milliseconden na probe aanbieding). Na ongeveer 250 milliseconden zou de verwerking van probes al voor een groot deel de visuele cortex gepasseerd moeten zijn. Een mogelijke verklaring voor deze vertraging wordt besproken in Hoofdstuk 4.

In een tweede experiment werden in plaats van woorden met dezelfde betekenis als objecten geassocieerde woorden gebruikt (bijv. harp - 'muziek'). Net als in het eerste experiment vonden we dat ongerelateerde woorden in een sterkere N400 resulteerden, opnieuw gevolgd door een langdurige negativive golf boven o.a. visuele gebieden. Ook vonden we opnieuw dat probes aangeboden in het bovenste visuele veld tot een sterkere onderdrukking van deze negativiteit leidden dan probes aangeboden in het onderste visuele veld. Echter, een duidelijk verschil met experiment 1 was dat het eerder beschreven late effect (250 - 280 milliseconden) afwezig was. Dit suggereert dat feedback vanuit het semantische niveau naar perceptuele gebieden afhankelijk is van de relatie tussen verbale en perceptuele informatie. Alleen woorden die direct verwijzen naar de visuele eigenschappen van het object lijken hiertoe in staat te zijn.

Gemeenschappelijke Neurale Basis voor Visueel Object-werkgeheugen en Visuele Semantiek

Over het algemeen vinden mensen concrete woorden (bijv. 'leeuw') makkelijker te begrijpen en te onthouden dan abstracte woorden (bijv. 'idee'). Eén van de voornaamste redenen voor dit verschil is waarschijnlijk dat concrete woorden over het algemeen goed voorstelbaar zijn, dit in tegenstelling tot abstracte woorden. Dit idee is zeker niet nieuw. Echter, er is zeer weinig bekend over de neurale mechanismen die mogelijkerwijs een rol spelen bij de voorstelbaarheid van woorden. Een van de belangrijkste kandidaten die betrokken zou kunnen zijn bij het activeren van visueel-semantische kennis van concrete woorden is het visuele object-werkgeheugen (Baddeley, 1986; Ungerleider et al., 1998). Eerder onderzoek heeft aangetoond dat ons visuele werkgeheugen in twee aparte gedeelten onderverdeeld kan worden (Owen et al., 1996; Smith & Jonides, 1997; Belger et al., 1998; Courtney et al., 1998). Eén gedeelte houdt zich specifiek bezig met de verwerking van spatiële informatie (hoe ziet een hoofdletter 'A' er op zijn kop uit?): het spatiële werkgeheugen. Het andere gedeelte betreft het werkgeheugen waarin de visuele aspecten (bijv. vorm of kleur) van objecten worden gerepresenteerd (wat is groener? Het groen van gras, of het groen van een dennenboom): het object-werkgeheugen.

Deze studie is erop gericht om inzicht te verkrijgen in de corticale mechanismen die betrokken zijn bij het activeren van visueel-semantische kennis van concrete woorden. De mogelijkheid is onderzocht dat concrete woorden hun visuele betekenis activeren via het corticale netwerk voor object-werkgeheugen. Concrete (voorstelbare) woorden en abstracte (niet voorstelbare) woorden werden aangeboden in condities die verschilden in de hoeveelheid belasting die er gelegd werd op het object-werkgeheugen. De object-werkgeheugentaak bestond er uit dat proefpersonen gedurende een aantal seconden een abstracte visuele vorm dienden te onthouden. Er waren drie niveaus van belasting. Ofwel de te onthouden vorm was makkelijk (een polygoon met vier hoeken), ofwel de te onthouden figuur was moeilijk (een polygoon met 10 hoeken). Er was ook een conditie zonder belasting. In deze conditie kregen proefpersonen zowel vierhoeken als tienhoeken te zien, maar deze hoefden niet onthouden te worden. Gedurende het polygoon-retentieïnterval werden abstracte en concrete woorden aangeboden. De verwachting was dat wanneer woorden werden aangeboden in condities met een hoge werkgeheugenbelasting, het moeilijker zou zijn om de visueel-semantische betekenis van deze woorden te activeren.

In één helft van het experiment dienden proefpersonen voor ieder woord aan te geven of het woord concreet was of abstract. In het andere gedeelte van het experiment dienden proefpersonen voor ieder woord te beslissen of het een echt woord betrof, dan wel een pseudowoord (in deze conditie waren dus ook af en toe pseudowoorden te horen).[4] Het onderscheid tussen de concreet-abstract-beslissingtaak en de lexicale-beslissingtaak diende ertoe om inzicht te verkrijgen in de voorwaarden waaronder de visuele betekenis van concrete woorden geactiveerd wordt. Gebeurt dit te allen tijde automatisch wanneer het woord herkend wordt (lexicale-beslissingtaak), of treedt dit slechts op wanneer er een expliciete noodzaak bestaat (concreet-abstract-beslissingtaak).

ERP resultaten ondersteunden de hypothese dat de visuele betekenis van concrete woorden geactiveerd wordt via het object-werkgeheugen. Daarbij suggereerden ERPs dat dit proces zich in twee fasen voltrekt. Visuele kennis van concrete woorden wordt waarschijnlijk eerst opgehaald uit het lange-termijngeheugen (weerspiegeld door de sterkere frontale N400 en occipitale positiviteit voor concrete woorden t.o.v. abstracte woorden) en vervolgens gevisualiseerd via het netwerk voor object-werkgeheugen (aangegeven door een positiviteit boven de linker ventrolaterale frontale cortex en een bilaterale negativiteit boven occipitale (visuele) gebieden). Zowel de frontale positiviteit en de occipitale negativiteit waren tevens kenmerkend voor de polygoon-werkgeheugentaak.

De overeenkomst tussen het concreetheid-effect en de werkgeheugentaak was het meest duidelijk voor de woorden die aangeboden werden in de lexicale-beslissingtaak. Dit ondersteunt de hypothese dat de visuele betekenis van woorden automatisch geactiveerd wordt wanneer het woord wordt herkend. Tevens vonden we in deze conditie een duidelijk effect van de object-werkgeheugentaak op de ERP-effecten van concrete woorden. De frontale effecten van concreetheid werden onderdrukt wanneer woorden werden aangeboden in condities waarin een object onthouden diende te worden. In de concreet-abstract-beslissingtaak vonden we afwijkende ERP-effecten op concrete woorden. Dit lijkt er op te wijzen dat, wanneer er sprake is van doelbewuste visualisatie er (gedeeltelijk) andere mechanismen betrokken zijn. In deze taakconditie vonden we geen interacties tussen de effecten van concreetheid en de object-werkgeheugentaak.

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[4] Pseudowoorden klinken net zo normaal als echte woorden, echter ze hebben geen betekenis (bijv. 'genner').

Conclusie

De voornaamste conclusie van dit proefschrift is dat de semantische verwerking van concrete woorden niet slechts berust op autonome cognitieve processen die selectief zijn voor taal, maar dat semantische processen een sterke relatie onderhouden en gebruik maken van diverse andersoortige cognitieve functies en processen die niet direct tot de taal gerekend worden. De resultaten van hoofdstuk 3 lijken de hypothese te bevestigen dat de organisatie van semantische kennis in de hersenen gekoppeld is aan de distributie van perceptuele functies in het dorsale en ventrale pad. Semantische kennis van manipuleerbare objecten lijkt opgeslagen in het dorsale pad dat gespecialiseerd is in het reiken naar en manipuleren van objecten in het onderste visuele veld. Semantische kennis van niet-manipuleerbare objecten is daarentegen waarschijnlijk opgeslagen in het ventrale pad dat gespecialiseerd is in visueel zoeken en het herkennen van objecten in het bovenste visuele veld. Zowel visueel-semantische kennis als perceptuele functies lijken zich georganiseerd te hebben in relatie tot de eigenschappen van onze visuele omgeving. Het gegeven dat onze handen veelal objecten manipuleren in het onderste visuele veld heeft mogelijk geleid tot de ontwikkeling van een specialisatie voor object manipulatie in het dorsale pad. Het herkennen en zoeken van objecten die zich buiten onze directe invloed bevinden zou bijgedragen kunnen hebben aan de ontwikkeling van een systeem voor objectherkenning in het ventrale pad.

Het proefschrift ondersteunt de gedachte dat het semantische geheugen voor concrete taal zich ontwikkeld heeft in relatie tot de perceptuele ervaring met objecten. De resultaten in hoofdstuk 5 laten zien dat de visuele betekenis van een concreet woord automatisch geactiveerd wordt wanneer de lexicale identiteit van het woord bekend wordt. De resultaten ondersteunen een model van visuele semantiek waarin visueel-beschrijvende informatie eerst wordt opgehaald uit het langetermijngeheugen en vervolgens wordt geactiveerd in het object-werkgeheugen. Het object-werkgeheugen lijkt een belangrijke rol te spelen voor zowel het begrip van taal alsook voor de visuele waarneming. De resultaten van hoofdstuk 4 suggereren dat het werkgeheugen van belang zou kunnen zijn in de koppeling tussen talige en visuele informatie.

Concluderend denk ik dat het proefschrift een interessant beeld geeft van de relatie tussen semantische, visuele en talige processen. Resultaten geven aan dat het semantische geheugen voor concrete woorden een intieme verbinding onderhoudt met het visuele systeem. Hoewel er in toenemende mate onderzoek wordt verricht naar de relatie tussen semantische processen en visuele functie (in de meeste gevallen is dit onderzoek met een neuropsychologische achtergrond), is het zo dat deze relatie onvoldoende is onderkend in de cognitieve neurowetenschappen. Voor een aanzienlijk deel is dit te wijten aan het feit dat visueel onderzoek en taal onderzoek vanuit hun historische achtergronden veelal gezien worden als aparte wetenschappelijke disciplines. De resultaten in dit proefschrift laten zien dat een dergelijk perspectief niet opgaat voor visuele semantiek.

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Groningen, 12 januari 2003,

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Stellingen
behorende bij het proefschrift
Visual Semantics
door Hein van Schie

1. Taalverwerking is geenszins een geïsoleerd cognitief proces. Het begrijpen van gesproken en geschreven taal doet een sterk beroep op visuele cognitieve functies (dit proefschrift).

2. De betekenis van concrete woorden komt o.a. tot uitdrukking via het visuele werkgeheugen waarin ook objecten worden gerepresenteerd en onthouden (dit proefschrift).

3. De representatie van visuele semantiek in het brein is in sterke mate gekoppeld aan de organisatie van het visueel-perceptuele systeem (dit proefschrift).

4. Het gebruik van het bovenste en onderste visuele veld als methode voor onderzoek naar de organisatie van functie in ventrale en dorsale gebieden is ten onrechte onderbelicht gebleven in de experimentele psychologie (dit proefschrift).

5. Het is geen toeval dat ondertiteling bij films in het onderste visuele veld wordt aangeboden aangezien woordverwerking in dit deel van het veld grote voordelen lijkt te hebben (dit proefschrift).

6. Hoewel er binnen de cognitieve neurowetenschappen een vrij goed beeld is ontstaan m.b.t. de representatie van concrete semantische informatie tast men nog in het duister wanneer het gaat om de organisatie van abstracte kennis.

7. EEG-technieken zullen het gebruik van de reactietijdmethode vervangen aangezien deze een nauwkeuriger en completer beeld geven van de timing van interne processen.

8. In tijden van economische neergang worden de sinterklaasgedichten langer.

9. De kunst van het leven is thuis te zijn alsof op vakantie.