Part II

Event-related Potentials
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

\(^1\)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.
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. 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 canthus 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: PI-CLOC (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 pseudopictures. 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.
4.3 Results

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 0.8µV. For the two middle maps (left frontal SW and right occipital SW) isopotential lines are separated by 0.4µV. Isopotential lines in the outer most right map (central SW) are separated by 0.2µV.

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.
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 elec-
4.3 Results

trodes 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).
4.3 Results

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 0.1 µV.

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 pro-
longed 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.
4.4 Discussion

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 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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4Peripheral 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
4.7 Results

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
Relationship between Semantics and Perception

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 outermost left map, isopotential lines are separated by 0.4 µV. Isopotential lines in the other three maps are separated by 0.2 µV.

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 PROBE-LOC; F1,19 = 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 (F1,19 = 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 experi-
ment, 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 atten-
tion 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.