AUTOMATIC AND ATTENTIONALLY CONTROLLED PROCESSING IN THE CEREBRAL HEMISPHERES

by

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Abstract

The thesis describes research investigating differences between the two hemispheres in automatic and in attentionally controlled processes. It is suggested that the interaction between these two processes may be a source of hemispheric differences. Three different paradigms that each imply different definitions of automatic and attentionally controlled processes are used: A paradigm used to demonstrate illusory conjunctions, a modified priming paradigm and a modified Stroop-task.

Converging evidence from all three paradigms indicates that automatic processes are common to both hemispheres. Lateral asymmetries only emerge in attentional effects. For verbal information, selective attention mechanisms in the left hemisphere are found to be selective for left hemisphere items only, whereas right hemisphere mechanisms are sensitive to information from both hemispheres.

The right hemisphere appears to be able to give some automatic support to attended verbal processing in the left hemisphere, while the reverse seems to be more difficult.

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I. INTRODUCTION

The distinction between two modes of processing, automatic and attentionally controlled (Schiffrin and Schneider, 1977) has been an important focus for much research in recent years. Typically, these modes of processing are viewed as hierarchically organised, with attentional processes either operating on or being at least strongly influenced by the outcomes of prior, automatic processes. Shiffrin and Schneider (1977) gave their subjects different target sets of letters or digits on each trial. They found that if targets and distractors were mapped consistently across trials, i.e. none of the targets was ever used as a distractor, target detection seemed to become automatic and independent of load. If the assignment of targets and distractors was inconsistent across trials, however, search seemed to be attentionally controlled and strongly dependent on load.

Different and sometimes new characteristics of the two modes have been emphasized by other writers. The terms automatic and attentionally controlled have been used to describe involuntary versus voluntary processing (e.g. Posner and Snyder, 1975), preattentive versus attentive processing (e.g. Neisser, 1967, Treisman and Gelade, 1980), unconscious versus conscious processing (e.g. Posner and Snyder, 1975, Marcel, in press) or parallel versus serial processing (e.g. Treisman and Gelade, 1980).

Dichotomous descriptions of information processing also prevail in research on the cerebral hemispheres, gaining intuitive support from the hemispheres' anatomical structure. Thus, hemispheric functioning has been described in terms of two different modes of processing, as, for example, analytic versus holistic (e.g. Gardner, 1974) or serial versus parallel processing (e.g. Cohen, 1973). Another approach to hemispheric differences has emphasized differences in the different types of information processed in each hemisphere, as, for example, verbal versus visuospatial information (e.g. Kimura, 1966). In a rather recent and very interesting approach Sergent (1982) claims that the hemispheres differ in their sensitivity to the spatial frequencies of visual percepts.

Some of the older functional dichotomies are controversial, however. They are not sufficient for explaining the great diversity of experimental results. Specifically, the level or stage at which functional differences emerge, and the stability of functional differences over different task situations, remained open questions.

Attempts to answer such questions gave rise to a number of new hypotheses that specify a precise functional level, i.e. the 'interface' between preattentive and attentional processes, at which hemispheric differences are believed to emerge (e.g. Kinsbourne, 1982, Moscovitch, 1979). Other models deal with situational variables believed to produce asymmetries that are superimposed on basic asymmetries in hemispheric function.

Above all, attentional factors were thought to be important (e.g. Kinsbourne, 1975, Hellige, Cox and Litvac, 1979, Friedman and Polson, 1981).

Evidence from clinical studies strongly suggests that functional differences between the hemispheres do exist; yet, despite a vast number of experimental findings and numerous models, they still seem to evade a comprehensive and yet parsimonious description.

The present study was undertaken in order to examine whether there are differences in hemispheric functioning which can consistently be described in terms of automatic and attentionally controlled processing. For the sake of simplicity, a hierarchical view of information processing is adopted. It is assumed that automatic processes occur prior to attentionally controlled processes, i.e. attention is thought to operate on evidence from the prior automatic stage. The hemispheres are believed to be similar in their automatic stage, independent of whether this stage involves only early sensory or also higher levels of information processing. However, the hemispheres are thought perhaps to differ in the way in which automatic and attentionally controlled processes interact. The interaction between the two modes of processing may be characterized by emphasizing any of the following relations between automatic and attentional levels:

1) attention may integrate - i.e. information from the automatic stage may be synthesized into higher order units.

2) attention may select - i.e. information from the automatic stage may either be rejected or selected for further processing.

3) attention may weight - i.e. weights varying in size and/or sign may be attached to evidence from the automatic stage

Differences between the hemispheres could conceivably take any of the above mentioned forms and it could prove difficult to decide conclusively where exactly they arise. The present study was designed to yield some information on each of these three possibilities.

Three different paradigms that deal with automatic and attentionally controlled processes were chosen. They all bear on the possible relation between the two processes, - integration, selection and weighting. These relations imply different definitions and functions for attentional processing. By using different paradigms rather than variants of a single one, it was hoped that converging or complementary evidence for hemispheric functioning would be found. The paradigm originally used by Shiffrin and Schneider (1977), however, which involves giving subjects memory loads and also extensive practice, was not chosen. It was felt that memory loads and practice could only complicate assumptions about processes occuring in either one or the other hemisphere.

1.1. Automatic and attentionally controlled processing: Evidence from three paradigms

1.1.1. Illusory conjunctions :

Quite recently a feature-integration theory of attention has been proposed (Treisman and Gelade, 1980, Treisman and Schmidt, 1982). It assigns focal attention and thus serial processing a central function in a defined stage of object perception. The theory distinguishes between an early parallel and a subsequent serial stage of processing in the perception of objects. During the early parallel stage, features on separable dimensions are registered (where ´dimension´ refers to the set of possible mutually exclusive states of a variable, e.g. the set of colors, and ´feature´ refers to a particular value on a dimension, e.g. red). Features within a single dimension may be partly organized within their own spatial map at this early, preattentive stage. However, they can only be integrated with features from other dimensions and formed into multidimensional objects by means of focal attention at a later, serial stage of processing.

It is important to note that this focal attention need not lead to conscious awareness. Perception and integration of features may both occur unconsciously.

One of the theory´s predictions, namely that if attention is overloaded or prevented, feature integration will be interfered with to the extent that illusory conjunctions of features may occur, has recently been verified in a number of experiments (Treisman and Schmidt, 1982). Two typical experimental paradigms contrast free report and search for objects defined by conjunctions of properties.

In this model attention operates on the outcomes of prior automatic processes to ensure the correct perception of objects whenever top-down constraints are insufficient.

Thus, conjunction errors, if they occur, are preattentive in the sense that attention has failed, and they provide a means to investigate the effects of a preattentive, parallel and an attentional, serial mode of processing at a defined functional level in object perception. More specifically, the characteristics of the integrative function of attention may be studied.

1.1.2. The priming paradigm :

In a typical priming task, the subject makes a judgement (usually a lexical decision) about a target stimulus (target), which is preceded by a cueing or priming stimulus (prime). Depending on the relationship between the two stimuli, subjects' responses to the target may be influenced by the cue. The nature of this relationship between target and cue may be investigated by varying the following three characteristics: The cue-validity (i.e. its predictive value), the temporal relation between target and cue (i.e.

the stimulus onset asynchrony (SOA)), and the type of association between target and cue, which can either be prior and habitual or novel and experimentally defined.
The effects of such variations have been studied by means of the cost/benefit analysis (Posner and Snyder, 1975). Typically, with short SOAs (< ca. 300 msec), prior and habitual associations between prime and target will lead to facilitation (benefit), independent of prime validity; with longer SOAs (> ca. 300 msec) this effect is reduced. Instead, in the case of high cue validity, novel experimentally defined associations may lead to facilitation (benefit), if subjects´ expectations are confirmed, or to interference (cost), if subjects´ expectations are not confirmed (Posner and Snyder, 1975, Neely, 1977).

Early facilitation effects are thought to be produced by ´inhibitionless spreading activation´ (Posner and Snyder, 1975), which takes place involuntarily and is not under subjects´ control. In the case that prime and target are words, for example, activation is thought to spread from the long-term memory node or logogen of the prime to those of semantically associated words, which include the target. These words are thus activated to a level closer to their threshold and need less information to reach it, which is reflected in faciliation for the lexical decision (Morton, 1969). Late facilitation and inhibition effects are thought to be produced by a ´slow limited-capacity conscious-attention mechanism´ (Posner and Snyder, 1975).

Typically, cue and target are presented successively and there is no positional uncertainty for either of them. Subjects always know when and where cue and target appear. Thus, only one kind of selection is involved: an internal target is selected by priming or expectancy. This may occur either automatically or voluntarily. There is another kind of selection, however, in which an external stimulus relevant to the response is selected (filtering). The priming paradigm may be modified to introduce such a target selection by presenting a target with a simultaneous distractor. The paradigm will then be interference dominant, since selecting the appropriate target is interfered with by an irrelevant nontarget. Priming in this case is characterized as a reduction of interference rather than a pure facilitation effect. Any nontarget will primarily cause interference, but a prime will do less so than an unrelated nontarget.

Thus, the priming paradigm can be used to study the following forms of selection: automatic selection of an internal target (automatic priming), attentional selection of an internal target (priming by expectancy) or attentional selection of an external target (filtering).

1.1.3. The Stroop-task :

In a Stroop-task, subjects have to make a judgement about one dimension of a multidimensional stimulus. Typically, the color of a word is used as the relevant or reported dimension and the identity of the word is used as the irrelevant or unreported dimension. Information from the unreported dimension may influence performance on the reported dimension. If the relationship between dimensions is consistent (e.g. the word 'RED' printed in red ink) facilitation results. An inconsistent relationship (e.g. the word 'RED' printed in green ink), however, will interfere with the judgement about the reported dimension.

Typically it had been thought that the processing of the unreported dimension was automatic in the sense of being strategy-invariant. Recently it has been shown, however, that the Stroop-task may also involve attentionally controlled, strategic processes (Logan and Zbrodoff, 1979, Logan, 1980). By varying the relative frequency of consistent (reported and unreported dimension specify the same meaning) and inconsistent trials (the two dimensions specify a different meaning), they were able to show that subjects may use a strategy of dividing their attention between the two dimensions. Their results indicate that when inconsistent trials are more frequent than consistent ones, subjects are able to strategically adjust to this situation: they are actually faster responding to inconsistent than to consistent trials. This is a reversal of the usual Stroop-effect and strong evidence against the notion of its pure automaticity. Subjects must be attending to the unreported dimension in order to show such a strategy effect.

Logan and Zbrodoff (1979) and Logan (1980) suggested that this effect can be described by a model of weighted decision making. In the two-choice situation of the simplest Stroop-task (the reported dimension has two possible alternative outcomes) evidence for one alternative is evidence against the other. Information about the unreported dimension may be viewed as shifting the initial state of evidence about the reported dimension toward one decision threshold or the other. The current state of evidence bearing on the decision is expressed as a weighted sum of the evidence available about the reported dimension and the evidence available about the unreported dimension (Logan and Zbrodoff, 1979).

In this framework, dividing attention between the two dimensions means that subjects attentionally assign weights to evidence available from each dimension. If the two dimensions are consistent, each of these attentional weights will have the same (i.e. a positive) sign. If the two dimensions are inconsistent, the weights will have opposite signs; the one attached to evidence from the reported dimension will be positive, the other one, which is assigned to the unreported dimension, will be negative. In addition, evidence from the unreported dimension may also be weighted automatically. Thus, if responses to inconsistent trials are found to be faster when inconsistent trials are more frequent than consistent ones, the weight assigned attentionally to the unreported dimension must be larger than the automatic weight in order to overcome habitual response tendencies, but it must remain small enough that it does not produce a response without some information from the reported dimension.

Automatic weights are assumed to be constant in sign and magnitude, whereas attentional weights may vary in sign and magnitude reflecting the current strategy that allows for optimal performance. The effects of attentional and automatic weights are assumed to combine additively (Logan and Zbrodoff, 1979, Logan, 1980).

In the Stroop-task, then, when consistent and inconsistent trials are equally frequent, processing may be automatic in the sense of being strategy-invariant. In addition, when the relative frequency of consistent and inconsistent trials is varied, attentional effects reflecting strategic control may be involved. Thus, the paradigm allows one to investigate automatic (strategy-invariant) and attentionally controlled effects under divided attention. In particular, effects of attentional (strategic) control can be described in terms of weights attached to evidence from automatic processes.

1.1.4. Converging results?

In the present study, illusory conjunctions were expected to shed light on early perceptual operations occuring in the absence of focal attention. Conjunction errors were not used to investigate the integrative function of attention, however. The priming paradigm was used to investigate automatic priming as well as selective attention (filtering).
Finally, the Stroop-paradigm was used to examine automatic, strategy-invariant processes on the one hand, and effects of attentional or strategic control on the other hand.

The three paradigms implicate three different definitions of attention that may in turn implicate different levels in information processing at which automatic and attentional processes interact. Illusory conjunctions would certainly reflect a failure of attention at a very early stage in perception. Interference and facilitation found in a Stroop-task are believed to arise rather late in the processing sequence when response selection takes place. However, the attentional and automatic processing of the unreported dimension may occur at an earlier level.
Priming effects in a lexical decision presumably occur at a lexical or semantic level of word recognition. Interference effects of selective attention, however, are more difficult to locate. If selection of the target is based on very simple physical properties of the stimuli, it may occur very early in processing. It is not known, however, what kind of a

selection strategy subjects will actually use. They may choose to divide their attention between the stimuli, in which case selection would only take place at a later stage in processing. Thus, the locus of interference due to selective attention is difficult to determine in this paradigm.
As to the three different aspects of interaction between automatic and attentionally controlled processes, the present study investigated only two of them: selection and weighting.

To summarize, the three paradigms should yield evidence about automatic processes at different levels in information processing and should emphasize different characteristics of the relation between the two processes.

1.2. Hemispheric Processing: Functional and Capacity Models

1.2.1. Functional dichotomies

A crucial role for language had long been claimed for the left hemisphere (LH) by Broca and Wernicke. It was not until fairly recently, that the right hemisphere (RH) was also credited with the capability to process linguistic material. Kimura (1966) still characterized the LH and RH as exclusively specialized for verbal and spatial processing, respectively. Supportive evidence for this dichotomy came from a vast number of studies, showing, for example, a RVF(LH) superiority for word recognition (e.g. Ellis, 1974, Hines, 1976), and a RH superiority for shapes or faces (e.g. Rizzolati et. al., 1971).

Clinical studies on neurosurgical patients demonstrated, however, that the RH is quite capable of comprehending words, although it is mute and has no access to speech production. Only recently Zaidel (1978a), employing novel techniques that permit prolonged unilateral stimulation, showed that while the RH has no speech, it has some writing, substantial visual vocabularies and surprisingly rich auditory lexicons. The RH seems to have very little syntax, however. He suggested, that the semantic structure of the RH vocabulary is more diffuse and connotative than in the LH. Since his subjects are split-brain or hemispherectomized patients, they may actually display more sophisticated language functions in the RH than would be found in the intact brain. It is clear, however, that describing the RH as nonverbal and the LH as verbal is an oversimplification.

In an attempt to link this verbal/visuospatial distinction to a more general theory of information processing, Cohen (1973) proposed a serial versus parallel distinction. These two modes of processing had been suggested to be basic to all information processing. Since verbally mediated matching had been found to be generally serial, whereas parallel processing is usually confined to matching on the basis of physical characteristics (Beller, 1970), Cohen chose a matching task with both verbal and nonverbal stimuli. She examined reaction times to judge a set of items 'same' (all identical) or 'different' (one item differing from the rest). She found that if the stimuli were linguistic (i.e. letters), increasing their number produced an increase in reaction time in the LH, as in serial processing, but not in the RH, as in parallel processing. When the items were unnameable shapes, however, both hemispheres seemed to process in parallel. Thus, she suggested that linguistic material may be analyzed either verbally or visuospatially and she proposed that the LH employs a serial, verbal mode of processing, whereas the RH employs a parallel, visuospatial mode of processing.

Even if restricted to matching tasks with verbal material, the results could not be consistently replicated (e.g. White and White, 1975). In addition, there is evidence that the RH might be specialized for perceiving faces (e.g. Rizzolati et.

al., 1971) and memorizing melodies (Milner, 1962), both of which it does in a serial manner. Thus, the serial/parallel distinction did not prove to be a very useful one.

In a recent and very interesting model, Sergent (1982) suggests that a verbal/nonverbal distinction does not grasp an aspect of visual information that is essential for information processing in the hemispheres. Instead, she proposes that a more basic dichotomy emerges from the fact that verbal stimuli (i.e. letters) represent a finite set of highly familiar, overlearned and precisely structured stimuli. 'Visuospatial' material, however, as used in some laterality studies, represents a potentially infinite and unfamiliar set of stimuli. Consequently, given brief exposure and lateral viewing conditions, verbal and nonverbal stimuli may differ as to how completely or accurately they can be encoded, and they may not achieve a qualitatively similar visual representation. Sergent (1982) proposes that the RH is more efficient at processing early-available low-spatial-frequency contents, whereas the LH is better at dealing with later-available high frequency contents of a visual image. Her model leads to intruigingly plausible explanations for a variety of previously puzzling findings: For example, that very brief exposure durations or stimulus degradation, which will prevent higher frequencies from becoming accessible, will typically produce a RH advantage; or that familiarity of a stimulus will lead to a LH advantage, by allowing for more refined and detailed analysis of higher spatial frequencies. She even speculates on the gradual ontogenetic development of a LH dominance: the more detailed visual processing of increasingly familiar material becomes, the more it will tend to be lateralized in the LH.

One problem in demonstrating hemispheric specialization is to distinguish genuine cerebral asymmetries from other factors that may contribute to visual field asymmetries.. Reading order is one obvious candidate. Schwartz and Kirsner (1982) showed that attentional effects may also play a crucial role. They were able to produce left/right visual field asymmetries by varying stimulus probability, and they showed that the same asymmetries could be observed in vertically defined visual fields (i.e. above and below the fixation). They conclude that it may often be unnecessary to invoke differential hemispheric specialization in order to account for visual field differences.

Some of the dichotomies could also not be integrated into more general theories of perception and cognition. It remains unclear to what extent alternative modes of processing are lateralized and at what level or stage in processing they occur. For example, if the RH processes more in parallel and the LH more serially, is this true for both preattentive and attentional processes? Does attentional processing which general cognitive theories typically claim to be serial, occur in parallel in the RH, or not exist? Such questions can not be answered by these dichotomies of hemispheric functioning.

1.2.2. Capacity models:

The oldest and most simple model states that wherever information has direct access to the hemisphere specialized for processing it, superior and/or faster processing will result. It quickly became evident, however, that this model could not account for the observed variability in laterality effects. More dynamic attentional models had to be developed in order to account for fluctuations in asymmetry.

One such approach is the selective activation hypothesis by Kinsbourne (1975). He claims that the involvement of a hemisphere in a task will result in a maximum of attention being directed to the contralateral visual field. Any stimulus presented contralaterally to the more activated hemisphere should thus be processed more efficiently than a comparable stimulus presented ipsilaterally. This effect will be independent of, or rather will overwhelm small asymmetries due to hemispheric specialization.

The model was subsequently revised, since it could not account for the interference frequently found in dual tasks. Interference effects are now incorporated into the revised model of functional cerebral distance (Kinsbourne and Hicks, 1978), in which facilitation effects are conceived of as one of two possible predictions. However, as long as the theory can not predict in advance which effect, facilitation or interference, should occur in any given task, it will retain a certain post hoc quality.

Another example of research showing attentional factors to be of importance was proposed by Hellige, Cox and Litvac (1979). Using tasks with a concurrent memory load of two to six words, they found that the memory load shifted a left visual field (LVF(RH)) superiority for a memory match of polygons to a right visual field (RVF(LH)) advantage. The same load shifted a RVF(LH) superiority to the LVF(RH) for letter-name matching. As neither the direct access nor the functional cerebral distance model can explain these effects, Hellige,Cox and Litvac (1979) suggested that the two hemispheres function as separate information processing systems to a certain degree, but that they cooperate to maximize processing efficiency. Thus, if the LH is more activated than the RH by a verbal memory load, it may be more efficient at visuospatial processing than the RH. If however, the LH is overloaded by a verbal task concurrent with a verbal memory load, the RH may be more efficient at performing the verbal task. According to their view, hemispheric activation and hemisphere-of-presentation interact to determine the observed laterality pattern.

The last model to be introduced here is the multiple-resources model proposed by Friedman and Polson (1981). They suggest, that the two hemispheres comprise a system of two mutually inaccessible and finite pools of resource supplies. Furthermore, they claim that these two pools of resources cannot be made available in differing amounts. If one hemisphere is activated by a task, the same amount of resources is available in both hemispheres. Thus, if two concurrent tasks draw on resources from only one hemisphere, they are likely to interfere with each other; if each of them draws on resources from a different hemisphere, both tasks will be facilitated. This model makes assumptions as to how lateralized a given task is (i.e. what resources it will draw on) and when it will reach its capacity limits. These assumptions can, in some tasks, plausibly be made in more than one way. Thus, the model does not always make clear predictions.

Summarizing, it seems that in an effort to accommodate complex patterns of visual field asymmetries, more and more complicated models were developed. Unforunately, they have to rely on functional dichotomies in order to predict or explain attentional demands a given task will make on one or the other hemisphere. Such assumptions about hemispheric functional specialization and lateralized task performance are controversial in themselves, however. Thus, these models have to be used very cautiously. It is probably best to apply them only to well established lateralized functions, like, for example, language.

1.2.3. Functional Loci:

This section introduces two hypotheses that specify a precise functional level at which hemispheric differences start to emerge.

Kinsbourne (1982) looks at hemispheric specialization from an evolutionary point of view and claims that only processes pertaining to focal attention are lateralized, whereas all preattentive processes are represented bilaterally. He proposes that under focal attention two processes proceed in parallel in the two hemispheres: a serial feature extraction in the LH, and a concurrent registering of feature locations on a centrally represented feature map in the RH.

The transmitted-lateralization hypothesis proposed by Moscovitch (1979) and Moscovitch and Klein (1980) also holds that an early sensory and preattentional stage of information processing is common to both hemispheres and that differences between them only occur at the level of a central processor beyond the initial feature extraction. Within his framework, the LH concentrates primarily on functional and nominal aspects of the input, whereas the RH processes and encodes information on the basis of appearance.

II. EXPERIMENT 1: Conjunction errors

In this experiment early, automatic and preattentional processes were investigated. From both Kinsbourne's (1982) and Moscovitch's (1979) theories one would predict that there should not be any hemispheric differences in the number of conjunction errors, since these errors are assumed to be preattentional. In terms of the serial/parallel distinction, one would expect the more serial hemisphere, i.e. the LH, to produce more conjunction errors when attention is overloaded and the serial integration of features impaired.

Experiment 1a:

In a first experiment (1a) colored letters were used as stimuli, with color and shape representing the two dimensions of each stimulus. A detection task with free verbal report was used. Since neither reaction times nor accuracy were analyzed and since conjunction errors are believed not to depend on verbal coding (Treisman and Schmidt, 1982), the verbal report was not thought to introduce a confound with any hemispheric differences.

Method :

Subjects: 13 female and 17 male students from UBC served as subjects. Each was paid $4.00 for a 1-hour session. All subjects were righthanded as asessed by a laterality questionnaire developed by Coren et al. (1979).

Apparatus and stimuli: The stimuli consisted of a vertical line of three colored uppercase letters; they were chosen from a set of five possible letters: I,N,O,S and X, and from a set of five possible colors: yellow,green,pink,blue, and brown. Each letter subtended a visual angle of 1.10x1.38 deg. The whole configuration subtended a visual angle of 1.10x5.09 deg. By mistake, the letters were moved out too far from the center, and the closest edge appeared 4.82 deg of visual angle to the right or left of the center. In the center, two black digits,1,6,8 or 9, were presented. Each digit subtended a visual angle of 0.69x1.10 deg and one of them was positioned 0.82 deg of visual angle above, the other one at the same distance below the center. Each color and letter appeared equally often in each position. Each of the different color-letter combinations appeared between 3 and 5 times in each position.

30 cards were made. The stimuli were drawn by hand, using colored inks and stencils on white cards. A black and white noise mask, consisting of equal numbers of randomly arranged black or white 2-mm squares, and subtending the whole visual field was used. It had a black fixation dot in the center.

Procedure: Alternating which way up, the set of 30 cards was shown four times to each subject. The order of cards was randomized for each block and each subject. Examples of the stimulus cards with all possible colors, lettershapes and digits were shown to each subject before the experimental trials started. Subjects were instructed to report the two central digits first and subsequently as many of the colors, shapes and their positions as they could remember. They were told to be as accurate as possible on the numbers. They were asked only to report colors and shapes if they were sure they had seen them, or else to indicate, if they reported something they were uncertain about, and this was noted by the experimenter.

The stimulus cards were presented in a Cambridge two-field tachistoscope. The experimenter gave a verbal 'ready' signal and initiated a trial by pressing a button. Subjects first fixated on a black dot in the center of the noise mask, which also apeared again immediately after each trial. The exposure duration for the stimulus cards was initially set at 300 msec for each subject. Since they had to have their eyes focused on the center for the digit naming task, 300 msec seemed short enough to prevent eyemovements. Exposure duration was then adjusted for each subject according to the following rule: if a feature error (reporting a color or a shape that was not on the card), or if less than one color and one shape was reported on two consecutive trials, exposure duration was increased by one step, but only to a maximum of 300 msec; if at least one color and one shape were reported on 7 successive trials, exposure duration was reduced by one step. For the first 20 subjects the steps were 300,200,150,130,115,100,90 and 80 msec. For the last 10 subjects a new timer was introduced in the hope of reducing the error rate. The following smaller steps could then be used: 20 msec steps down to an exposure duration of 150 msec, and then the same steps as for the first 20 subjects mentioned above.

If subjects made a mistake on the digits, that trial was discarded and rerun at least 5 trials later. All subjects were given 10 practice trials. On these trials feedback was given for feature errors. After the practice trials no feedback was provided.

Results :

The following types of responses were of interest: conjunction errors (two correct features wrongly recombined from two different items) and feature errors (an incorrect feature either conjoined with a correct or an incorrect feature). Neither overall nor for the separate visual fields were there significantly more conjunction than feature errors. From the total of 30 subjects, nine showed more feature than conjunction errors. The mean number per trial of feature and conjunction errors are shown in Table I, along with other types of responses. Conjunction errors are certainly not meaningful if they occur less frequently than feature errors.

They may just represent feature errors for which the misperceived color or shape happened to be among those on the card rather than among those not presented.

Only four subjects had a substantial excess of conjunction over feature errors. One of them showed no asymmetry in this measure, one had a bigger excess of conjunction over feature errors in the LVF(RH) and the other two in the RVF(LH). The main question of interest, whether conjunction errors would be more likely to occur in one visual field than the other, could thus not be answered conclusively. However, the results suggest that there are no hemispheric differences in this measure.

Table I: Mean number per trial of different types of responses for all subjects (n=30) in both visual fields.

	LVF(RH)	RVF(LH)
Items correct	1.61	1.67
Single features correct	.59	.62
Feature errors	.11	.11
Single feature wrong	.04	.03
Conjunction errors	.17	.17
Conjunction minus feature errors	.06	.06

Experiment 1b:

In this experiment objects defined by different components of shape were chosen. Subjects performed a search task with dollarsigns as target stimuli was chosen. The targets were in a background of arrows and ´S´-signs, from which an illusory dollarsign could be formed. In this task a simple ´yes-no´ response was required.

Method :

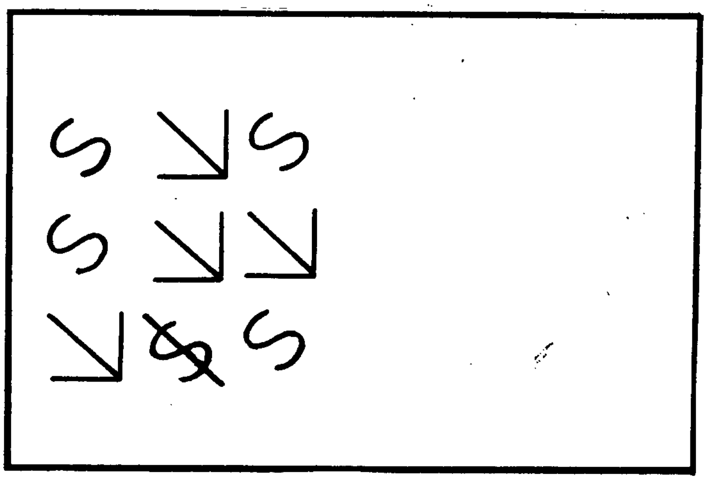
Subjects: 4 female and 6 male students from UBC volunteered to serve as subjects. All of them were right-handed as asessed by a questionnaire on behavioral lateral preference designed by Coren et al.(1979).

Apparatus and stimuli: The stimuli were tilted ´S´- and ´$´-signs and arrows (see Figure 1). There were 9 stimulus items on each card, arranged at equal distances from each other in a square of 5.03x5.03 deg of visual angle. The arrows and ´$´- signs subtended a visual angle of 1.36x1.36 each, the plain ´S´-signs were slightly smaller, subtending a visual angle of 1.09x1.09 deg each. The closest edge of any item was 2.05 deg of visual angle to the right or left of the center. 64 cards were made.

The stimuli were drawn by hand using red ink and stencils. 32

of the cards had the stimuli in the RVF, the other 32 had them in the LVF. On 16 of the cards from each visual field the stimuli were tilted 45 deg to the right, with the arrows pointing to the upper right-hand corner; on the remaining 16 cards the stimuli were tilted 45 deg to the left, with the arrows pointing to the upper left-hand corner. 12 cards showed 9 arrows, and 12 cards showed 9 ´S´-signs. 24 cards showed 4 arrows and 5 ´S´-signs in what appeared to be random positions. Thus, on these cards the slash in the arrow and the ´S´-sign could be combined to form an illusory ´$´-sign. On 16 cards there was a ´$´-sign: 8 of them showed 4 ´S´-signs, 4 arrows and a ´$´-sign in what appeared to be random arrangements, the ´$´-sign being in a different position on each card. 4 cards showed 8 ´S´-signs and a ´$´-sign and the remaining four cards showed 8 arrows and a ´$´-sign. Again, the ´$´-signs were in different positions on each card. A black and white noise mask, consisting of equal numbers of black and white 2-mm squares and subtending the whole visual field, was used. It had a black fixation dot in the center.

Figure 1: Example of a stimulus display with tilted 'S'- and $-signs and arrows.



Procedure: Alternating which way up, the set of 64 cards was shown four times to each subject. The order of cards was randomized for each block and each subject. Examples of all types of stimulus cards were shown to subjects and each subject was given 10 practice trials before the experimental trials started. Subjects were instructed to look for the '$'-signs and say 'yes' if they saw one or otherwise say 'no'. They were told to indicate if they were uncertain about a response they were giving, and this was noted by the experimenter. On the practice trials, subjects were told whether their response was correct or not. On the experimental trials no feedback was provided. The cards were shown in a two-field Cambridge tachistoscope. The experimenter gave a verbal 'ready' signal and initiated a trial by pressing a button. Subjects first fixated on a black dot in the center of the noise mask, which also appeared again immediately after each trial. Exposure duration was initially set at 80 msec. If subjects were uncertain with most of their answers, exposure duration was increased to 100 msec and then, if possible, reduced to 80 msec again after one block.

Results :

The doubtful category was used on 31% of the trials. It seems that the subjects were thus not all that sure about what they had seen. Conjunction errors in the present experiment were defined as reporting a ´$´-sign from a display of arrows and ´S´-signs. Feature errors were defined as reporting a ´$´-sign when either only arrows or only ´S´-signs were presented. All subjects made more conjunction than feature errors in the present task.

A 2-way ANOVA (Sex x Visual field) was done on C-F erors. The overall mean for conjunction minus feature errors (C-F) was the same for both visual fields (see Table II) and the main effect for visual field was clearly not significant ($F(1,8)<1$). Neither was there a significant interaction ($F(1,8) = 1.422$, $p>.10$). Females had more C-F errors overall than males (see Table II). The trend of the main effect for sex reflected this fact ($F(1,8)= 3.791$, $p<.10$).

In this experiment, then, there were clearly no differences between the visual fields. The only trend found was that females tended to have more C-F errors than males.

Table II: Mean number per trial of different types of responses for both visual fields. F = females, M = males.

		LVF(RH)	RVF(LH)
Correct targets	F	.82	.83
	M	.86	.85
Feature errors	F	.03	.02
	M	.03	.03
Conjunction errors	F	.15	.15
	M	.11	.10
Conjunction minus feature errors	F	.12	.13
	M	.08	.07

Discussion :

In the present search task, no visual field differences were found for conjunction minus feature errors. A trend was found indicating that females tend to show more conjunction errors than males. There were clearly not enough subjects of either sex, however, to be sure that this is not a random effect.

The results from both illusory conjunction experiments are taken as evidence that there are no differences between visual fields on the measure of conjunction errors.

In terms of the serial/parallel distinction it had been hypothesized that the LH should show more conjunction errors than the RH. This was not the case, however. Rather, the above experiments lend support to the transmitted-lateralization hypothesis (Moscovitch, 1979) and to the hypothesis proposed by Kinsbourne (1982), which claim that early sensory and preattentional processes are represented bilaterally. Conjunction errors supposedly occur at a very early, perceptual level prior to object and event identification (Treisman and Schmidt, 1982), and it seems that at this level there exist no hemispheric differences.

This conclusion means accepting the null hypothesis, however, and should have some further experimental support.

Even though conjunction errors are not believed to depend on verbal report, the results should be confirmed in an experiment using, for example, a matching task and a manual response. Subjects could then be assigned two keys to each hand which would preserve task-hemispheric integrity (Wickens, Mountford and Schreiner, 1981).

The results should further be corroborated by using tasks with different features or different dimensions to specify the multidimensional objects. For example, geometric shapes (circles, squares etc.) instead of letters would eliminate the possibility of a confound with ´verbal´ stimuli. As additional dimensions size or solidity (Treisman and Schmidt, 1982) could be used. Since the RH is often viewed as the hemisphere more concerned with spatial relations than the LH (e.g. Kinsbourne, 1982, Moscovitch, 1979), a conjunction experiment involving shapes of different sizes would yield evidence as to whether the RH would be less likely than the LH to switch the ´size-features´.

The feature-integration theory of attention (Treisman and Schmidt, 1982) also allows for top-down constraints on conjunction formation. So far these have not been experimentally demonstrated. If such constraints can be shown to exist, however, it would be interesting to show that early perceptual stages are similar in the two hemispheres not only without top-down constraints, but also under the general constraints of the perception of the everyday environment.

To summarize the two experiments, it was found that the hemispheres do not differ in an early, automatic and preattentional stage of perception.

III. EXPERIMENT 2: A priming task

In this experiment it was investigated whether the finding from experiment 1 that there are no hemispheric differences in an early preattentional stage would extend to automatic processes occuring later on in information processing. In addition, effects of attentional selection were introduced. The experiment used a lexical decision task, with a target word or nonword in lowercase letters presented in either the right or left visual field. On some trials a neutral or a semantically associated word in uppercase was shown simultaneously with the target. Thus, the two possible kinds of selection could be investigated. Neutral words were expected to interfere with the selection of the target (filtering). This interference effect could be determined by comparing the target plus neutral word to a single target condition. Primewords were expected to reduce some of this interference (automatic priming). The target plus prime condition was thus expected to show facilitation when compared to the target plus neutral word condition.
The spatial arrangements were such that target and nontarget could be presented in the same (LH-S and RH-S) or in opposite (LH-O and RH-O) hemispheres. Thus, interference and priming effects produced by ipsi- or contralateral nontargets could be compared.

For ipsilateral arrangements (see Figure 2) the serial/parallel distinction (Cohen, 1973) applies. One might expect the RH to be able to process the two simultaneous words in parallel, whereas the LH might process them serially and select only the target. Thus, for ipsilateral arrangements, the LH could initially, at the perceptual stage, be expected to show more interference than the RH, since it has to select the target from the two presented stimuli.

The amount of interference should depend on how simple a physical property the decision can be based on. Since the target was written in lowercase and the nontarget in uppercase letters, the resulting difference in size between the words provided quite a salient physical cue. Thus, these early interference effects in the LH need not be substantial.

At a later stage of response selection, the RH can be expected to show more interference than the LH. If it has processed the two words in parallel, it then has to select one of two processed words for a response. Late selection (as in the RH) is assumed to cause more interference than early selection (as in the LH).

For the same reasons, namely that the prime is processed to a higher degree in the RH, this hemisphere should also show more priming than the LH, which might not process the prime at all or only after having processed the target.

Capacity models lead to different predictions for these ipsilateral arrangements. From a direct access approach, which implies that all words are transferred to the LH for processing, two predictions could be made: if cross-callosal transfer of two words is less efficient than transfer of just one word, then the RH should show more interference and less priming than the LH. If, however, cross-callosal transfer for two words is as efficient as for a single word, both hemispheres should show equal amounts of interference and priming. The multiple resources model (Friedman and Polson, 1981) would imply equal amounts of interference and priming in both hemispheres, if there are no capacity limits to this task. If the task does reach capacity limits, however, it would do so first in the less language specialized RH. The RH should then show more interference and less priming.

For ipsilateral arrangements, then, more interference in the RH than in the LH can be accomodated by all of the above models. Two of them, the direct access approach and the multiple resources model (Friedman and Polson, 1981), can also explain equal amounts of interference in both hemispheres. For priming effects the models lead to contradictory predictions (see Figure 2).

For contralateral arrangements (see Figure 2) the cooperation of the hemispheres comes into play as a new variable. One can expect the LH to display a general dominance over the RH and to show a certain degree of control over response selection. Zaidel (1978b), for example, has suggested that the LH may be dominant in response selection even for tasks it is not specialized for. He showed that more interference arises if a target stimulus is presented to the RH and a response selected by the LH than vice versa, which indicates a kind of 'non-cooperativity' of the LH.

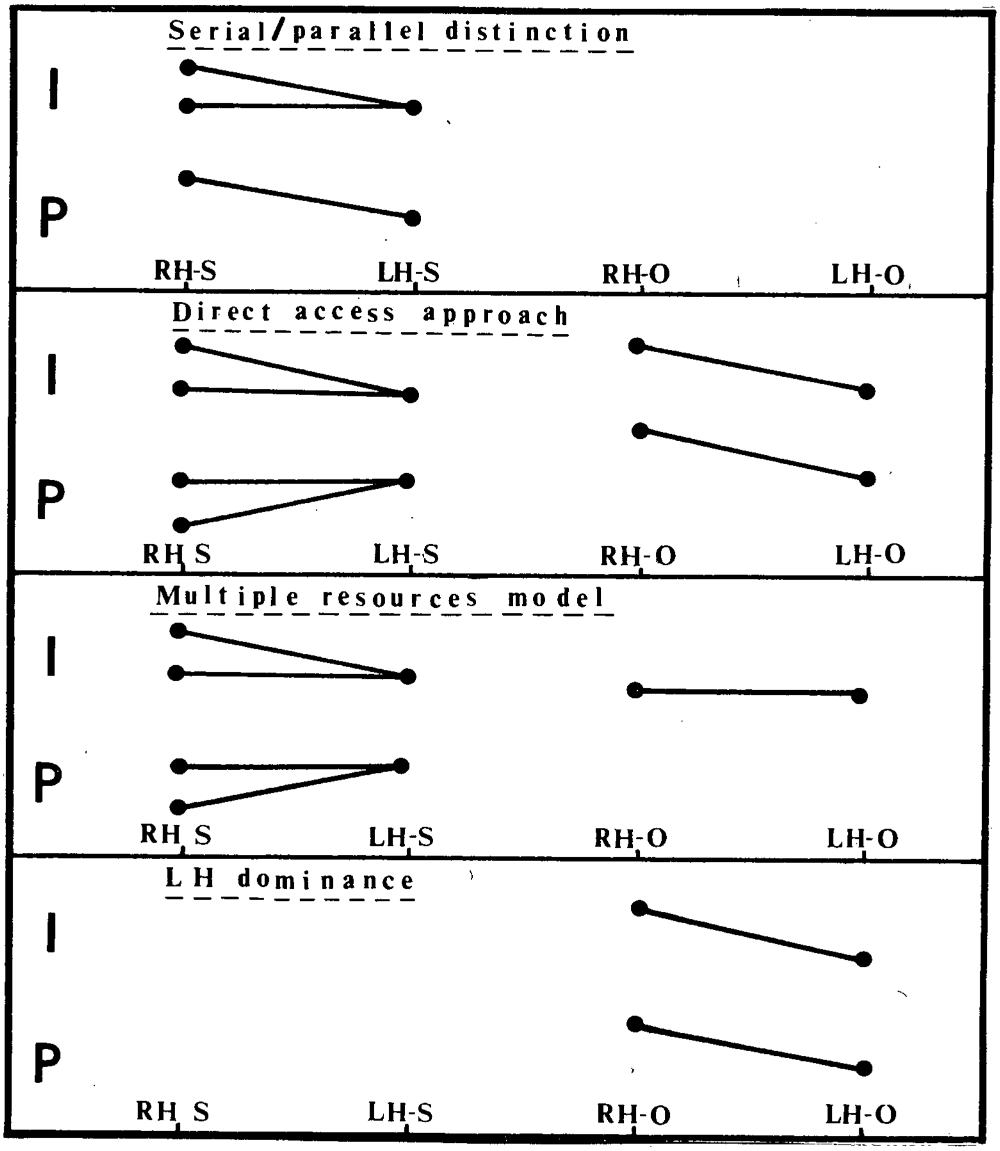
Another phenomenon that may be interpreted along the same line is the left-side neglect syndrome resulting from RH damage. The LH tends to attend to stimuli on the right side only and ignore the left side. The reverse is true much less frequently for the RH (Heilman and Watson, 1977), however, since the RH monitors whether the LH has received information or not (Geschwind, 1981).

Dominance of the LH should be particularly pronounced in a verbal task that the LH is more specialized for. Thus, in the present experiment, interference and priming should be high for the RH-O arrangement, since the RH monitors information in the LH. In the LH-O arrangement, however, little interference and priming should be found, since the LH will tend to ignore any information in the RH.

The direct access approach also applies for the contralateral arrangements. According to this model, a target in the LH is little affected by a nontarget in the RH (LH-O), since the nontarget, being transferred from the RH, will reach the LH after the target. For the opposite arrangement (RH-O), however, substantial interference and priming should be found, since the nontarget has direct access to the LH and is processed prior to the target. The multiple resources model (Friedman and Polson, 1981) implies that the same amount of resources required to process the target in one hemisphere is also available in the opposite hemisphere. Thus, processing of the nontarget should not draw resources away from the target. Less interference is then expected in these contralateral arrangements than in the ipsilateral arrangements.

The serial/parallel distinction does not make any predictions for these contralateral arrangements.

Figure 2: Predictions for priming and interference effects derived from different hemispheric models. LH = target to LH, RH = target to RH, S = nontarget to the same, O = nontarget to the opposite hemisphere than target, I = interference effects, P = priming effects.



Method:

Subjects: 15 female and 15 male students from UBC volunteered to take part in the experiment. They were all right-handed, as assessed by a questionnaire (Coren et. al., 1979) and they were paid $ 4.00 for a 1-hour session.

Apparatus and stimuli: The stimuli were words, nonwords (scrambled letters) or blanks. On each trial, a target that could either be a word (T) or a nonword (t) was shown simultaneously with a prime (P) (semantically associated word), a neutral (N) (semantically not associated) word or a blank (Bl). Thus, there were the following 5 conditions that all appeared equally often: T+P, T+N, T+Bl, t+N and t+Bl. All targets were written in lowercase and all nontargets in uppercase letters.

There were four spatial positions on the screen: Top right, top left, bottom right and bottom left. Excluding diagonal placement, all stimuli could appear in all spatial positions. Ignoring differences between top and bottom rows, which were counterbalanced, 8 different possible spatial arrangements resulted for each condition. The target could be presented to the RH or the LH and the cue to the same (S) or opposite (O) hemisphere. This yielded the following arrangements of interest: RH-S, LH-S, RH-O and LH-O.

Target and prime words were taken from 'An atlas of normative free association data' by Shapiro and Palermo (1968). Their primary responses were chosen as target words, whereas their target stimuli were taken as prime words. Keeping word frequency and associative strength as high as possible, 320 word pairs were chosen. Each word was between 3 and 7 letters long. The nonwords were made by randomly scrambling all the letters of each target word except the first one. Thus, the nonwords were easy to distinguish from the words, but the first letters did not carry any information. One neutral non-associated word for each target word was selected from the same pool of words, approximately matched in length and frequency.

Each letter subtended a visual angle of about 0.71 x 1.33 deg. A 7-letter word subtended a visual angle of 6.95 x 1.33 deg. Since the task was very difficult to do, the stimuli were moved in as close as possible to the center. Thus, the closest edge of any word appeared 1.78 deg of visual angle from the central fixation point. This was considered peripheral enough since the first letter of each stimulus was not especially crucial and the second letter was already 2.82 deg of visual angle from the center. The centers of the words on top and on the bottom were 3.33 deg of visual angle apart. A pattern mask, made up of letter fragments, appeared in all four spatial positions and subtended a visual angle of four times 7.07 x 1.78 deg.

Subjects had four response keys, two for the right hand and stimuli in the RVF, and two for the left hand and stimuli in the LVF. This arrangement maintains what Wickens, Mountford and Schreiner (1981) have termed 'task hemisphere integrity',

i.e. processing and response occur in the same hemisphere.
The displays were shown on a VT-11 graphic display processor, under the control of a PDP-11/34 computer (Digital equipment corporation). The stimuli were white on a dark background. A head-rest was used to ensure a constant viewing distance of 64 cm.

Procedure: The 320 stimulus sets of 5 items each (T, t, N, P and Bl) were always presented in the same order. For each trial a target and one of the other three items (i.e. one of the 5 conditions) were chosen. The condition selected varied in each block and for each subject. Each subject had six blocks with 320 trials each. Each condition appeared equally often in each of the 8 spatial arrangements. Within the above constraints, conditions and spatial arrangements were completely randomized for each subject and each block.
Before each block, the message 'Press any key when ready' was shown and subjects started the trials themselves. Subjects were instructed to do a lexical decision task on the lowercase words. Accuracy was emphasized rather than speed, and error rates were the dependent variable. All subjects used the inside key of each hand to indicate words and the outside key to indicate nonwords. Each trial started with a central fixation dot for 900 msecs, followed by the stimuli for 250 msecs. Immediately afterwards the pattern mask appeared in all four spatial positions. It went off again as soon as the subjects gave a response and the next trial began.

Results:

The overall error rate in the double word conditions was 32%, with a range of 17 - 39%. Subjects with an error rate higher than 40% were discarded, since an error rate of 50% reflected chance responding.

The percent correct and percent false positives errors were used to calculate d´s in each of the three target word conditions. These are given in Table III.

Interference produced by showing two compared to only a single word was calculated by subtracting the d´s of T+N from those of T+BL. Priming was calculated by subtracting the d´s of T+N from those of T+P. These differences are also shown in Table III.

A 2-way ANOVA (Sex x Visual field) was done for the single target word condition. Performance was superior for the RVF(LH) (mean d´: 1.72 for the LVF(RH) and 1.92 for the RVF(LH)), and the main effect for visual field was significant ($F(1,28) = 6.451$, $p<.02$). Seven females and 11 males were more accurate in the RVF(LH) than in the LVF(RH). The opposite was true for 8 females and 4 males. There was neither a main effect for sex nor an interaction (both $Fs(1,28) < 3$, $p>.10$).

The analyses for interference and priming in the double word conditions examined the effect of target position (RH-S, RH-O versus LH-S, LH-O), and the effect of prime position (RH-S, LH-S versus RH-S, LH-O). Sex was used as an additional factor.

Thus, a 3-way ANOVA (Sex x Target position x Prime position) yielded the following results (see Table III).

Interference effects: Showing a neutral word together with the target word caused more interference for the RH (RH-S and RH-O) than for the LH (LH-S and LH-O), and the main effect for target position was significant ($F(1,28) = 5.651$, $p<.05$). This effect was mainly due to high interference in the RH-O, and very low interference in the LH-O arrangement. The means for RH-S and LH-S were almost identical.

RH-O showed more interference than RH-S, whereas the reverse was true for the LH, and the interaction targetposition x primeposition was significant ($F(1,28) = 6.510$, $p<.05$). A Bonferroni t-test on the four means showed that three differences between means were significant: RH-O, RH-S and LH-S were higher than LH-O (all $ts(28) > 2.70$, $p<.01$).

There was neither a main effect for sex nor any interactions with sex (all $Fs(1,28) < 2$, $p>.10$).

Priming effects: There were no main effects or interactions for priming (all $Fs(1,28) < 3$, $p>.10$). t-tests showed that priming was highly significant in the RH-O and LH-O arrangements (both $ts(29) > 3.0$, $p<.005$), only just reached significance in the RH-S arrangement ($t(29) = 1.889$, $p<.05$) and was not significant in the LH-S arrangement ($t(29) = 1.657$, $p<.10$). Substantial priming was thus only found in the RH-O and LH-O arrangements.

Table III : The d´s for all three target word conditions as well as priming and interference effects in all spatial arrangements. RH = target to RH, LH = target to LH, S = nontarget on same side, O = nontarget on opposite side than target.

	RH-S	LH-S	RH-O	LH-O
Target plus prime	.96	1.18	.96	1.52
Target plus neutral word	.84	1.08	.76	1.32
Single target	1.72	1.92	1.72	1.92
Interference	.87	.83	.96	.60
Priming	.12	.10	.21	.20

Discussion:

Overall, a clear RVF(LH) superiority was found for the single target condition. This is consistent with results, for example, by Bradshaw and Gates (1978) and Day (1977). The finding that 8 females and 4 males (n=30) showed a LVF(RH) advantage is not surprising. In fact, Bradshaw and Gates (1978) concluded from a series of experiments that ´a RH verbal mechanism, which is more strongly developed in females than in males, is associated with lexical decisions, if both phonological and graphological criteria may apply´ (as is the case with non-pronouncable nonwords used in this experiment). Similarly, Day (1977) found that an overall RVF(LH) advantage was reversed for some female subjects.

So the results support the generally held beliefs that language is typically lateralized in the LH and that this lateralization is less pronounced in females than in males Ox(see McGlone, 1980).

The two effects investigated in the double word conditions were interference and priming. Interference effects were substantial and larger than the priming effects.
Generally, the following picture seems to emerge from the results. For ipsilateral arrangements interference and priming were the same for both hemispheres. Thus, target selection probably takes place at the same stage in both hemispheres. In addition, influence from the automatic stage on the subsequent attentionally controlled stage (the priming effect) is the same in both hemispheres. So the finding from experiment 1 (illusory conjunctions) that there are no hemispheric differences in early preattentional processes seems to extend to automatic processes involving higher levels of information processing.
For contralateral arrangements, it seems that the LH represents a processing system that is relatively independent of the RH. Interference is lowest with a nontarget in the RH. The LH is thus not interfered with much by verbal processing occuring in the RH. Since priming was found in the LH-O arrangement, however, there must be a transfer of lexical or semantic codes from the RH to the LH. This is an example of benefit without substantial cost, which according to Posner and Snyder (1975) characterizes automatic processing. The results suggest that target selection in the LH is based on information that was originally presented to that hemisphere.

If evidence from the RH happens to be consistent with the semantic information in the LH, it may produce facilitation; however, if evidence from the RH is unrelated to the information in the LH, it produces less filtering cost than in any other arrangment.
The RH on the other hand is influenced by a contralateral nontarget at least as much as by an ipsilateral nontarget. It seems that the RH can not process verbal information independently of any processing occuring in the LH. A nontarget in the LH seems to attract attention away from a RH target, and produce both cost when unrelated and benefit when associated. Thus, it seems that attention can be better focussed on verbal information presented to the LH and not be attracted away by verbal information in the RH. In other words, the RH appears to be able to give some automatic support to verbal processing in the LH, while the reverse seems more difficult.

With respect to the predictions derived from different models of hemispheric functioning, ipsilateral arrangements will again be discussed first. The predictions made for interference in the framework of the serial/parallel distinction were not precise. If one assumes that the amount of interference is similar for early target selection (as in the LH) or late target selection (as in the RH), one could accommodate the absence of lateral differences in interference. The predicted difference in priming (more priming in the RH than in the LH) was not found, however.

Thus, it is reasonable to conclude that the serial/parallel distinction is not supported by the results.

One of the possible predictions for ipsilateral nontargets derived from the multiple resources model (Friedman and Polson, 1981), i.e. equal amounts of priming and interference in both hemispheres, holds if one is willing to assume that there are no capacity limits to this task.

Corss-callosal transfer of information, as suggested by a direct access approach, could produce the ipsilateral interference results that were found if cross-callosal transfer of two words is assumed to be as efficient as for only a single word. Under the same assumption, this model is also compatible with the results found for priming.

The pattern of results in the contralateral arrangements was predicted from the direct access approach and from the notion of LH dominance. The multiple resources model (Friedman and Polson, 1981), however, was not supported. A contralateral arrangement only facilitated processing of the target (as compared to ipsilateral arrangements) in the LH.

Priming was the same for RH-O and LH-O. The fact that LH-O showed as much priming as RH-O is surprising and can not be accomodated by any of the models so far discussed.

Thus, except for priming effects found for the LH-O arrangement, the contralateral results support the direct access approach and the notion of LH dominance.

To conclude the discussion of hemispheric models, it seems that if cross-callosal transfer of two words is as efficient as for a single word, the direct access approach can accommodate all but one (priming in LH-O) of the effects found in the present experiment. The notion of LH dominance only applies to contralateral arrangements and is supported by the results. The multiple resources model (Friedman and Polson, 1981) in conjunction with an assumption about capacity limits was consistent with the ipsilateral results only. It can not accommodate the effects found in the contralateral arrangements. The serial/parallel distinction could not accomodate the results, however.

Summarizing, the results suggest that automatic processing is shared and common to both hemispheres. Any facilitative effects produced by automatic processes seem to be similar both within and across hemispheres. Lateral asymmetries arise, however, at an attentionally controlled stage of processing. The data show that interference effects arising from attentional selection are similar in both hemispheres for ipsilateral target and nontarget arrangements. In contralateral arrangements, however, the RH suffers much more interference than the LH. It seems that attention can be better focussed on verbal material in the LH than in the RH.

IV. EXPERIMENT 3: A Stroop task

This experiment was undertaken in order to further compare hemispheric differences in automatic and strategic effects.
The experiment involved three different conditions. In one condition consistent and inconsistent trials appeared equally often. This condition represented the typical situation for a Stroop-task. Thus, the unreported dimension yields inconsistent information about the reported dimension. Unless facilitation on consistent trials greatly outweighs interference on inconsistent trials or vice versa, the best strategy is to ignore the unreported dimension and selectively pay attention to the reported dimension only. The Stroop-effect found under such circumstances is considered to be an automatic and strategy-independent effect.
In two further conditions the relative frequency of consistent and inconsistent trials was varied. In these conditions subjects were expected to use a strategy of dividing their attention between the reported and the unreported dimensions. Thus, effects due to weights assigned to the unreported dimension were expected to be found.

Method:

Subjects: 12 female and 12 male student volunteers from UBC served as subjects. They were all right-handed as assessed by a questionnaire (Coren et al., 1979). They were paid $ 4.00 for a 1-hour session.

Apparatus and stimuli: The stimuli were the word ´ABOVE´ and the word ´BELOW´, written in capital letters and appearing either above or below a cross (a lowercase ´x´). The whole configuration (word plus cross) appeared either in the RVF or in the LVF, thus making four possible spatial positions for the word and two for the cross.

Each letter subtended a visual angle of .71x1.33 deg. The cross was slightly smaller and subtended a visual angle of .71x.88 deg. Each word subtended a visual angle of 4.87 deg horizontally and 1.33 deg vertically. The closest edge of any word appeared 2.66 deg of visual angle to the right or left of the center. The cross was 5.31 deg of visual angle to the right or left of a central fixation point and appeared 2.22 deg of visual angle above or below the middle letter of the words.

A pattern mask made up of letter fragments appeared in all four possible spatial positions and subtended a visual angle of four times 7.07x1.78 deg. The closest edge of the mask was 1.78 deg to the right or left and 2.66 deg of visual angle above or below the fixation point.

There were 6 blocks of 320 trials each. Each of 3 different conditions was run for two consecutive blocks. In condition 1 (50/50) 50% of the trials were consistent ('ABOVE' above and 'BELOW' below the cross) and 50% of the trials were inconsistent ('ABOVE' below and 'BELOW' above the cross). In condition 2 (80/20) 80% of the trials were consistent and 20% inconsistent. In condition 3 (20/80) 20% of the trials were consistent and 80% inconsistent. The two words and visual fields were completely balanced within subjects. Within the above constraints, the order of trials was randomized for each subject. The order of conditions was counterbalanced between subjects.

As in experiment 2, subjects had four response keys, two for the right hand and stimuli in the RVF and two for the left hand and stimuli in the LVF.

The stimuli were shown on a VT-11 graphic display processor, under the control of a PDP-11/34 computer (Digital equipment corporation). They were white on a dark background. A head-rest ensured a constant viewing distance of 64 cm.

Procedure: The subjects' task was to respond to the words' identity, independent of their spatial position. Half the subjects used the inside keys of each hand to indicate 'ABOVE' and the outside keys to indicate 'BELOW', the other half did the opposite. Before each two blocks, they were told which condition would be presented and it was stressed that they should try to avoid all errors. Before each block, the message 'Press any key when ready' appeared and subjects started the trials themselves. Each trial started with a central fixation dot for 900 msecs, followed by the word-cross configuration for 250 msecs. Immediately afterwards the pattern mask came on in all four spatial positions and stayed on for 1500 msecs or until the subject gave a response (whichever was longer), and then the next trial began. The first 20 trials of each condition were discarded as practice trials.

Results:

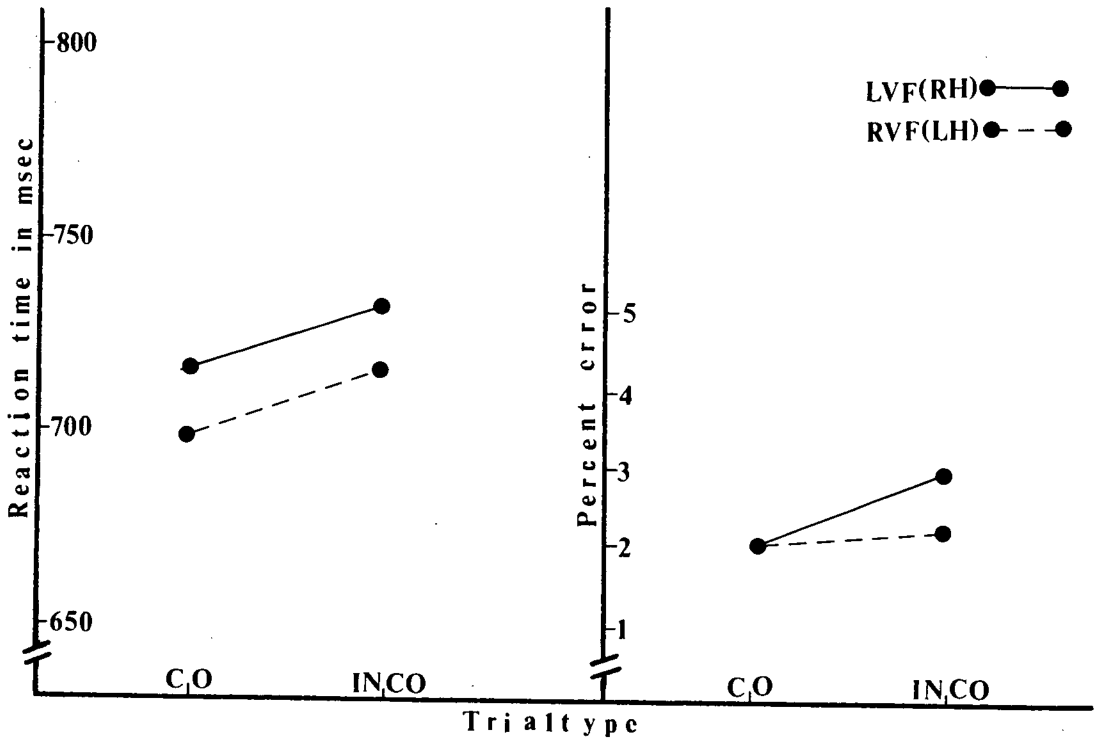
Condition 1 (50/50) was analyzed separately from conditions 2 (80/20) and 3 (20/80).

For condition 1 (50/50) a 3-way ANOVA (Sex x Visual field x Trialtype) was done on the reaction times (RTs) for correct responses (see Figure 3).

Subjects showed a Stroop-effect of 17 msec (inconsistent minus consistent trials) and the main effect for trialtype (Co/Inco) was highly significant ($F(1,22) = 9.868$, $p<.01$). The main effect for visual field was also significant ($F(1,22) = 4.690$, $p<.05$), reflecting the fact that overall RTs in the RVF(LH) were faster by 17 msec than those in the LVF(RH). There was no main effect for sex ($F(1,22)<1$) and no significant interactions (all $Fs(1,22)<2.7$, $p>.10$).

Since error rates were fairly high, the same analysis was also done on these (see Figure 3). All the means went in the same direction as the RTs, but there were no significant main effects or interactions. It is thus justified to say that there were no error trade-offs in condition 1 (50/50) and for this condition only the results for RTs will be discussed.

Figure 3: Mean reaction times (RTs) for correct responses and error rates for consistent (CO) and inconsistent (INCO) trials in condition 1 (50/50) for both visual fields.

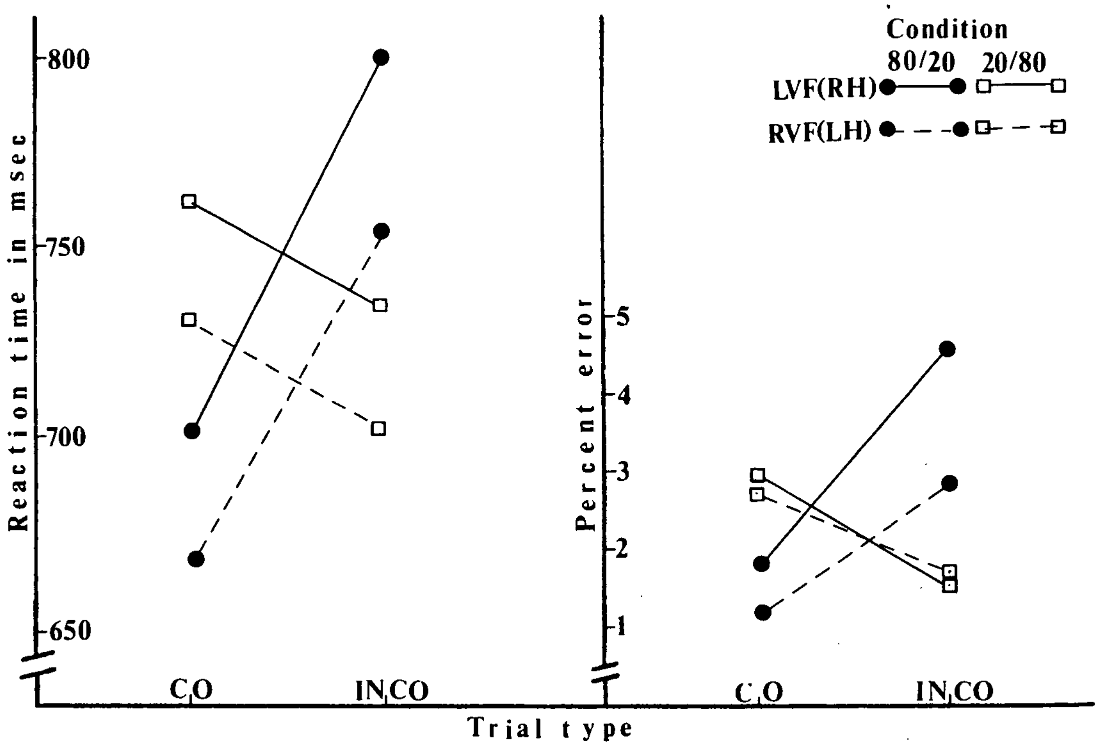


RTs for correct responses and error rates for the two extreme conditions are plotted in Figure 4. The results for these two conditions basically replicate Logan and Zbrodoff's (1979) findings. When inconsistent trials were relatively rare, RTs to inconsistent stimuli were slower (by 97 msec for the LVF(RH) and by 86 msec for the RVF(LH)) than those to consistent stimuli. When inconsistent trials were relatively frequent, however, the opposite was true: RTs to inconsistent trials were faster (by 28 msec for the LVF(RH) and by 29 msec for the RVF(LH)) than those to consistent trials. Thus, compared to condition 1 (50/50) a much enhanced Stroop-effect was found in condition 2 (80/20), whereas in condition 3 (20/80) it was reversed.

A 4-way ANOVA (Sex x Condition x Visual field x Trialtype) was done on RTs for correct responses. Inconsistent trials were slower overall than consistent ones and the main effect for trial type was significant ($F(1,22) = 13.723$, $p<.001$). The interaction for condition x trial-type(Co/Inco) was also highly significant, reflecting the fact that in condition 2 (80/20) there was the usual Stroop-effect, whereas in condition 3 (20/80) the Stroop-effect was reversed (i.e. inconsistent trials were faster than consistent ones). The difference in Stroop-effect between conditions 2 (80/20) and 3 (20/80) will subsequently be referred to as the 'strategy effect'.

Again, like in condition 1 (50/50), the RVF(LH) showed overall faster RTs than the LVF(RH) (by 35 msec) and the main effect for visual field was significant ($F(1,22) = 20.648$, $p<.001$).

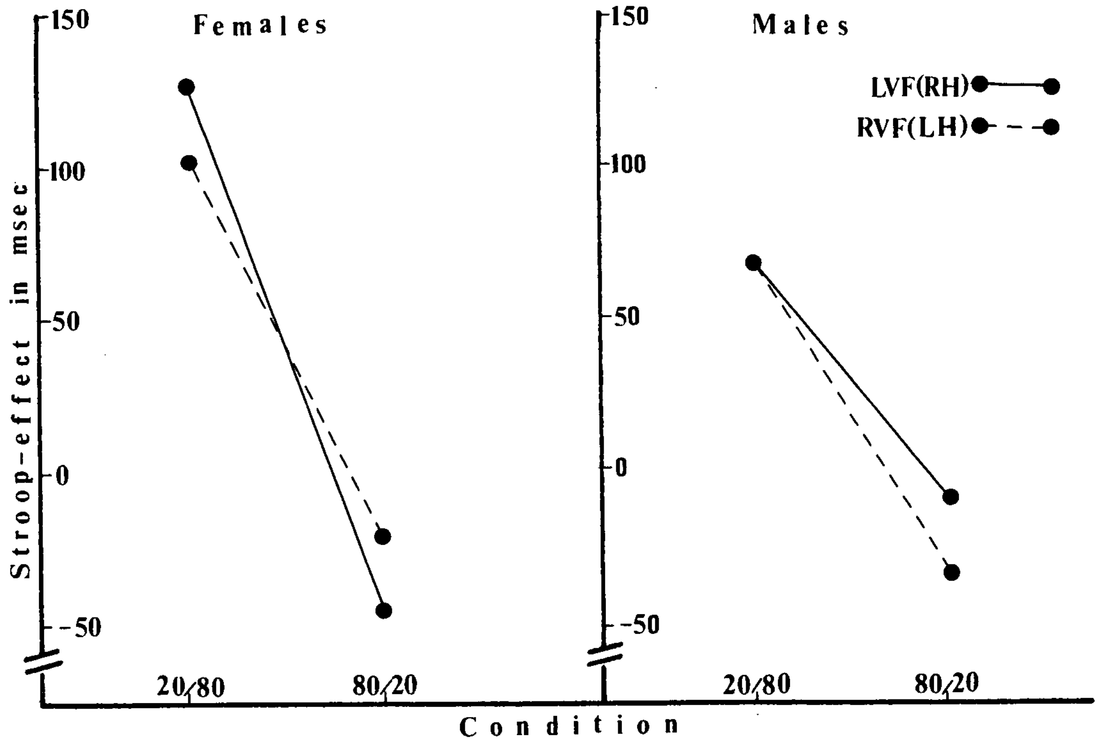
Figure 4: Mean reaction times (RTs) for correct responses and error rates for consistent (CO) and inconsistent (INCO) trials for both visual fields in the two extreme conditions.



The question of interest was, however, whether the pattern of Stroop-effects across conditions (enhanced Stroop-effect in condition 2 (80/20) and reversal in condition 3 (20/80)) would be different for the two visual fields. This was not the case and the interaction between the factors condition x visual field x trialtype(Co/Inco) was not significant ($F(1,22)<1$) (see Figure 5).

It seems, however, that differences in strategy effects between visual fields tended to go in opposite directions for females and males, and the interaction between all four factors reflected this trend ($F(1,22) = 3.742$, $p<.10$). The individual data showed that overall 9 females had a bigger strategy effect in the RH than in the LH, wheras the reverse was true for 7 males. 1 female showed no asymmetry.

Figure 5: Stroop-effect (inconsistent-consistent) for both visual fields and the two extreme conditions.



The same analyses were done on error rates again (see Figure 4). The interaction condition x trialtype(Co/Inco) was highly significant like for the RTs ($F(1,22)$ 19.323, $p<.001$), reflecting the reversal of the Stroop-effect in condition 3 (20/80). No other significant effects were found in the error rates, although the means went in the same direction as the means for RTs: the error rates were higher for inconsistent than for consistent trials, and also higher for the LVF(RH) than the RVF(LH). Thus, like in condition 1 (50/50), no error trade-offs were found in these two conditions and only results for RTs will be discussed.

The effects of weights were calculated for both visual fields and both sexes (see Figure 6). In condition 2 (80/20) attentional and automatic weights have the same sign. RTs to frequent consistent and infrequent inconsistent trials, then, reflect the summed effects of attentional and automatic weights with the same sign. For the frequent consistent trials the weights shift the decision threshold in the correct direction. The opposite is true for infrequent inconsistent trials, however. So the differences between infrequent inconsistent and frequent consistent trials reflect the effects of two positive attentional and two positive automatic weights. In condition 3 (20/80) attentional and automatic weights have opposite signs and the differences between infrequent consistent and frequent inconsistent trials reflect the effects of two positive attentional and two negative automatic weights. The effects of attentional weights can thus be estimated as:

1/4((RT(I,In) - RT(F,Co)) + (RT(I,Co) - RT(F,In)),

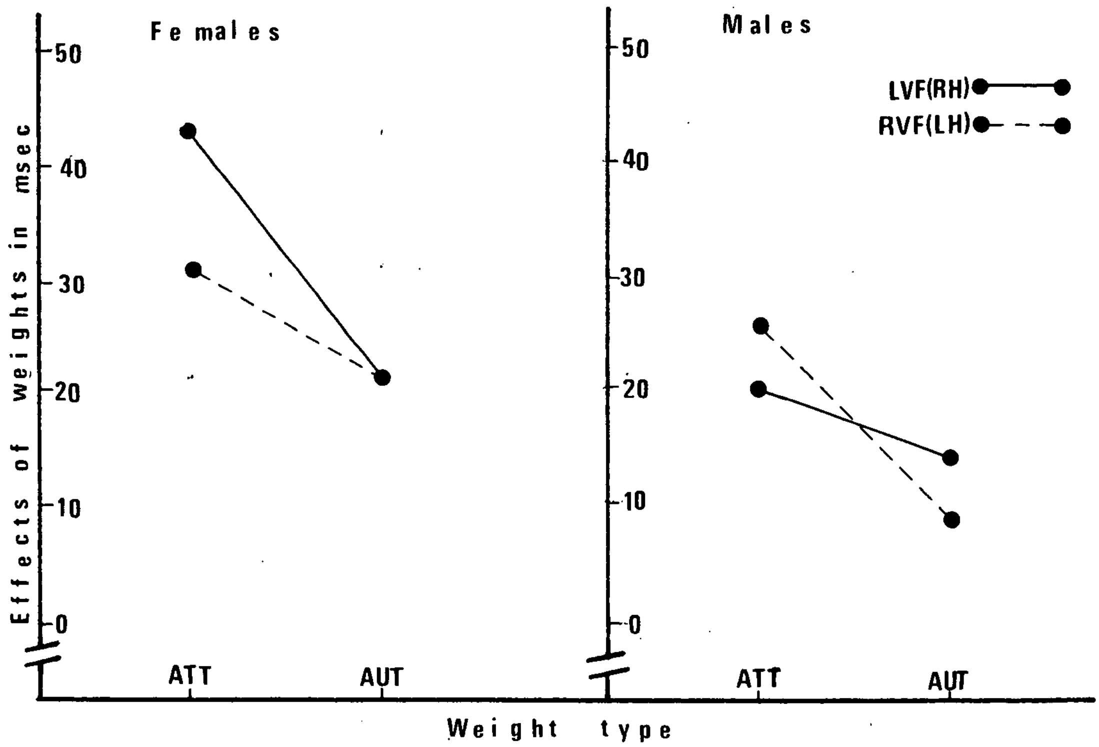
and the effects of automatic weights as:

1/4((RT(I,In) - RT(F,Co)) - (RT(I,Co) - RT(F,In)),

where I = infrequent, F = frequent, Co = consistent, In = inconsistent trials (see Logan and Zbrodoff, 1979, Logan, 1980).

The effects of the weights were analyzed with a 3-way ANOVA (Sex x Weight type x Visual field). As expected, the effects of attentional weights were larger than those of automatic weights, and the main effect for weight type was significant ($F(1,22) = 9.590$, $p<.01$). For the females, the effects of attentional weights tended to be bigger in the LVF(RH) than in the RVF(LH), whereas the opposite was true for the males. This was reflected in a trend for the interaction between all three factors ($F(1,22) = 4.152$, $p<.06$). Like for the RTs, the asymmetry was more consistent for females than for males: 9 females had bigger attentional weights in the RH than in the LH, the reverse was true for 7 males. 1 female showed no asymmetry.

Figure 6: Effects of attentional and automatic weights for both visual fields.



Discussion:

Condition 1 (50/50) was analyzed separately from the two extreme conditions, since in this condition only automatic effects were expected to occur.
Subjects showed a substantial Stroop-effect, but there were no effects for sex or visual field. Like in the priming task, no hemispheric differences for an automatic effect were found. These results are in agreement with findings in a colored word naming task by Schmit and Davis (1974) and by Warren and Marsh (1978).
Along the lines of a direct access approach, one could argue that in spite of the response key arrangement which preserves task-hemispheric integrity (Wickens, Mountford and Schreiner,1981), the words are always processed in the LH and never in the RH. This could be what the slower RTs of the RH reflect, and this is how the above mentioned authors argue. Since there is no reason why the RH should also transfer any positional information (i.e. the unreported dimension) to the LH in the present task, the LH would be predicted to show a bigger Stroop-effect. This was not the case, however. With colored words as used by Schmit and Davis (1974) and Warren and Marsh (1978), the assumption that the word is transferred as a colored word, which would abolish all hemispheric differences in the Stroop-effect, may be a more plausible one. In the present context the assumption that the hemispheres performed the task separately from each other is preferred.

It seems, then, that there are no hemispheric differences in the extent to which responses to the words (the reported dimension) are influenced by the automatic processing of position information (the unreported dimension)in the present Stroop-task.

The results from condition 2 (80/20) and condition 3 (20/80) showed that subjects used a strategy of dividing their attention between the unreported and the reported dimension. There were no effects of visual field on this strategic allocation of attention. A trend was found in the data, however, which suggested that for the females, the strategic effects were bigger for the LVF(RH) than for the RVF(LH), whereas the opposite was true for the males. This was also reflected in a trend of the effects of the weights: the effects of attentional weights were bigger in the LVF(RH) than in the RVF(LH) for the females, whereas the opposite was true for the males. A consistent asymmetry of strategy effects was really only evident in the females, however.
Thus, it seems that in the present task the RH in females uses an optimized strategy more efficiently than the LH and may be able to attach larger attentional weights to evidence from automatic processes than the LH.
Since automatic weights are assumed to be constant in size and sign, the effects of the automatic weights calculated for the two extreme conditions may tentatively be applied to condition 1 (50/50). In this condition the difference between inconsistent and consistent trials should reflect the effets

of two automatic weights. This was true for the males (see Figures 3 and 6). For the females, however, the Stroop-effect was smaller than would have been expected from the automatic weights. Females may thus have attached 'negative' attentional weights to the unreported dimension, similar to condition 3 (20/80), which would reduce the Stroop-effect. This conclusion is only very speculative, however.

V. GENERAL DISCUSSION

At the beginning of this study a framework for the interaction of automatic and attentionally controlled processes was outlined. Attention was described as operating on evidence from automatic processes. It was indicated that certain aspects of the attentional operation, i.e. integration, selection or weighting of evidence from automatic processes, may be possible sources of hemispheric differences. Three experiments that imply different functions of attention and different levels where automatic and attentional processes interact, were run in order to find evidence for two suggestions: first, that the automatic stage is similar in both hemispheres, and second, that hemispheric differences arise at the 'interface' of automatic and attentionally controlled processes.
In addition, several models of hemispheric function were introduced and discussed with respect to the different experiments.

To summarize, evidence was found that automatic processing is indeed similar in both hemispheres, independent of whether it involves only early sensory or also higher levels of information processing. This conclusion is based on the finding that differences between the hemispheres were neither present for a very early automatic stage of object perception (illusory conjunctions) nor for the effects of automatic processes believed to involve higher levels of information processing (priming effect and Stroop-effect in condition 1 (50/50)).

It seems that automatic stages are common to both hemispheres. This claim is substantiated by the finding that illusory conjunctions are made ´across hemispheres´ (Treisman and Schmidt, 1982). Pilot data from an illusory conjunction experiment using colored letters support this finding. Two letters were positioned vertically in one visual field and a third one horizontally across in the opposite field. The mean number of conjunction errors per trial was .13 across and .09 within visual fields.

Some suggestions on how the findings could be corroborated further have already been made for illusory conjunctions. The findings in the priming task and the Stroop-task could be generalized to task situations involving, for example, words (the unreported dimension or nontarget) and pictures or color bars (the reported dimension or target).

Two of the three aspects of attentional operation mentioned, namely selection and weighting, were explored in this study. The third one, an integrative function of attention, could be examined by manipulating attentional load in an illusory conjunction task. Any effects of load on the number or type of conjunction errors should then reflect this integrative function of attention.

In a selective attention situation no hemispheric differences were found for items within each hemisphere (priming task with ipsilateral nontargets). However, when items from both hemifields were involved (priming task with contralateral nontargets), the RH suffered more interference from a LH-item than the LH suffered from a RH-item. It is possible that the LH may focus attention to a high degree on information originally received in that hemisphere. Attention in the RH on the other hand, seems to be attracted away by items in the LH.

This result should also be extended to different task situations. It would be interesting to find out whether the same pattern of effects would be found for more Stroop-like tasks. So far, the Stroop-effect has been interpreted as purely automatic. However, this might be only true for Stroop-facilitation. Stroop-interference effects are believed to arise as a result of response conflict, which could be interpreted as an attentionally controlled response selection. By introducing neutral trials, facilitation and interference effects could be anlayzed separately. A task with words and color-bars, for example, would allow for ipsi- and contralateral presentations. Thus, the question whether a similar aymmetry as in the selective attention task would also be found for later interference effects of a more Stroop-like task could be answered.

If the interpretation that the LH tends to attract attention away form the RH is correct, the facilitative effects found in the priming task may not be purely automatic as has been suggested so far. It would be interesting to manipulate the frequency of semantically associated trials and thereby the extent to which subjects divide their attention between the two simultaneous words. With more attention being paid to the nontarget, more facilitation for semantically associated words and more interference for unrelated words are expected. If RH support of processing in the LH is somewhat automatic, this manipulation should have little influence on targets in the LH in contralateral arrangements. If LH support of processing in the RH involves attentional effects, on the other hand, the extent to which attention is divided should affect facilitation and interference for the processing of contralateral targets in the RH.

With attention viewed as a weighting tool, it was found that females tend to attach larger attentional weights in the RH than in the LH. The results also suggested that females may have used attentional strategies in a condition believed to involve only automatic effects (Stroop-effect in condition 1 (50/50)).

This finding is somewhat puzzling. If attention tends to be focused in the LH, as suggested by the priming task, then one would expect bigger attentional effects in the LH rather than in the RH. It is possible, that different functions of attention, i.e. integration, selection or weighting, show different lateral asymmetries. The LH may be more specialized for selection, while the RH may be more specialized for integration or weighting. Clearly, this trendwise effect needs further investigation. One manipulation that comes to mind is to vary the relative frequency of consistent and inconsistent trials of a Stroop-task separately for each visual field. It would be valuable to know whether a strategy can be controlled independently in the two hemispheres, or whether its use in one hemisphere automatically generalizes to the other hemisphere.

As to the models of hemispheric function that were discussed, the results from the illusory conjunction experiments supported Kinsbourne's (1982) and Moscovitch's (1979) hypotheses claiming that there are no hemispheric differences in early, preattentional and automatic processes. However, the findings in the priming task and the Stroop-task suggest that the locus where lateral asymmetries emerge may be better described in terms of automatic versus attentionally controlled stages than in terms of early sensory and preattentional versus attentional stages, as proposed by Kinsbourne (1982) and Moscovitch (1979). It seems that not only early sensory processing, but also higher level processing, if performed automatically, is similar in both hemispheres. Also, in disagreement with Kinsbourne's (1982) and Moscovitch's (1979) hypotheses, it is suggested that if lateral asymmetries do emerge, they may be described in terms of attentional control rather than in terms of hemispheric specialization of function.

The results in the priming task also provided some, although not very strong support for a direct access approach and the multiple resources model (Friedman and Polson, 1981). The serial/parallel distinction, as proposed by Cohen (1973) was refuted, however.

It seems that the results found in the three experiments complement each other and provide a sufficiently clearcut picture to make speculative claims about the functional locus of hemispheric differences.

It is speculatively concluded that the locus where hemispheric differences emerge is the 'interface' between automatic and attentionally controlled processes. Automatic processes may involve different stages in information processing, depending on the task requirements. It seems that for all stages explored in the present study these automatic processes are shared and common to both hemispheres. Lateral asymmetries are believed to arise only from attentional operations. Three possible characteristics of such attentional operation were introduced: integration, selection and weighting of evidence from automatic processes. For the weighting function of attention a trend for a sex difference emerged. The RH in females seemed to weight evidence from automatic processes more attentionally than the LH. Males tended to show the opposite effect. Clear evidence was found for selective mechanisms, however, which seem to differ in the two hemispheres when items from both visual fields are involved. It seems that the RH can support processing in the LH in an automatic fashion with relatively little cost. The LH, on the other hand, seems to attract attention away from the RH and produces substantial interference (cost) as well as facilitation for processing in the RH.

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