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STUDIES ON LATERALITY

Controversial issues in the approach of hemisphere specialization

Paul Eling

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TABLE OF CONTENTS

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Chapter 4: On the theory and measurement of laterality.
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Chapter 6: Consistency of ear advantage in two verbal dichotic tasks.
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Chapter 7: Consistency of ear advantage: an improvement due to increase in presentation rate.
Published in: Neuropsychologia, 1983, 21, 419-423.

Chapter 8: Comparing different measures of laterality: do they relate to a single mechanism?
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1. THE INVESTIGATION OF LATERALITY AS AN APPROACH OF THE STUDY OF THE BRAIN

How does the brain perform complex cognitive functions such as language? One approach to this issue has been the study of laterality. Why have investigations looked at asymmetric structural and functional features of the two brain halves? The answer to this question brings us back to the study of the brain as it was performed and reported in the 19th century. A more detailed overview of the many studies in the area of laterality will be presented in Chapters 2 and 3. In this chapter I will outline some of the more basic assumptions underlying the concept of laterality. The discussion of these assumptions will lead to the formulation of an interpretation of laterality phenomena that differs from the traditional conceptualization. This thesis also reports studies that attempt to provide evidence in support of this alternative view.

Let us go back to the issue of why the study of laterality is of such great interest. One clear answer is the following: it is a means (albeit gross) of attempting to localize functions in the brain. Even before the 19th century there were numerous accounts of writers pointing to particular places in the body, arguing that one place or another is the seat of a specific psychological faculty. Gall published his ideas on this matter around 1800. He is generally considered to be the first to collect systematic evidence showing that particular regions of the brain are devoted to different faculties. The official medical and biological authorities of the time criticized Gall's work severely. The idea that such complex human capacities such as language could be localized in areas of cerebral cortex of approximately one square centimeter was unacceptable (and still is for a number of scientists). Nevertheless, the idea that psychological functions arise from specific regions of the cortex was becoming acceptable. These regions are smaller than the whole surface but it was questionable how small. For that reason Bouillaud (1825) did not restrict the area responsible for the language function to a limited region as Gall did, but he pointed to the whole of the anterior part of the brain. In doing so he elicited a discussion on the differential effect of anterior and posterior lesions on language behaviour. A paper on the left-right differences of lesions, read by Dax in 1836 on a conference in Montpellier, went unnoticed. Broca, a pupil of Bouillaud, collected important and apparently decisive evidence in support of his teacher's thesis. However, in so doing, he noticed that there was a peculiar asymmetry in the case studies he had collected: almost all the lesions resulting in a severe language disorder, which is generally referred to as aphasia, affected the left hemisphere. After two or three years of hesitation, Broca was finally convinced that 'we speak with our left hemisphere'. The objection that it seems implausible that a function can be localized in a restricted region, in this case an entire hemisphere, has hardly been made to this type of localization models. Strict localization is considered naive; non-strict localization, however, is a scientifically acceptable alternative.

There is yet another reason why the study of laterality is exceptionally intriguing. This reason has to do with an important assumption in the physiological study of the relationship between 'form and function': it is usually assumed that the 'form' of an organ tells us something about its function. Conrad formulated this as follows: 'Einerseits formt die Leistung die Organe, aber ihre Form bestimmt bereits diese Leistung so daß man sagen könnte: Die Leistung der Form der Organe formt die Leistung der Organe' (Conrad, 1949). It seems logical to deduce from this assumption that organs with identical forms have identical functions. Indeed, we have two lungs and they both seem to serve the same function. There are other 'paired organs' where this is true. However, it does not hold for the two cerebral hemispheres. That is to say, lesion studies show that unilateral lesions to the left hemisphere can lead to quite different symptoms from those seen after right hemisphere damage. Why should these brain halves look so very similar, yet have such strikingly different functions? This question leads to a highly speculative discussion and only occasionally have tentative answers been suggested. A question that was easier to tackle for scientists was the following: in what respects do the two hemispheres differ? There have been a number of different approaches attempting to contribute to this issue. One may classify them as anatomical studies, clinical studies, and studies of the normal brain.

The anatomical studies have shown that certain features like weight, length of the Sylvian fissure and the width of the planum temporale are asymmetrical. However, in almost all studies it is admitted that we do not know what, if anything, these anatomical findings tell us about the functioning of the left and right hemisphere. From a theoretical point of view the anatomical studies have not played an important role.

In contrast, the clinical or lesion studies have 'set the scene' for all theorizing on the nature of the duality of the brain. Broca (1865) showed that lesions in the anterior part of the left hemisphere resulted in speech problems. Wernicke (1874) demonstrated that lesions in the posterior part of the left hemisphere result in language comprehension disorders. Finally, Liepmann underlined the dominating role of the left hemisphere by showing that apraxia (a disability to perform certain movements, which is not the result of a paralysis of the limbs) also results after left sided lesions. This led to the classical notion of laterality, generally referred to as 'cerebral dominance'. It states that one hemisphere, usually the left, dominates the other in all higher functions. It is implicit in this hypothesis that functions may, in fact, be represented symmetrically in the right and left hemisphere but the slowly developing sideness is due to an 'extra' dominating influence. This may be expected to develop and to be flexible in response to conditions at least in childhood. In contrast the structural notion of laterality leads to different types of hypotheses.

Even in the very first recorded discussion on left-right asymmetries it was suggested that handedness is related to this phenomenon of laterality. Many studies have been reported in the literature that are directed to this topic. The strong form of the hypothesis of this relation says that handedness and cerebral dominance for language are directly and causally related: right handers have their speech represented in the left hemisphere and left handers show right hemisphere dominance. To my knowledge no one has taken this extreme position except, perhaps, Levy and Nagylaki (1972). The relation is very often stated in a somewhat weaker form: right handers have speech in the left hemisphere and in left handers cerebral dominance is not as clear-cut as in right handers. This formulation leaves room for many different standpoints; these have indeed been taken. For instance, one can state that right hemisphere speech representation is much more frequent in left handers than in right handers. In this way the strong form of the relation is still suggested. On the other hand, the weaker form of the hypothesis allows one to argue that a considerable proportion of left handers also appear to have their speech in the left hemisphere. This interpretation has, apparently, not necessitated the rejection of the notion that there is a relation between cerebral dominance and handedness. Such a rejection was not even the result of two studies on the relation of aphasia with side of lesion and handedness, in which the authors come to the conclusion that the results suggest that language laterality and handedness may be dissociated (Conrad, 1949; Goodglass and Quadfasel, 1954)! In Chapter 2 this topic will be dealt with in more detail, when the anatomical and clinical evidence are reviewed.

Clinical studies have also been a principal source of evidence as regards the role of the 'minor' hemisphere. In 1926 Henschen was still convinced that the dominant hemisphere performed the higher psychological functions. The alternative view, advocated by Hughlings Jackson as early as 1874, namely that each hemisphere contributed to the normal functioning of the brain, and that each contained a specific set of functions, was neglected until after world war II. The work of Zangwill and Hêcaen in particular pointed to the relevance of the right hemisphere in visuospatial functioning. However, the final blow to the classical cerebral dominance theory was given by the 'split-brain studies' of Sperry and his co-workers (for references, see Searleman, 1977). In the 1960s approximately twenty patients underwent a major brain operation for treatment of intractable forms of epilepsy. The corpus callosum, a bundle of fibers connecting the two hemispheres, was severed in these patients, leaving the two brain halves intact as relatively independent systems. With the use of special techniques it was possible to project information selectively to the right or the left hemisphere. It appeared from a large number of experiments on these split brain patients that the right hemisphere was capable of performing many tasks, even those in which linguistic material was presented. Furthermore, the right hemisphere seemed to be 'specialized' for certain tasks. The concept of cerebral dominance was replaced by that of 'hemisphere specialization'. One basic issue in the study of laterality now became the question as to what was the specialization of the left and right hemisphere. This has led to what may be characterized as dichotomy models: a pair of contrasting adjectives is suggested as describing the fundamental difference between the left and right hemisphere. The two most influential of these dichotomies are: verbal-nonverbal and analytic-holistic. The notions of analytic processing as characteristic for the left hemisphere and holistic processing as describing the functioning of the right hemisphere were introduced by Levy (1974). There is, however, no clear definition presented for each of these types of information. Moreover, only after an experiment it can be decided whether a given task was analytic or holistic (Marshall, 1981). This class of models has another feature that seems highly undesirable. The dichotomies suggest that the brain can be conceived of as two independent systems: functions are localized either in the right or in the left hemisphere. This would imply that the concept of 'degree of lateralization' simply is not applicable to the system. Indeed, it has been argued by Colbourn (1978) that we (can and) should measure laterality only at the nominal level. However, as I argue in Chapter 4, this is in contrast with the intuitions of many researchers working in this area. They were under the impression that (a) individual differences in degree of lateralization could explain phenomena like the rate of recovery from aphasia and that (b) differences in degree to which verbal material demanded access to the 'speech processor' was reflected in the different degrees of lateralization of particular classes of phonemes. Another set of data, suggesting that 'laterality' was not expressed as either 'right' or 'left' but rather as a continuous variable, were the studies on handedness. It is well known that 'pure' left handers are relatively rare. It is not uncommon that one or two (or more) items of a handedness questionnaire are responded to 'right', by a person, who is otherwise to be regarded as left-handed.

These considerations have led to a decrease in interest in theorizing along the lines of the dichotomies. Bradshaw and Nettleton (1981) suggested that the traditional verbal/nonverbal dichotomy is inadequate and should be replaced by the analytic/holistic dimension. They simultaneously attempted, however, to argue that there is a 'continuum of function between the hemispheres, the differences being quantitative rather than qualitative'. Indeed, from the reactions in the Open Peer Commentary following this paper it is very obvious that the whole idea of dichotomies is rejected by most critics. McKeever (1981) goes so far as to talk of 'laterality research and dichotomania'. In a less agressive way Bertelson (1981) asks, at least in my opinion, the most fundamental question: "Why should there be a single principle?" There is no convincing reason in the data reported in the literature which make us believe that all left-right differences that can be measured are all due to the functioning of a single mechanism. It seems that both the cerebral dominance model and the class of dichotomous models resulting from the 'hemispheric specialization view' have generalized unduly over an arbitrary set of phenomena, which only have in common that they show some left-right asymmetry.

The problem becomes clearer if we consider for a moment what is meant by the concept of 'function'. This concept has replaced the word 'faculty', which was used in the 19th century and which has a long history. In the literature on the relationship between functions and the brain the term function is hardly ever defined. If we disregard for a while the more extreme Phrenological descriptions by Gall and his followers, we see that functions that are regularly considered in attempts to localize mental capacities in the brain are: language, vision, memory, spatial orientation, face recognition, arithmetics and the like. Conrad (1949) recognizes that it is 'speculation, dressed up as a theory' to assert that 'the function of growth of an organism is localized in the thymus, because growth is disturbed when this organ is affected by disease'. In the same vein, he argues, one cannot infer the localization of a function on the basis of a localizable symptom. Luria (1973) discusses this issue in a similar way. He goes on to argue that the function of, for instance, 'digestion' cannot be localized in the stomach nor in any other single part of the body. Does this mean that functions cannot be localized? Luria (1973) solved the problem, at least partly, by introducing the concept of a 'functional system'. Many subsystems would interact in such a way that together they can perform a function. What is not solved by this answer is the question of whether functional systems can be localized. However, the notion that a psychological function such as language consists of a set of subsystems seems more in line with studies on the effects of lesions at different places in cortical and subcortical areas on language on the one hand and with psycholinguistic models of normal language processing on the other hand. If we now further assume that for different linguistic tasks a different subset of subsystems of the functional system will be involved in performing that task, we may predict that localization, and more specifically lateralization will vary according to the task involved. As I will show in this thesis, such a view of the functioning of the brain has important implications for the interpretation of the concept of laterality and for the measurement of laterality.

This hypothesis has been elaborated in Chapter 5 and applied to the problem of development of laterality. According to Lenneberg (1967) the two hemispheres can be considered as equipotential at birth. During childhood, until approximately the age of 14, there is supposed to be a gradual shift of the language function towards the left hemisphere. Lenneberg developed this theory in order to explain the effects of unilateral lesions in children, which seemed to suggest a pattern different from that in adults. A long series of dichotic studies attempted to provide evidence for the position of Lenneberg. The results were unexpected and disappointing. Satz et al. (1975) attempted to demonstrate that all failures of earlier studies were due to methodological and statistical shortcomings. This explanation, however, is not applicable to Kimura (1963). Her study does not show a ceiling effect as Satz et al. argue.

However, if we look at the dichotic tasks that have been used in studies of this kind, it appears that a different explanation is possible. Usually, children of various ages are presented with dichotic pairs of digits or consonant-vowel syllables and they are asked to recall as many items as possible. It is hard to see that this type of task measures relevant aspects of development of language processing. If we conceive of language development as the building of new subsystems we should use tasks that tap these subsystems in order to study the relationship between language development and other variables such as laterality. To that end we developed two new dichotic tasks, category monitoring and rhyme monitoring. In the first the subject is requested to respond to words that belong to a semantic category, e.g., fruits. In the second task the word has to rhyme with a given word. It is assumed that the first task requires processing at a semantic level and in the second task phonological information is more important. The choice of these two tasks can be argued on the basis of split-brain studies, which showed that the right hemisphere could recognize some words, in particular nouns, but did not seem to be able to perform phonological processing. So, if laterality develops, one might predict that in the course of development the laterality score of the rhyme monitoring task increases more than that of the category monitoring task.

This also leads to the prediction that in adults different laterality scores for these two tasks should be demonstrable. In Chapters 5 and 6 some experiments are reported that test this prediction. It is known from the literature that almost any dichotic task tends to show a significant laterality effect in approximately 70% of the subjects. At the same time this effect appears to be rather unreliable. At retesting 70% of the subjects will again show a laterality effect, but these subjects are not necessarily the same as those who showed the effect on the first test. In order to be able to draw somewhat firmer conclusions, we have tried to improve the dichotic technique as will be described in Chapters 5 and 6.

The same line of reasoning that led to the development of two comparable but slightly different verbal dichotic tasks has also led to the last study to be reported. In this experiment the argument is pushed a little further. If we accept the view that the class of dichotomous models does not do justice to the intricate way in which functions, regarded as being performed by sets of interacting subsystems, are localized in the brain, then we do not have to assume any longer that functions which are (in part) localized in a particular hemisphere are localized there for a generalized dichotomous reason. The main issue dichotomy models attempted to answer was the question of why a particular set of functions happened to be localized in the left (or right) hemisphere. I do not consider this to be the right question. Indeed, as yet there is no solid evidence that functions are lateralized to the same extent and, what is of more significance, direction of lateralization has not yet been shown to correlate for a particular set of functions. I would suggest that there need not be a general principle causing particular functions to be represented in the same hemisphere. That is, their lateralizations do not necessarily have to correlate. This leads to the hypothesis that function x may be localized in the left hemisphere in the majority of the subjects; function y may also be located in the left hemisphere in a majority, but these need not be the same subjects. The two subsets of subjects showing left lateralization for function x and function y respectively may even differ in magnitude. To test this prediction, lateral differences were measured in a relatively large group of adults on various tasks, viz., several dichotic and visual half-field tasks and three tasks measuring performance differences between the hands. This study is presented in Chapter 7.

The studies reported in this thesis were carried out as part of a research project on development of laterality. When performing the experiment, as reported in Chapter 4, it was noted that some implicit assumptions with respect to the traditional interpretation of dichotic tasks were not confirmed by our results as well as by other relevant studies reported in the literature. Instead of studying development of laterality in groups of children with several types of disorders, it was decided to concentrate on looking more carefully into the issue of the validity and reliability of dichotic listening. It should be noted that the results of the reliability studies were not available at the time the validity study, reported in Chapter 8, was started. For that reason a dichotic task has been used in the validity study with a slow rate of presentation of dichotic pairs. However, we do not think that this invalidates the results of the study in which various laterality measures are compared.

2. LATERALITY IN ANATOMICAL AND CLINICAL STUDIES OF THE BRAIN

2.1 Introduction

In the previous chapter it has been argued that the study of hemispheric differences is a special branch of the attempt to localize psychological functions in specific areas in the brain. Since the days of Descartes the discussion on the 'body-mind' problem has attracted the attention of an increasing number of scientists. However, Franz Joseph Gall is generally considered to be the first 'localizationist'. An interesting account of the history of the study of localization of functions can be found in Clark and Dewhurst (1972). The present chapter will review the line of research that stems directly from the work of Gall. This concerns studies that investigated the functioning of the (parts of the) brain by looking at effects of localized lesions and studying structural features of the brains post mortem.

While Gall was severely criticized in the traditional scientific circles, Bouillaud attempted to save part of Gall's ideas. He produced evidence that the 'faculty of language' was resident in the anterior parts of the brain (Bouillaud, 1825). The evidence consisted of patients some of whom showed signs of language disorder after cerebral damage and it was obvious that the frontal part of the brain, that is, anterior of the fissura Rolandi, was involved in all of them. His pupils took over this method of studying the localization of functions: they described patients with lesions in particular parts of the brain and inferred (a) whether the principle of localization was supported and (b) whether language resided in the anterior part of the brain.

One of these pupils was Broca. He discovered the case of 'Tan', a patient who had not been able to speak, except for a few short utterances, for approximately twenty years. Shortly after the death of Tan, Broca showed his brain to the members of the Anthropological Society and the predicted frontal lesion was there. Although not everyone was willing to accept this as the final proof, it seemed that this case settled the discussion. In four years time Broca collected about twenty new cases, practically all supporting his position. However, he became slowly convinced that the damage not only had to be located in the anterior parts of the brain but that the language disorder, which he called 'aphemia', resulted from left hemispheric lesions. In 1865 he was prepared to state his well known dictum: "we speak with our left hemisphere." The original anterior-posterior dimension was replaced, in a sense, by the left-right dimension. Students of the brain, whom we might call 'strict localizationists' like Fritsch and Hitzig (1870), Ferrier (1886), and Von Monakow (1914), using mostly animal studies adhered to the anterior-posterior dimension and equated that with motoric and sensoric functions.

This shift towards the study of the differential effects of unilateral lesions has elicited a still increasing number of studies. Many new paradigms have been introduced, but they all try to contribute to the basic questions: what is the fundamental difference between the hemispheres, why is there an asymmetry and how did it evolve (Teuber, 1974). Almost all individual studies and theories are directed to only one of these questions. This imposes serious limitations upon any comparison of such theories: they serve different purposes. I will not restrict myself to a particular type of theories, providing answers to the question of 'what', 'why', or 'how' of laterality, because this review is not directed to one of these issues in particular. In the review presented below the emphasis will be on describing the most important arguments as they can be found in the literature. The number of studies is so enormous that it is hardly possible to try to be both brief and complete. First I will shortly describe the measurement of anatomical asymmetries in the brain. In comparison to the lesion studies and the studies of functional differences, which will be described in the following chapter, the anatomical data are the least interesting from a theoretical point of view. I will then outline, with the lesion studies, the effects of unilateral lesions on language, motor and music behavior; work on the 'split-brain' patients; and finally studies on patients in whom one hemisphere was taken away, hemispherectomy patients. However, no clear picture arises from these studies. This is partly due to the fact that a certain set of data is interpreted differently by different authors. It appears that, although these different lines of interpretation have co-existed almost from the beginnings of laterality research, at one moment one interpretation was preferred above the other, which was only to be (re)discovered a number of years later. I will return to this issue in the next chapter in the section on the developmental studies.

2.2 Anatomical aspects of laterality

Research into the differences between the two hemispheres has been performed with respect to several aspects (for reviews, see Von Bonin, 1961; Witelson, 1977; Lecours, 1981). At first, fairly global measures were used, such as the weight of the hemispheres. Students then began to concentrate on the size of those parts of the brain that, according to clinical studies, were involved in the function showing the clearest signs of asymmetry of the hemispheres: language.

2.2.1 Weight

One of the first features of the brain to be measured systematically was the weight of each hemisphere. Boyd (1861) argued that the left hemisphere was a little heavier than the right. Several studies followed, however, which demonstrated the opposite. For instance Wagner (1864), Thurnham (1866), Broca (1875) and Braune (1891) observed that the right hemisphere was heavier. It must be noted that the brain studies were very often those of neurological patients, so that their weight could have been altered (in either direction) by the disease that had afflicted the brain.

The assumption underlying these measurements was not so much that there was a relation between the amount of brain tissue and the number (or kind) of functions, but rather that, due to the specific gravity which is higher for the gray matter than for the white matter, the functionally more important hemisphere should weigh more. Differences between hemispheres should be reflected in the relative amount of cortex and this would lead to differences in weight, assuming of course that the total volume of the two hemispheres is equal.

2.2.2 Surface

Before Gall's publication (1809), higher cognitive functions were localized in the center of the brain; since then, however, the cerebral cortex was considered to be the seat of these functions. More and more attention was paid to the strange-looking surface pattern: most specifically, the notions of 'sulcus' (or groove) and 'gyrus' (or convolution) were introduced by Gratiolet. It was noted that lower animals have a smooth(er) cortical brain surface in contrast to higher animals such as primates and humans. The higher the position in the phylogenetic hierarchy the more convoluted was the cortex. It is generally assumed that these convolutions extend the total cortical surface. Due to the sulci and gyri, however, it is very difficult to measure the surface in humans. Studies on differences in surface between left and right hemisphere, therefore, were restricted to the inside of the skull. Hoadley and Pearson (1929) thought that the surface on the right side is larger than that on the left. But Halperin (1931) argued the opposite. A number of studies examined, though not systematically, some prehistoric human skulls. Here, too, differences were reported (Hoadley and Pearson, 1929).

2.2.3 Sylvian Fissure

On the side of both halves of the brain, there is a deep horizontal cleavage, the fissura Sylvii. It divides the frontal lobe from the temporal lobe. From many neurological reports it is known that especially the area surrounding the fissure is involved in language. Eberstaller (1890) and Cunningham (1892) described differences in length between the left and right Sylvian fissure (in favor of the left) in a large number of adult brains. Von Economo and Horn (1930), Shellshear (1937) and Connolly (1950) showed that this fissure was longer in the left hemisphere; in particular they showed that the differences were due to the fact that the fissure extended further back on the left and angled upward earlier on the right. From these observations it could be concluded that the parietal and posterior-temporal operculi (an area on the cortex on either side of the cleavage) had to be asymmetrical. Rubens, Mahowald and Hutton (1976) demonstrated in a well-designed study that there were asymmetries in the posterior region of 26 out of 30 brains studied: in the right hemisphere the fissure angled sharply upward at a point where in the left hemisphere it continued for about 1.5 cm before it ended there, either in a simple split or in a small angle.

2.2.4 The Planum Temporale

Due to measurements on the Sylvian fissure, attention has been paid to the planum temporale. This area becomes visible when a cut is made in the horizontal plane along the Sylvian fissure. The extent of this area is determined at the outer surface by the course of the Sylvian fissure. A study on this area which is quoted frequently is that by Geschwind and Levitsky (1968). After the conclusion by Von Bonin (1961) that the anatomical asymmetries are relatively small, and probably unimportant in comparison to the large functional differences, Geschwind and Levitsky's study gave renewed impetus to research on anatomical differences. These authors studied 100 adult brains and noticed, amongst other things, that in 65 cases the planum temporale was larger at the left side, and in 11 cases larger at the right side. These data have been confirmed by other studies (e.g. Rubens et al., 1976).

The four features discussed thus far are the most prominent gross anatomical aspects in which important differences between left and right hemispheres have been noted. Many other structures in the body, often located outside the brain, have also been found to be asymmetrical. For instance, systematical differences in skeletal bones and ovaries have been demonstrated. A very extensive overview of such studies can be found in Corballis and Morgan (1978). It is not impossible that these asymmetries are related to the functional left-right differences in the human brain. In fact, this is the central hypothesis of Corballis and Morgan themselves. There is, however, no obvious reason why this should be so: we do not see how data on asymmetries of bodily structures, except those in cerebral regions could be relevant for studies on functional differences in memory, perceptual or language capacity between the two hemispheres (cf. Hudson and Marshall's commentary (1978) for conceptual problems in Corballis and Morgan's theorizing).

Some potentially promising results have been reported by Galaburda and his colleagues (Galaburda et al., 1978, 1979). They performed cyto-architectonic studies on the planum temporale and were able to relate (anatomical) hemisphere asymmetries to (cyto-architectonic) differences in auditory areas, traditionally identified in gross morphology as being language areas. They have also suggested that this approach could be of relevance in demonstrating very small abnormalities in brain structure in (some) dyslexics.

2.2.5 Anatomical studies in children

A separate matter in the area of laterality research is the question of whether laterality is already determined when the child is born or whether there is a progressive development of laterality. Although both positions can be combined, this has not been an important theoretical stance in the literature (but see Broca, 1865). Witelson and Pallie (1973) studied adult brains and the brains of 14 children of whom 11 were newborns. They used several measures in order to compare the left and right planum temporale and found that in these children all measures showed a significantly larger planum temporale in the left hemisphere. Wada, Clark and Hamm (1975) studied the brains of unborn fetuses and compared these with the brains of adults. Even in these fetuses similar differences between the temporal planes were obtained. However, Wada et al. noticed that the differences were somewhat larger in adults. They interpreted these data as supporting the notion of development of laterality. Summarizing, we can conclude that apparently some degree of anatomical asymmetry is observable in young infants even before birth. This does not support the position that both hemispheres are 'equal' at the beginning. But on the other hand, we cannot exclude the possibility that this anatomical asymmetry increases with age, and, of course, with respect to functional asymmetry, we cannot conclude anything from these studies.

2.3 Effects of unilateral lesions

2.3.1 Aphasia

The first period of localization research is characterized by discussions on the issue of whether only anterior, or whether posterior lesions can also produce language disorders (for a review, see Hécaen, 1979). Broca was a student of Bouillaud and defended the thesis of his master (Broca, 1861), apparently with great authority, since many authors refer to Broca as the person who established this notion. The original theoretical position of Broca, namely that speech is localized in the anterior part of the brain, was not shared by all of his colleagues. In a beautifully recorded discussion (see Hécaen and Dubois, 1969), Laborde brought forward two arguments against the line of reasoning of Broca: first, there was a patient in whom a lesion of the anterior part of the left hemisphere did not result in aphasia, and second there was a patient in whom right-sided frontal brain-damage did not result in a language disorder. Laborde also mentions some other patients in whom brain damage resulted in the loss of only a part of the spoken language, or who could write, in contrast to a claim made by Broca. Broca defended his position by pointing out that Laborde's interpretation of the concept of aphasia was incorrect. For Broca it referred to patients who cannot speak at all, except perhaps for one or two recurring words. This is a very restricted description indeed, compared to what is currently (and perhaps was also in Laborde's view) denoted by the concept of aphasia. Furthermore, Broca defended himself by arguing that the speech area is only present in the left hemisphere. The patient with the right frontal lesion without aphasia Broca considered to be confirming his position, rather than a counter-example to his theory. This development, the change from anterior-posterior to left-right comparisons of lesion effects, was not only very important for the study of aphasia but it can also be considered as the first step in laterality research.

Another opponent of Broca's view was Wernicke (1874). He based his arguments predominantly on histological research into the course of the auditory nerve fibres rather than on clinical studies, and he suggested that posterior lesions of the left hemisphere can also lead to a certain language disorder, which was later commonly referred to as Wernicke's aphasia. The latter type of aphasia was, however, believed to be of a different nature from that of the patients with anterior lesions. Broca had asserted very positively that intelligence and language comprehension were intact in his patients. Wernicke, in contrast, described a language disorder characterized by loss of language comprehension but without problems regarding the motoric aspects of speech. On the basis of these results and his own histological findings, Wernicke also predicted a syndrome which was later indeed observed: it came to be known as conduction aphasia. Wernicke's work was rapidly accepted by many neurologists and the way was now wide open for the researchers.

Apart from the significance that Wernicke's work has for the study of aphasia, it was also important for laterality research. Broca recognized not only that a specific area in the anterior part of the left hemisphere was involved in the general language process; other areas were admitted to be involved as well. But Broca did not mention which those other areas were nor did he describe exactly what role they played in the language process. Wernicke, on the other hand, described how different parts of the brain could be related to each other and how each area is involved in a specific part of the process of language production or comprehension, via either the auditory or the visual modality. A consequence of Wernicke's attempt was that language, production as well as perception, was seen as localized in the left hemisphere. In view of the importance of this function for human communication, it is not surprising that in the writings of researchers following Wernicke, the role assigned to the right hemisphere became gradually devalued.

After the publication of Wernicke's dissertation in 1874, there were, of course, a number of authors who criticized his work. Bastian (1887), for instance, argued that as early as 1867 he had pointed out the existence of sensoric aphasia and the importance of nerve fibers connecting visual and auditory centers. Of greater theoretical significance is the voluminous work of Hughlings Jackson (1931). He is the first and perhaps the only author who has attempted to explain how the left and right hemispheres co-operate in language processes. In his article 'On the nature of the duality of the brain', written in 1874, he gave a very detailed description of what we now call 'hemisphere specialization'. To him, laterality does not mean that the left hemisphere performs certain functions and the right certain other functions; nor that all functions are represented double. Hughlings Jackson conceived of laterality as showing that certain components of complex psychological functions were performed by one hemisphere, others by the other hemisphere and that both hemispheres were required for any function. Which components were performed by the left was dependent on the 'degree of automaticity'. Automaticity, in his view, is not an inherent characteristic of words or acts but is determined by the specific meaning or intention behind the expression. In order to understand fully what Hughlings Jackson was pointing out, one must consider that he viewed language in a manner completely different from most of his contemporaries who studied the functioning of the brain. To him, language was not the seriation of sounds into words, words into sentences or their decomposition in the reverse order. Instead, he described language production in terms of processes that have to do with formulating propositions. This is not the right place to discuss Jackson's ideas on language processing into more detail. It is more important to note that Hughlings Jackson argued that in laterality research the object of study should not be the kinds of materials (e.g. verbal-nonverbal) but the kinds of processes involved. Furthermore, he stated that the brain should not be considered as two independent systems, each with its own specialized capabilities. He placed much emphasis on the continuous hemisphere interaction going on during the performance of every task. Hughlings Jackson's work was not generally appreciated. The theory of cerebral dominance was widely accepted, as can be seen in Henschen (1926). He argues that all language processes as well as other higher psychological functions are located in the left hemisphere. He even suggests that the right hemisphere is merely a 'reserve organ'.

In the discussion on aphasia and laterality a separate issue is formed by the study on the influence of handedness on the effects of unilateral lesions. This point was already raised in one of the first discussions on laterality between Broca and Laborde in 1863. Following these discussions a number of case studies have been described in the literature, which attempt to undermine the position of Broca. These can be divided into two classes: patients who did not have aphasia, although that could have been expected on the basis of the side and the place of the lesion; another group of cases consists of patients showing aphasia after lesions on the other side than that which one would have expected. Bramwell (1899) introduced the notion of 'crossed aphasia' to describe cases of aphasia that were apparently due to a lesion on the same side as the preferred hand. In 1936 Chesher has been said to argue that pure handedness is always correlated with exclusively contralateral language laterality. Conrad (1949) studied the effect of unilateral lesions in 808 patients, of whom 47 were left-handed. Of the right-handers 26% was aphasic and in the left-handers this percentage was 38%. When he looks at the side of the lesion causing aphasia he finds very interesting results: in right-handers the lesion is on the left in 88% of the cases, on the right side in 5.8%, and bilateral in the remaining 6.2%. In the left-handed aphasics, however, the picture is not reversed: left-sided lesions are found in 55.5%, right-sided in 39% and bilateral lesions occur in 5.5%. From these results Conrad concludes that left-handers show all forms and degrees of lateralization, ranging from bilateral to unilateral specialization. He interprets this in an evolutionary process, of which the end mark is unilateral representation. This interpretation of his data is certainly not straightforward. First, Conrad notices to his surprise that in left-handers the lesion is in the left hemisphere in the majority of the cases. Furthermore, in aphasic left-handers bilateral lesions are not found more frequently than in right-handers. Finally, he notes that recovery from aphasia occurs to a lesser degree in right-handers than in left-handers. Conrad argues that 'all specialization implies a better performance, but always at the cost of the ability to adapt!' Conrad's study clearly recognizes that hemisphere specialization was contrary to the governing opinions. However, it must be noted that the association between side of lesion and handedness in aphasic patients was not analyzed statistically until 1954 in a paper by Goodglass and Quadfasel.

A similar picture emerges from the studies of Goodglass and Quadfasel (1954), Ettlinger, Jackson and Zangwill (1956) and Newcombe and Ratcliff (1973), even extended in the sense that also the relation with other measures of laterality such as eyedness and familial sinistrality was determined. It is interesting to note that Goodglass and Quadfasel state that '*these data are most consistent with the hypothesis that the various functions, e.g. language, handedness, eyedness, establish themselves independently more on one side or the other but most often on the left.*' (my italics).

Ettlinger et al. stress that 'deviating' patterns of language laterality are not related to familial left-handedness. They argue, furthermore, that unilateral representation of speech, in particular in the left hemisphere, is the prevalent form.

Roberts (1956) in a survey of 345 patients (including 33 sinistrals) who had undergone brain operations by Penfield, claims not to have found a single case of permanent aphasia resulting from a lesion limited to the right hemisphere. The results of these large-scale studies on aphasia in right- and left-handed patients has been supported by the findings of Penfield and Roberts (1959). They used the method of electrical stimulation of the brain in patients during their surgical treatment. Further evidence comes from studies using the Wada-technique. In this technique sodium amytal is injected in the right and left internal carotis successively; it 'paralyses' the ipsilateral hemisphere for a short period. If the dominant hemisphere is paralyzed, the patient cannot speak nor can he understand what is said to him. Rasmussen and Milner (1977) present the results of 396 such cases. These are all epileptic patients. In the left-handed patients without early brain injury 70% showed speech disturbance after injection into the left hemisphere and not after injection into the right.

In summary, the studies that have looked at large samples of patients clearly demonstrate that in left-handers language is represented in the left hemisphere in the majority of cases. Furthermore, the notion that language is represented bilaterally in left-handers is not confirmed by the data. This may hold for a minority of cases (approximately 5-15%) and even then it is unknown whether this means that each hemisphere is capable of speech or whether some (transient) language disturbance will be observed upon a lesion of either hemisphere. These conclusions are incompatible with the hypothesis that language lateralization and handedness are simply correlated.

2.3.2 Apraxia

A decisive step in the first phase of laterality studies was made by Liepmann (1905). He is best known for his work on apraxia, a disorder in the execution of certain movements without signs of paresis (for overviews, see Hécaen, 1967; De Ajuriaguerra and Tissot, 1969). It was well known that the use of the limbs is controlled in the contralateral hemispheres. Liepmann, however, suggested that the execution of certain movements with the left hand could be disturbed by lesions of the left hemisphere. According to Liepmann this was possible because the 'idea of the movement' was stored in the left hemisphere. With the latter 'discovery' the left hemisphere was given the role of supremacy. Although Liepmann's theory was criticized by Pfeiffer (1918, 1922), supported by clinical observations and empirical studies, this view of the leading role of the left hemisphere in the execution of specific movements was widely accepted. The right half of the brain hardly served any purpose in this conception.

For several reasons it does not seem appropriate to describe here this area of research in as much detail as that of aphasia. First, the results of apraxia studies did not have such a great influence on theorizing in the area of laterality. Instead, the results are most frequently related to (psychological) theories of motor control. A second reason is that lesions resulting in a particular type of apraxia are often not restricted to a specific site or hemisphere, as is (to a certain degree) the case with aphasia. In comparison to aphasia, lesions are apparently much more evenly distributed over the two hemispheres. Nevertheless, it may be noted that even soon after the first observations on apraxia, several forms were distinguished. At present there is no general agreement on what types can be accepted as distinct apraxias. Nor is there agreement on the interpretation of what disturbance is responsible for a specific type. However, one can say that posterior lesions of the dominant hemisphere may cause disturbance of simple gestures (e.g. waving good-bye) complex motor acts (especially due to problem of sequencing) and 'constructional apraxia' (e.g. drawing of a house). Non-dominant hemisphere lesions, however, mainly seem to cause 'constructional apraxia'.

2.3.3 Amusia

Another function typically ascribed to the right hemisphere is the performance of and listening to music. Damasio and Damasio (1977) present a review of clinical studies on brain damage and musical capabilities. Henschen (1926) claimed that most forms of amusia are caused by left-hemisphere lesions. It appears, however, that early studies on amusia were performed on patients who were experienced musicians. Central issue in these studies was not so much the site of the lesion causing amusia but rather the question whether music and language were intrinsically related to each other. In more recent studies the musical abilities of less experienced musicians with brain-damage have also been studied and a more systematic distinction has been made between the perception and the performance of music. Damasio and Damasio (1977) conclude in their survey that performing music is a right-hemisphere function, relatively independent from musical knowledge and training. The laterality of music perception, on the contrary, does show a 'training effect'. In beginning musicians it seems to be predominantly a non-dominant hemisphere function while in experienced musicians it tends to become a dominant hemisphere function.

Leaving aside the correctness of any of these conclusions, it is clear that the view on the role of the right hemisphere has changed markedly during this century.

A special branch of studies on brain-damaged patients is formed by studies on split-brain patients. These studies have, on the one hand, provided a large amount of evidence for the 'hemisphere specialization' hypothesis, and on the other hand they have greatly raised the interest in laterality, making it a very popular research topic, maybe even somewhat too popular. I shall discuss the outcome of these studies in the next section.

2.3.4 Split-brain studies

Dejerine (1892) and Liepmann (1905) took the role of the corpus callosum into account in explaining particular neuro-psychological deficits. They maintained that nerve impulses were sent along the corpus callosum from centers in one hemisphere to centers in the other. Not only is relevant information transferred along these commissures, it is also possible that a focal epileptic discharge starting in one hemisphere generalizes along this path. Therefore, Van Wagenen and Herren (1940) tried to prevent generalization of an attack in epileptic patients by dissecting, more or less completely, the corpus callosum (for overviews see Sperry, Gazzaniga, Bogen (1967); Gazzaniga (1970) and Gazzaniga and LeDoux (1977)). In a number of cases they were successful in the sense that the epileptic symptoms were markedly reduced. Furthermore, Akelaitis (1944) concluded that no specific defects could be demonstrated as the result of this treatment. Sperry and Gazzaniga and some co-workers have subjected a relatively small number of split-brain patients (approximately twenty) to a large series of studies upon their discovery that specific effects could be demonstrated by presenting the stimuli to which the subjects had to react, to a single hemisphere. The experimenters also had to prevent information from being transferred from one hemisphere to the other by 'cross-cueing', i.e. the possibility that the left hemisphere infers (from, for example, manipulations of the left hand) what the right hemisphere is trying to express. With proper control conditions it could be shown that a particular task could be performed by the hemisphere to which the stimuli were presented but not by the other. It also appeared that certain tasks were performed better by the left hemisphere and other tasks better by the right. The latter conclusion was heavily emphasized by Gazzaniga (1970) and by Dimond (1972) in an attempt to attack the notion of 'cerebral dominance'. Using the visual half-field-paradigm, Gazzaniga presented data suggesting that, within limits, even verbal information could be processed by the right hemisphere. In retrospect one may wonder whether this is surprising; after all, the right hemisphere apparently understood instructions to perform non-verbal tasks. However, this finding was of great significance. Until then, the right hemisphere was considered 'minor': it could perform, perhaps some, but certainly only low-level functions. The split-brain studies showed that the right hemisphere of these patients was not as limited in its function as traditional views had judged it. Room was now given to proponents of a more balanced view of the two hemispheres in which emphasis was placed on the great similarity of the two brain halves. The concept of 'unilateral dominance' was definitely discarded and replaced by 'hemispheric specialization'.

A disconnection of the corpus callosum appears to occur as a natural phenomenon as well: in some human beings the corpus callosum simply does not develop. This is usually referred to as agenesis of the corpus callosum. The condition is fairly rare, but it probably occurs more often than it is detected. It is generally accepted that agenesis itself is asymptomatic (for a review, see Milner and Jeeves, 1979). In many cases it is diagnosed at necropsy. It has been observed that the anterior commissure is increased in size in some cases (Bossy, 1970; Geschwind, 1974). However, it is also frequently associated with malformations which appear to play the dominant role in the production of symptoms.

Studies on the visual and auditory abilities as well as on the skilled performance in 'acallosals' suggest that there is only minimal loss of efficiency in these functions. Milner and Jeeves conclude that the brain is capable of some compensation, both structurally and behaviorally. Acallosals do not show the characteristic features of split-brain patients. For instance, in dichotic stimulation a slight advantage for material presented to the right ear is observed in acallosals just as in normal subjects (Bryden and Zurif, 1970), whereas in split-brain patients stimuli presented to the left ear is usually not recalled. According to Milner and Jeeves (1979) there are two known agenesis cases in which localization of language was studied with the Wada-test. In the first case language was represented in the left hemisphere; the second case, a left handed patient showed signs of bilateral representation.

In general, the study of the rare phenomenon of agenesis of the corpus callosum is difficult to evaluate with respect to its impact on models of laterality. The neurological status, especially the structural alterations, are unclear at the moment. They primarily demonstrate the remarkable ability of the human brain to compensate for the absence of the major commissure linking the two hemispheres.

2.3.5 Lesion studies in children

Directly following his famous dictum 'nous parlons avec l'hemisphêre gauche', Broca states: 'c'est une habitude que nous prenons dês notre premiêre enfance' (Broca, 1865, p. 384). He made this statement without much discussion and without referring to any relevant data. Broca (1865) however, also discusses the possibility that in children, but not in adults, the right hemisphere can take over language if the left hemisphere has suffered damage. Developmental aspects have not been studied systematically in the early period of laterality research. If they were studied at all, it was mostly in the context of handedness. Weber (1905) mentions that it was known to neurologists that there was a difference between children and adults with respect to aphasia as a result brain lesions. In a few pages he describes the line of reasoning with respect to differential effects of brain lesion on language processes in children and adults, which has often been attributed to Lenneberg (1967). Weber refers to studies of Henock, Clarus, Olliver and Freitel, which show that children recover from aphasic disorders both more rapidly and much better than adults; that lesions on either side may produce aphasia in children; and that upon a very extensive left-hemisphere lesion the child's right hemisphere can apparently take over all functions. This is indeed remarkably similar to what, approximately 60 years later, Lenneberg (1967) formulated in a more elaborated way.

However, there is also a distinction between Lenneberg and Weber. Lenneberg considers 'development of laterality' to be an intrinsic characteristic of the biological system, which is responsible for an increasing logicalization of functions in one hemisphere. Left-hemisphere speech representation and right-handedness are both the result of this developmental process. Weber, on the other hand, argues that right-handedness, and especially writing with the right hand, results in the formation of a speech centre in the left hemisphere which is superior to that in the right. Irrespective of their theoretical distinctness, however, both Weber and Lenneberg start from the same observations: the different effects of right and left-hemisphere lesions on language processes in children and adults. Both authors take the position that representation of speech in one hemisphere is due to developmental changes.

Hécaen (1976) described a series of 26 cases of cortical lesions in children from 3,5 to 15 years of age (17 leftsided, 6 rightsided and 3 bilateral), in which 19 had varying degrees of language disturbance. In general, his results are in agreement with those of Basser (1962) and in principle he accepts the position taken by Lenneberg. However, he argues that the critical period during which each hemisphere is able to support language is of a briefer duration than is suggested by Lenneberg. According to Lenneberg this critical period lasts until approximately puberty, whereas Hécaen confines it until the age of 5. Furthermore, he recognizes that there is convincing evidence that some anatomical and functional features are asymmetrical at a very early stage and this has forced him to reconsider the concept of critical period.

Woods and Teuber (1978) reviewed the literature on the effects of unilateral lesions in children. They argue that only pathological data collected before 1930-1940 favour the higher incidence of aphasia due to rightsided lesions in children. The authors point out that these patients had no access to antibiotics. As it is the case that systemic infectious diseases were often the cause of the symptoms observed, it seems plausible to assume bilateral encephalopathy. Seron (1981) also reviewed some newly reported cases and confirms the view of Woods and Teuber: the hypothesis that right hemisphere potentialities decrease in the course of ontogenesis seems to possess no firm basis, if we are to infer those from a change in the incidence of language disorders and recovery after unilateral damage over age.

This very same notion, namely that the right hemisphere can take over the language function in an early stage has led to a surgical intervention in children which suffered from severe forms of unilateral hemiplegia. This technique is known as hemispherectomy. In the area of laterality research the study of hemispherectomized children has played an important role and it still does.

2.3.6 Hemispherectomy

A very important source of data on the development of language in relation to laterality are the studies on the effects of hemispherectomy. In 1935 this surgical treatment was introduced by Zollinger. The idea behind the operation was that the affected hemisphere interfered with the functioning of the intact hemisphere. This phenomenon is sometimes referred to as 'diaschisis', a concept introduced by Von Monakow (1914). By removing the affected hemisphere, the remaining hemisphere could function at a higher level. It appeared that children who underwent this treatment recovered remarkably well. After a period of training, they typically regained most of the normal functions. More particularly, in children who were operated before the age of two, it was believed that the residual effects were minimal and even language development seemed close to normal. However, when Dennis and her colleagues (1975, 1976) presented a detailed battery of language tests to left hemispherectomized children, it appeard that subtle, but linguistically important, defects could be demonstrated. This raises the question whether the right hemisphere processes language in an identical fashion as the left hemisphere, when it takes over the language function.

Leleux and Lebrun (1981) studied two cases of left hemispherectomy. Using the test material of Dennis they were not able to confirm the conclusions drawn by Dennis. They demonstrate, however, that these patients, if given time, were able to reach a satisfactory level of linguistic performance. Even granting that the studies are conflicting at some points, it is perfectly clear that the right hemisphere in hemispherectomized children is certainly capable of most language and that only sophisticated testing can reveal deficits.

2.4 Evaluation of lesion studies

The 'classical' neurological notions on the relation between side and effect of lesion have remained upright for a long time. They also began to exert influence on the views hold about the development of the central nervous system in children. Only since about 1930-1940 has the right hemisphere been seen to play its own part again, albeit still a minor one. More and more case studies appeared reporting on patients with right-sided brain-damage, showing specific defects like construction disorders or apraxia for dressing. The work by Teuber and his co-workers have redirected the research towards the differential effect of left and right-sided brain lesions. Semmes (1968) presents a model of laterality, largely based on this work. She found that the relationship between the site of lesion and spots of insensitivity on the right side of the body was much closer than for lesions in the right hemisphere and the left side of the body. A given lesion in the right hemisphere apparently resulted in more than one insensitive spot and they were distributed over a large area. These observations led her to formulate a theory on the difference between the two hemispheres, which is in my view directed at the differences in localization of functions rather than at the differences in processing styles. Basically she claims that functions are represented in the left hemisphere more focally and in the right hemisphere in a more diffuse way.

In view of the critical comments that have been made from the beginning of laterality research, the 're-discovery' of the capacities of the right hemisphere can be characterized as the final recognition of a vision too long suppressed by the 'classical notions', rather than as a new insight into this matter. Yet another aspect becomes clear when early studies are contrasted with recent reports. While in the 19th century attention was devoted to localizing the precise site on the cortex, with a relative neglect of an analysis of the nature of the faculty or function under consideration, this picture seems to be reversed in current studies.

The traditional interpretation of the data on the effects of unilateral lesions on language performance has been that they show that language is represented in the left hemisphere in right-handers and in the right hemisphere or bilaterally in left-handers. However, studies using relatively large numbers of cases clearly demonstrate that language is represented in the left hemisphere in the majority (approximately 70%) of the left-handers also and that bilateral representation is relatively rare in both right- and left-handers. If it were not for the fact that right-handedness and left-brainedness are disproportionally frequent in the population, there would not have been any reason to think of a correlation between handedness and brainedness in general.

Although aphasia typically occurs after leftsided lesions, the role of the right hemisphere in general has been underestimated. In view of the results of the split-brain studies and the hemispherectomized children this seems to hold for language as well. It may well be that apparent inconsistencies are due to the fact that we do not know the 'border lines' of the function of language. From a psycholinguistic point of view the classical neurological view of a very limited number of centers does not seem plausible. If we conceive of language as a functional system consisting of many subsystems we might well expect to find 'language areas' over a much wider part of the brain, including perhaps even subcortical structures, than has traditionally been assumed.

It is difficult to determine exactly what the results of split-brain studies on epileptic patients can tell us about the function of the normal brain. In some patients the brain damage was present at a very early age; in others it is plausible to assume that a long-standing and enduring illness may have had some effect on the functioning of and the organization in the brain. The surgical treatment has been given only to very serious cases, who were not responsive to other therapies such as pharmacological treatment. It is unclear whether or not the presence of epileptic foci can have induced an abnormal organization of the intact cortical areas during development. Finally, in split-brain patients we observe an information processing system which has been split in an artificial way: if one assumes that in the intact brain the processes of the two hemispheres are intrinsically integrated then one can be sure that almost every sign of the latter integration is lost in these patients. It is in fact quite likely that the published results of the surgical treatment (rather than, for example, any of those of the study on handedness or of the effects of brain lesions) are themselves responsible for the enormous increase in interest in laterality and for the production of that class of models which describe the two hemispheres as two more or less independent systems, capable of processing information of a particular nature (e.g. verbal-nonverbal) or in a specific manner (e.g. analytic-holistic). This view of the brain is too simplistic and misleading.

Finally, almost all hypotheses with regard to asymmetrical functioning of the brain are based on observations made on patients with brain damage. The clinical studies provided us with models. In the next chapter I will review experimental studies that have attempted to validate the picture that emerges from the clinical studies.

3. LATERALITY IN EXPERIMENTAL STUDIES OF THE BRAIN

3.1 Introduction

The present chapter will concentrate on studies in which subjects are studied whose brain is assumed to be intact. As discussed above, handedness has always been considered to be a feature related to laterality. Sometimes 'eyedness' and 'footedness' have been included in studies on handedness. In general, however, the picture with respect to the latter two measures of laterality is considered to be much less clear. For 'eyedness' different measures have been suggested. These include the preferred eye for sighting monocular instruments such as telescopes; the dominant eye in rivalry situations; the eye with the best acuity; the controlling or lead eye during reading; and the eye that is most difficult to wink. Many of these measures have subsequently proven to be unreliable, while other tests may measure a diversity of factors (Porac and Coren, 1976). Furthermore, they have hardly contributed to the discussion on the mechanisms underlying laterality. For these reasons they will not be reviewed in detail below.

During the last two decades two new experimental techniques have been applied in a large number of studies, namely dichotic listening tasks and visual half-field tasks. Basically, it is assumed that with these techniques stimuli can be presented initially to a single hemisphere and that from the responses to these stimuli conclusions can be drawn with respect to the different capacities of each hemisphere. A review of studies using these techniques, as well as a discussion of the validity of these techniques as measures of laterality, will be presented below.

First I will discuss handedness. There are a number of interesting aspects which have been studied, such as the inheritance of handedness, and the relation of handedness with other laterality measures. I will then describe studies using the two experimental paradigms, dichotic listening and vhf-stimulation. These three measures of laterality, viz., handedness, dichotic listening and vhf-stimulation, have also been used to study development of laterality. The results will be summarized in a separate section.

Finally, I will attempt to evaluate these experimental studies and formulate some conclusions that lead to the experimental studies presented in this thesis.

3.2 Handedness

Handedness has been studied for a long time even before Broca's publications (1861, 1865). Harris (1980) has prepared an extensive historical overview of early theories on hand preference and left-handedness. He reaches the conclusion that most (not to say practically all) early theories on the relation between handedness and other variables can still be found in current papers. Indeed, it is strange that more than 150 years of data-gathering have not been able to produce a significant change in this picture. Most explanations of left-handedness are still being supported by at least several adherents; there is, however, not a single explanation that has received general acceptance.

Before discussing studies on hand preference in greater detail, it may be useful to note three points. The reason for doing this is that I want to clarify the point that many explanations in the area of handedness merely refer to a specific feature such as 'preference' or 'left-handedness' without providing answers to several, let alone all of the most obvious of the undoubtedly related issues, such as 'is there a common mechanism for right- and left-handedness?', 'does handedness develop?', 'what is the relationship with cerebral dominance for speech?', 'is handedness genetically determined, and if so, how?'. A second reason is that these issues are intricately related to my view of laterality as discussed in Chapter I.

First, it is possible to make a distinction between the concepts of 'preference' and 'performance' with respect to handedness. Sometimes handedness is determined by asking a subject which hand he prefers to use for a particular task. One can also measure the difference in ability of the right and left hand, such as that of putting 10 pegs from one row of holes into another row. These two measures, preference and performance, do not correlate perfectly (Raczkowski, Kalat and Nebes, 1974). Furthermore, it is unclear whether a difference in performance is the result of an initial preference for using a particular hand, followed by a large amount of practice, or the other way round. Finally, performance measures produce a continuous distribution of laterality whereas preference is usually responded to with 'right', 'left', or 'both'. From this it is obvious that it is not necessarily the case that preference and performance measures can be used interchangeably.

A second point is the fact stated above that certain authors try to explain handedness as due to a single factor, whereas others recognize separate factors for right and for left-handedness. However, for some time now, there have been suggestions in the literature that both right and left-handedness may themselves be due to more than one factor (Satz, 1973).

The third and last point to be made here is the fact that many authors discuss handedness in a dichotomous fashion: a subject is either right or left handed. Even in earlier studies one can, however, find suggestions that, especially in non-righthanders, differences in degree of handedness are observed: some left-handers prefer their left hand for a number of tasks but their right hand for others. A person lacking a pronounced preference for either hand is usually called ambidextrous. This concept, however, may have different meanings in a way similar to that of 'bilateral representation in the brain'; it may mean that the subject performs a particular task with his left hand about as well as with his right, or just that he uses his left hand for task X and his right hand for task Y. Although it has been known for a long time that handedness may not be a simple dichotomous variable, attention has only recently been devoted to theory construction and empirical studies starting from the assumption that handedness is a continuous variable within the population. With these points in mind we will now look at the results of studies on handedness.

3.2.1 Inheritance of handedness

In the first half of this century a number of extensive studies were performed on the inheritance of (left-)handedness. Population studies were undertaken by Jordan (1911), Ramaley (1913), Chamberlain (1928) and Rife (1940). They all showed significant parent-child correlations for handedness, suggesting a genetic factor operating in the determination of handedness. Most of the proposed theories are simple mendelian models. During the last decades hand preference has been studied very extensively. In particular Annett has performed studies on large samples. On the basis of this material, very specific questions on the genetics of handedness can be answered. Annett (1978) has also provided convincing evidence that both hand preference and differential performance can best be considered as continuous variables. In her opinion, left or right-handedness is determined at random, unless a specific genetic factor, that she calls the Right-shift factor, is present. This factor is supposed to be present in most people. It increases the chance of becoming a right-hander and of developing a left-hemisphere dominance for speech.

Levy and Nagylaki (1972) have developed a different genetic model. In this model cerebral dominance and hand-preference are completely linked to one another in a special way. One factor regulates which hemisphere will be dominant for speech. A second factor determines whether motor control over the hand will be executed along the crossed or ipsilateral fibers. The latter model, however, appears to be incompatible with empirical data on handedness, especially in twins (for a discussion of the issue, see Hudson, 1975).

Many early explanations of handedness suggest mechanisms unrelated to the funtional and structural properties of the brain (cf. Harris, 1980).

However, it appears from the literature that all of the models on the ontogeny of hand preference that are currently taken seriously, attach great value to hemisphere specialization.

3.2.2 Handedness and other laterality measures

Handedness has served as an independent variable in many studies. In this way researchers have tried to compare subjects with assumed different patterns of hemisphere specialization. In a number of studies right and left-handers have been compared on dichotic listening or visual half-field stimulation tasks. These studies yield results very similar to those of clinical studies: a more or less clear picture with respect to hemisphere specialization for right-handed subjects and a much larger variation of lateralization and its degree in left-handers (for a more extensive review, see Hardyck and Petrinovitch, 1976). A majority of right-handers show left-hemisphere specialization for verbal processing and right-hemisphere specialization for visuo-spatial and musical information. Left-handers, in general, often seem to be 'less lateralized'.

Hardyck (1977) has discussed evidence which suggests that the picture for the left-handers becomes clearer if they are separated into two groups, those with left-handedness in the family and those without. In the group of familial left-handers, laterality (as measured by different methods such as dichotic listening and lesion effects) is particularly inconsistent.

Levy and Reid (1978) have made another suggestion for splitting up the group of left-handers (as well as the group of right-handers) namely on the basis of the position of the writing-hand; left-handers can be classified into those with a 'normal' position and those with the 'inverted' position. According to Levy and Reid hand preference and hand position during writing are determined by two factors: hemisphere dominance for language,and the question whether motor control occurs with the ipsilateral or contralateral fibers, respectively.

If in a given subject the left hemisphere is dominant for language and motor control is exerted via uncrossed fibers, the subject will be left-handed and write with the inverted hand position. The latter way of classifying left-handers has, however, not yet been as fruitful as the method proposed by Hardyck. A critical evaluation of the assumptions underlying this model and its empirical support, is given by Weber and Bradshaw (1981).

A number of studies suggest that the larger variance and the smaller degree of hemisphere dominance that has been observed in a number of tasks in left-handers can also be found in the degree of hand preference and differential performance: hand preference in non-right handers is in general not as outspoken as in right-handers. This may be concluded both from research using questionnaires (Annett, 1978b) and from studies using fairly simple motor tasks such as peg-board (Annett, 1970) or tapping tasks (Peters and Durding, 1979). It is unclear whether this proposition also holds for 'pure left-handers'. (See also Hicks and Kinsbourne (1978) for a literature review).

3.2.3 Evaluation of handedness studies

Shortly after Broca's suggestion (Broca, 1865), it was widely accepted that there was a close relationship between localization of the speech center and the preferred hand. There have been few serious attempts to answer the question whether these two variables are intrinsically related to one another, i.e. whether left-hemisphere specialization due to right-hand preference (or the other way round, cf. Kimura, 1976) or whether the observed relation is a pure coincidence. The fact that the relation seemed to hold for a large part of the population (because the speech center is only rarely found in the right hemisphere and the majority is right-handed), has no doubt contributed to the widely spread belief that the issue of laterality in brain and hand would be solved if an explanation could be found for the small number of 'deviant' laterality patterns. Such patterns are observed particularly in the group of left-handers where a relatively high number of cases of 'crossed aphasia' is observed as well as of bilateral representation of language. It now appears that these deviations cannot be explained by simple relationships, as I have discussed in the previous chapter.

Below I will show that it is possible that a similar, low correlation is obtained in dichotic and vhf-studies; most subjects report verbal stimuli better and/or faster from the right ear and from the right visual half field, and most subjects are also right-handed. However, there is no convincing evidence that those left-handers showing left-side preferences in dichotic listening or vhf-stimulation also have speech represented in the right hemisphere. Nor is there an explanation for the fact that, although approximately 95% of the right-handers may be assumed to have left hemisphere dominance for speech, generally only between 70 and 80% of them show a right-side performance advantage in dichotic and vhf-studies. The conclusion that hand preference and ear of field superiority are closely related may thus be unwarranted. In the next section, in which these dichotic and vhf-studies will be dealt with in more detail, I shall return to this issue.

Beside the possibility of a spurious correlation between hemisphere specialization for language and hand preference, there is yet another factor which may have contributed to the widely held opinion about hand preference as associated with hemisphere specialization. It is possible that this conception has been induced by the common assumption that asymmetries observed with different methods and techniques all refer to one and the same phenomenon: laterality. A nice example of a theory that explicitly conceives of laterality as a single factor resulting in asymmetries at different levels (structural, functional) is the theory proposed by Corballis and Morgan (1978). If one assumes only one factor to be responsible for all asymmetries then one would expect a consistent pattern of asymmetries in the population, except when disturbing external influences incurred during life have reversed the direction in one or more of them. However, it is generally accepted that a mixed pattern of laterality, e.g. a preference to use the right hand and left foot or left eye, is not an uncommon sign and is in itself not pathological. Nevertheless, the possibility remains that minor cerebral lesions may result in inconsistent laterality patterns.

In conclusion, it may be said that the phenomenon of laterality as regards handedness is well described by Annett (1978). Her model explains nicely the distribution of its occurrence in the population. Also the notion of a continuum of laterality is taken into account. However, the issue of the relationship of handedness towards other indices of asymmetrical functioning of the brain has not been settled in a satisfying manner.

3.3 New experimental measures of laterality

In the recent past, two experimental techniques have been developed which appeared to be useful for studying laterality: visual half-field stimulation and dichotic listening. Of both methods a number of different procedures have been described, varying, for instance, in the number or kind of stimuli presented, or in the way the subject has to respond.

Characteristic for vhf-studies is that the stimuli are briefly flashed, usually for less than 150 ms, to the left or to the right of a central fixation point. Dichotic listening is typically done by presenting two auditory stimuli simultaneously, one stimulus to the subject's left ear, the other to his or her right ear. The two methods are generally considered to be analogous ways of measuring laterality, although several factors are known to affect their results differentially. For detailed information and references, the reader is referred to White (1969, 1973), Bradshaw (1980), and Beaumont (1981), for vhf-studies; Berlin and McNeill (1977) and Berlin (1977) review dichotic studies.

3.3.1 Visual half-field studies

Mishkin and Forgays (1952) noticed that English words were better recognized when they were projected to the right half than to the left half of the visual half-field. The situation was reversed for Hebrew words. Mishkin and Forgays argued that this phenomenon could be explained by referring to the concept of 'reading direction'. It was assumed that 'post exposural scanning' was in the direction of the normal reading process, i.e. from left to right for English words, starting from the central fixation point. Words in the left visual half-field were presumably faded out before they could be properly perceived.

By using different manipulations with resnect to the stimulus (e.g. by placing letters in a vertical arrangement, or by using single letters) or with respect to the mode of stimulus presentation (e.g. one stimulus unilaterally or two simultaneous stimuli, one in each hemifield) it was demonstrated that the 'reading direction hypothesis' was insufficient as an explanation for the difference in recognition scores between the two visual half fields. The alternative interpretation is based on the connections of the retina to the cortex (see White, 1969, 1973). The left halves of both retinas are connected to the left hemisphere. If the fixation point is defined as the middle of the visual half field and if a stimulus is flashed in the right visual field, it will fall on the left hemi-retinas and from there it will, in first instance, be projected onto the left hemisphere. This holds, mutatis mutandis, for a picture presented in the left visual half-field. The technique was soon adopted for doing laterality research and it has been used in numerous studies on split-brain patients and normal subjects.

In a number of studies an interaction was found between handedness and half-field superiority in word recognition scores (see Bradshaw and Nettleton, 1981; Beaumont, 1982). The results of the first experiments were promising in that it seemed that the technique could be used to assess cerebral dominance. Nevertheless, from the beginning it had been obvious that there was no clear-cut relationship between handedness and word recognition scores. Typically only about 75% of the right-handers have higher word recognition scores for the right visual half-field (Bryden, 1964). However, between 90% and 99% of the right-handers are found to be left-dominant for speech on the basis of results of clinical studies using the sodium-amytal test. Similar inconsistencies between half-field preference and hemisphere specialization have been reported for left-handers (Annett, 1982).

Another way of demonstrating that a difference in word-recognition scores for the two half-fields is determined by 'cerebral dominance' is to show the existence of a statistical interaction between half-field scores and stimulus materials. If a left-hemisphere specialization for language leads to higher word recognition scores in the right visual field, then one may expect that the supposed right-hemisphere specialization for 'visuospatial' perception or for face recognition will result in higher left-visual field scores for stimuli such as portraits, geometrical shapes or dot patterns. A number of data consistent with this expectation have been reported but there are also a number of studies which fail to find a higher left-field score for nonverbal materials (Davidoff, 1982). It is possible that in certain tasks non-verbal material is verbally encoded in short term memory by the subjects. This argument has been invoked frequently in the literature to explain 'negative' results in studies that attempted to show a right hemisphere superiority for a certain kind of nonverbal stimulus-material, but it is at best post hoc. White (1969) formulates his conclusions with respect to the usefulness of the half-field technique for measuring laterality in a very careful and rather pessimistic way. He describes six factors that influence the observed laterality effect. These are (a) the type of stimulus presentation, unilateral or bilateral; (b) the amount, nature and spacing of the stimulus-information elements; (c) the intensity at which the information is shown; (d) the order in which the information is reported; (e) the viewing condition employed at the ocular dominance of the subjects; and (f) the handedness and lateralization of the subjects. Some of these factors, e.g. stimulus intensity and order of report, are unrelated to hemisphere asymmetries.

Somewhat more positive are the studies on split-brain patients using the vhf-technique (for reviews, see Gazzaniga (1970), and Dimond (1972)). To a large extent these studies were responsible for the abandonment of the 'unilateral dominance' view. It appeared that verbal material presented to the right hemisphere of a split-brain patient could in some instances be recognized, but not named aloud. If a patient was allowed to point with his left hand to an object that was denoted by a word in the left half-field, he seemed to be quite capable of performing the task. Furthermore, a patient presented with faces in the right visual field, could recognize these. Levy and Trevarthen (1969) presented 'chimeric' faces to these patients: the left half of one face combined with the right half of another. If the patient was asked to point to the face in a set of alternatives with his right hand, he would point at the portrait of which the right half had been presented in the right hemifield. However, when he was to use his left hand he would choose the portrait of the other half face. This demonstrates the relevance of the choice of response in vhf-studies, in split-brain patients and possibly normals, as a possible factor influencing the laterality score. Different types of responses have been used, e.g. vocal vs. manual, recall vs. recognition. Asymmetries have been observed irrespective of the response used. However, only very few studies have studied the effect of response type on the magnitude of laterality in terms of either relative difference between hemispheres or the proportion of subjects showing (significant) asymmetries. Results of this type are not compatible with a formulation of differences between the hemispheres in terms of the exclusive processing of a specific type of stimulus material either in the left or in the right hemisphere. That is, the characterization of the left hemisphere as the verbal hemisphere and the right and the non-verbal or visuo-spatial hemisphere was apparently not correct.

As an alternative to the latter dichotomy, Levy (1973) suggested that the major difference between the hemispheres is the way each hemisphere performs the perceptual act: the left hemisphere is hypothesized to perceive analytically, the right holistically. The discussion on this issue is still going on (Bradshaw and Nettleton, 1981). It is as yet unclear whether this dichotomy is any more valuable. Probably the concepts of analytic and holistic processing are too general: they can explain almost any difference between hemifields or ears but they often do so in an ad hoc manner (Bertelson, 1981; Marshall, 1981).

A recent demonstration of the weakness of this approach is the study by Bagnara, Boles, Simion and Umiltà (1982). They define 'same' responses to pairs of identical letters as the result of holistic processing and 'different' responses to non-identical letters as requiring analytic processing. In earlier studies (e.g. Egeth and Epstein, 1972), hemisphere differences between 'same' and 'different' responses had been demonstrated. Bagnara et al. failed to find any. They conclude from their study that both the right and left hemisphere are specialized in both analytic and holistic processing!

Technically, vhf-studies are easier to perform than dichotic studies. However, there is one problem with vhf-studies that should not be underestimated. It is the issue of controlling eye-fixation and eye-movements during the presentation of the stimulus. Young (1982) has prepared a review which specifically examines the question as to how fixation is controlled in the literature. A wide variety of procedures is used for that purpose, ranging from presenting a simple dot in the middle of the screen and just asking a subject to fixate, to recording the subject's eyes via a camera viewing the eyes through a hole in the centre of the visual field. Many procedures are accompanied by specific disadvantages. No general procedure has been accepted as satisfactory. However, it must also be noted that, to the author's knowledge, it has not yet been demonstrated experimentally that the use of proper control measures for fixation actually results in clearer laterality effects. The demand for eye movement control has, nevertheless, frequently been stated as a logically plausible argument against studies that fail to find 'expected' laterality effects. Besides the issue of proper fixation control there is the question, mentioned above, of the influence of response mode on observed laterality effects (Young, 1982). As stated this problem has hardly been studied systematically.

The vhf-technique has become popular in laterality research because the researcher is no longer restricted to clinical patients, who are sometimes hard to come by. Moreover, he can now study 'the normal functioning' brain. With the technique many questions about the functioning of the two halves of the brain, or differences between subject populations have been studied. However, only a few studies investigate the reliability of the technique and the results of these studies give little reason for enthusiasm (Young, 1982).

It seems doubtful that the observed laterality effects can be interpreted in a straightforward manner as showing functional differences between the two hemispheres. Nevertheless, it may at least be useful for dissociating psychological processes. It seems necessary that we soon learn more about its reliability and about such questions as how stimuli must (not) be presented, how fixation and eye-movements can best be controlled, and to what extent factors related to laterality can explain differences between hemifield scores.

3.3.2 Dichotic listening studies

In 1954 Broadbent published a study in which he presented a series of digits to the right ear and simultaneously another series of digits to the left ear. He wanted to study the effect of 'channel of input' on short-term memory encoding. Kimura (1961) used this technique in patients with lesions in either the right or the left temporal lobe. Apart from certain other interesting results, she noticed that the majority of the patients recalled more digits from the right ear than from the left. She related this differential recall to the left-hemisphere specialization for language. Her explanation of the phenomenon, sometimes referred to as the 'structural hypothesis' was as follows: each ear has connections to both hemispheres but the fibers going to the contralateral hemisphere are more important. From dichotic studies on split-brain patients (Milner et al., 1968) it may be concluded, as Kimura (1975) did, that during dichotic presentation under non-pathological conditions, contralateral connections suppress ipsilateral connections. Verbal information presented to the right ear has direct access to the language processing system. Simultaneous information coming from the left ear cannot enter to this system along the suppressed ipsilateral pathway. Rather, it is sent to the right hemisphere first and only subsequently, via the corpus callosum, to the left. Loss of left-ear information will occur because of the longer route that has to be travelled, or because of the fact that this information is held up until the stimuli from the right ear have been processed. In connection to this it is worth noting that (in addition to the fact that the left-ear score is usually lower than the right-ear score) the right-ear score is below the level of monaural presentation.

Kinsbourne (1970) has suggested a somewhat different explanation, sometimes referred to as the 'attentional hypothesis'. He suggests that, depending on the type of stimulus presented, one of the hemispheres (the one that is specialized for that type of material) will be 'activated' and consequently attention will be directed to the contralateral side in space.

Both these authors assume that dichotic tests primarily tap a lateralized perceptual system. Others have argued that the more important aspects measured are short-term memory encoding and recall strategies. For instance, it has been suggested (Inglis and Sykes, 1967) that loss of left-ear material is due to the fact that subjects tend to report right-ear digits first and left-ear digits later. In many studies subjects are therefore requested to report right-ear items first on one half of the trials and left-ear items on the other half. With this control procedure, however, there still tends to be a better recall of right-ear items. Reaction time studies have also been performed in order to circumvent the short-term memory explanation of the right-ear advantage (REA). This line of studies has also shown that an advantage exists (in terms of a larger number of correctly reported items and of shorter reaction times) for the right ear in the perception of verbal material. Thus it may be concluded that the REA cannot be solely attributed to memory factors. But the conclusion that the methods employed provide pure indices of laterality seems premature and unwarranted.

The interpretation of the differential recall, usually referred to as the REA for verbal material, has been validated to a certain degree by comparing ear advantages from right and left-handed subjects and by comparing ear advantages for verbal material and music. Originally, many experiments were performed with dichotic lists that were similar to those of Kimura (1 to 6 pairs of naturally spoken digits presented for either free or ordered recall). Researchers at the Haskins Laboratory (Shankweiler and Studdert Kennedy, 1975; Repp, 1978), however, introduced dichotic lists with only the syllables ba, da, ga, pa, ta and ka. Some of the tapes they prepared were generated by a speech synthesizing system, so that all acoustic aspects could be manipulated. One difference between the latter type of material and most other types is that it appears to be harder to process: if only one pair is presented and subjects are requested to report both syllables; they score at chance level for the syllable reported second, whereas in other tapes using digits or words both stimuli can be recognized relatively well (or even perfect) if only one pair is presented.

As with the visual half-field paradigm, many kinds of dichotic tests have been employed for studying the relation between laterality on the one hand, and on the other hand subject variables, such as age, sex, the presence of stuttering and dyslexia, as well as stimulus variables such as the items' consonant or vowellike characteristics.

The suggestion that ear advantages reflect 'laterality' has not often been questioned. Nevertheless, problems similar to the ones I have discussed with respect to the vhf-technique also apply to dichotic listening. For instance, not all subjects who can be assumed to have left-hemisphere speech representation show a REA. On the contrary, if one would infer from a left-ear advantage in a right-handed subject that his right hemisphere is specialized for speech, one would almost certainly be in error (Satz, 1975).

Another problem with respect to the validity of this technique is that subjects having a REA on a dichotic test do not necessarily show a right half-field advantage in a vhf-test (Zurif and Bryden, 1969). Furthermore, and perhaps related to the latter issue, there is the problem that the question of reliability of ear advantages has not yet been settled. Certainly not all materials are equally reliable. The consonant-vowel-type of stimuli (e.g. /ba/, /da/) used at the Haskins Laboratory and by Berlin (1977) and his co-workers (although hard to process; see above) do appear to yield relatively consistent data.

During the last few years an increase in awareness can be observed of the difficulties involved in the theoretical and statistical aspects of measuring laterality with dichotic tests and vhf-stimulation. Most authors interpret the results of their dichotic experiments in terms of 'degree of lateralization'. The legitimacy of this interpretation has, however, been questioned (Colbourn, 1978; Richardson, 1976) because it unduly assumes that we have a theory about laterality that is not in terms of right-hemisphere functions vs. left-hemisphere functions. It must be admitted that no such theory has as yet been presented, but many authors feel that the differences in degree of lateralization, as observed in dichotic studies (but also in studies on, for instance, handedness and effects of lesions) reflect an important aspect of the working of the brain. They represent the relative contributions of left and right-hemisphere subsystems that cooperate in a particular task. Related to this point is the question as to which measure of laterality should be used. The simplest one is the difference between scores for recognition or recall (R-ear minus L-ear). This measure has certain disadvantages, however, and a number of alternatives have been proposed during the past decade (for a discussion of most of the proposed measures, see Repp, 1977)). In order to decide which measure should be used, it must also be specified in advance what relationship there is between laterality (R-L) and absolute performance (R+L): is a more lateralized subject better in his overall performance or should these scores be considered independent of each other? During the last few years a number of papers have described how statistical properties of the measures used in laterality studies can lead to artefactual results (Stone, 1980).

Bryden (1978) has clearly shown that ear and half-field advantages not only reflect 'hemisphere specialization' for a particular function, but that other factors, unrelated to differences between hemispheres, contribute to these advantages as well. They have to do with the strategy a subject adopts when confronted with a dicotic task (Bryden, 1978). Considering that laterality effects generally are in the order of magnitude of 5-15% and assuming that in a given experiment a number of factors determine direction and magnitude of the effect, it is obvious that one cannot interpret left-right asymmetries in this type of experiment in a satisfying manner.

In conclusion, it may be stated that the use of the two recent experimental techniques for measuring laterality has resulted in a very large, perhaps even distressing (Marshall, 1981), number of experiments over a relatively short time. The results, thusfar, are neither really amazing nor even promising. Very often they confirm what was already observed in clinical studies and if they fail to confirm these, they are either ignored or explained away. However, the increased critical interests in the way the different concepts are used and measured in this area of research may be considered a positive effect of these studies. Furthermore, having accepted that difference scores are due only in part to hemisphere specialization, we can start determining to what extent laterality assessed by different paradigms refers to the same construct.

3.4 Developmental studies

Since the introduction of the dichotic listening technique as a means for measuring laterality, a large number of dichotic studies have examined the developmental aspects of language representation (for an overview, see Satz et al. (1975)). Starting from the traditional (i.e. Lenneberg's, 1967) point of view, one would expect to find no ear advantages in the youngest age groups and increasing ear advantages with increasing ages. In general, however, this developmental hypothesis is not confirmed. Most studies found significant ear advantages even in the youngest age groups tested. One interpretation involved the assumption that there was development but that it was completed before the child could be tested with dichotic listening. With the type of task originally used by Kimura (1961) it was not possible to test very young children. However, Molfese (1977) and co-workers performed a number of studies in which very young infants and newborns were studied. They presented cv-syllables dichotically and measured evoked potentials from the right and left hemisphere speech area. These studies showed more activity in the left hemisphere than in the right upon the presentation of speech stimuli. Studies using th vhf-paradigm tend to support these results (Young, 1981; Young and Bion, 1980).

This issue has not been settled finally. Until recently, the data of dichotic studies were simply the number of correctly recalled digits or cv-syllables, or reaction times involved in the recognition of target words. The underlying assumption in studies of this kind is that increasing laterality for speech will express itself in more words recalled or in faster reactions. This assumption looks reasonable if one argues that increased lateralization results in a more efficient system of processing. This type of measure, however, does not seem closely related to language development itself. That is, language development is generally believed to express itself not in a larger number of items produced but rather at the level of phonological and syntactical complexity. Thus, another approach may be to relate the development of laterality to the state of the verbal system at various ages. The fact that the language system develops implies that at a particular point in time certain aspects of the verbal information cannot be handled yet or are handled in a manner different from that at a later point in the development. If the process of lateralization is concerned with the development of specific components of the language system, it may be necessary to use dichotic tasks that are different from the more traditional ones.

Perhaps in response to the growing list of negative empirical studies, Kinsbourne and Hiscock (1977) re-evaluated the clinical material and the impressions described by Lenneberg. In a provocative chapter they argued that from a set of empirical studies in the areas of childhood aphasia, handedness, dichotic listening and anatomical studies, it was evident that laterality was demonstrable from the first days of life. They did not accept most clinical studies on childhood aphasia, firstly because the side and extent of the lesion were not always properly checked; and secondly, because there is a danger of reporting particularly interesting cases which might have resulted in an overrepresentation of right-hemisphere damaged aphasic children in the literature. Another possible artefact suggested by Woods and Teuber (1978) has been mentioned above. These authors noticed that cases of aphasic children with supposedly only right-hemisphere damage were all reported before antibiotics were introduced. They suggest that in these cases the original lesion could have involved the right hemisphere exclusively, but that this lesion may have spread to the left hemisphere through progressive infection.

It can be concluded from this section that it has long been assumed that laterality develops with age but that recent, more systematic, studies have given rise to considerable doubt. It is very informative in this respect to note how different authors have interpreted the data of Basser (1962) and have corrected one another on this point. Basser presented a review of cases of aphasia in adults and children after left and right-hemisphere lesions as they were described in the neurological literature. Primarily on the basis of these data, one author would accept the age of 14 as the final point of development of lateralization (Lenneberg, 1967), another would accept the age of 5 (Krashen, 1973) and yet others argue that there is no sign of development of laterality in these data (Kinsbourne and Hiscock, 1977). Indeed, the issue becomes very difficult to deal with if such different positions can be defended on the basis of the same set of data.

The problem of development of laterality has also been attacked in the study of handedness. Weber (1905) mentions studies showing that the first signs of preference for a particular hand can be observed at eight months of age and that preference is settled by the 13th month. The study most often referred to in this respect is that of Gesell and Ames (1947). These authors suggest that handedness may switch during infancy but is stable by the age of about eight years. Although this conclusion has been widely accepted, the evidence provided by Gesell and Ames is not very strong. They observed five children longitudinally from two months up till ten years of age who performed only a small number of tasks unimanually. These authors do not seem justified in concluding, e.g. from the result that 'deviations' of preference were observed in some children, that no preference is present in these children, let alone in the whole population of children at that age. A reasonable assumption seems to be that only a small proportion of children show some variability in hand preference, perhaps due to circumstantial factors. We should keep in mind that in adults approximately 30% of the subjects cannot be classified as either pure right-handed or pure left-handed. This implies that handedness does not develop.

A more systematic study has been performed by Annett (1970). She used a peg-board to measure the speech with which the right and left hand can put a number of pegs in a row of holes. With this measure, which appears to be a reliable and valid measure for handedness (Annett, Hudson and Turner, 1974), it appeared that the difference between the right and left hand remained unchanged over the different age groups. On the same line are the results obtained by Kinsbourne and his co-workers; they published studies in which they looked at the strength of the right and left hand of newborns and found indications of handedness comparable to those in older subjects (for a review, see Hicks and Kinsbourne, 1976). Thus it seems that, just as in the case of dichotic studies, the data on handedness also support the position that clear lateral differences are observable at birth. It still remains possible that at least of some of the differences between the two hemispheres become larger or more prominent with time; as yet, however, not many empirical results support such a view. The position that the two brain halves are equal at birth will most likely have to be rejected.

3.5 Evaluation of functional aspects of laterality

A wide variety of studies on laterality has been discussed. What is most prominent is that the different approaches (studies on handedness, vhf-stimulation and dichotic listening) have received increasing attention during the last twenty years. It appears that this development has resulted in an overwhelming number and variation of applications of the different approaches, even to such an extent that a high degree of specialization is required to follow exactly what is going on in each of these areas. This prevents me from formulating general conclusions concerning 'laterality'. Instead I would prefer to elaborate on some methodological issues which, though perhaps in an indirect way, may contribute considerably to the study of the working of the brain. The methodological discussions that have been going on in the literature during the past decade make us aware of the assumptions underlying the use of data that have been produced with a specific paradigm. In my view, conclusions such as, for instance, "the left hemisphere is specialized in analytic processes", are very likely to be rejected in the short run, because of the shortcomings of the studies upon which these conclusions are based. It is likely that results of dichotic studies will no longer be interpreted strictly in terms of hemispheric specialization. In the area of laterality it appears that conclusions have been accepted before solid evidence was collected. During the last decade some authors have realized that the sweeping and enthusiastic conclusions from the split-brain studies were not warranted. Very elementary, though in my view very fundamental questions such as whether we should measure on a nominal or higher level, have been discussed by several authors (Richardson, 1976; Colbourn, 1978; Eling, 1981). The answer to this question is crucial to the extent that, when only nominal measures are justified, one is forced to discuss the function of the brain in terms of the left hemisphere as specialized in function X and the right in function Y; interaction and cooperation of the two hemispheres in performing a task will be much harder to study. Whatever answer one may prefer, any researcher should be aware of the possible, or rather the permitted set of interpretations when deciding to study laterality phenomena using a particular level of measurement.

In the previous chapter I have reviewed clinical studies on laterality, describing the effects of unilateral lesions and of the dissection or absence of the corpus callosum. The present chapter deals with functional asymmetry in the intact brain. The results of the latter type have always been related to the clinical studies in a rather direct way.

An issue I would like to discuss here is the relationship between the *different measures of functional asymmetry and their relationship to the* clinical studies. The question here is one of validity. Is the REA a valid measure of hemisphere specialization? And what about the differential performance of the two hands on the peg board task? Are these measures intrinsically related to one another or is the only agreement that they measure differences between 'right' and 'left'? The answer to these questions cannot easily be given at this moment. There have been times that a generalized, positive answer was given without any hesitance. However, more and more evidence is piling up suggesting that laterality is not a simple phenomenon that can be studied with a large number of techniques. Moreover, it seems to me that these different approaches should in their turn be considered as different from lesion studies (Hardyck, 1983), at least to the extent that localization of symptoms should not directly be related to localization of functions.

Apart from these methodological points, what can we learn from the above studies on functional differences? One conclusion that seems to be generally accepted is that lesion studies tell us something about symptom localization: certain neuropsychological deficits can reliably be related to either left-sided or right-sided brain damage. Although it is very difficult to conclude from this line of evidence that function X is localized in the left hemisphere, one may conclude that the two hemispheres are not two functional mirror images. Results from experimental studies point to the same conclusion. While 'strict localization' (i.e., localizing a psychological function at a relatively small area of the cortex) seems to be impossible in the eyes of most researchers, it is perhaps possible to study the functioning of larger parts of the central nervous system by performing laterality studies. Apart from a general localization of functions (which to me, is not the most interesting part of laterality research), these studies could tell us something about the dynamic aspects of the information processing system. That is, we could learn the components and the relations among the components of the system, without strictly localizing each of these at a particular site. From the split-brain studies we can learn that, when the usual procedure is no longer available, the brain often develops other ways of performing a task. This holds for the damaged brain as well: it is not just a brain without the function(s) of the damaged area. Although this principle is well known, it has as yet failed to play a significant role in the discussion of language acquisition in hemispherectomized children. A second point we could learn from split-brain studies is that we should not conclude too quickly that any particular function cannot be performed by one hemisphere: it is possible that the response procedure chosen by the experimenter prevents that hemisphere from displaying its abilities. These principles can also be applied to studies on subjects having intact brains.

Summarizing we may conclude that we can contrast two different views of the functioning of the brain. The hemisphere specialization model suggests that the hemispheres can be considered as two independent systems. Each hemisphere is specialized in a number of functions. The fact that a particular set of functions is represented in a specific hemisphere can be explained by an underlying common feature which is shared by these functions. This feature can be characterized as 'requiring a particular type of information processing'. Implied in this model is the notion that different measures of laterality are closely interrelated. For the functions tapped by these measures are lateralized towards the same hemisphere because of that common principle.

The alternative view suggests that there is not a single fundamental principle underlying asymmetries between the two brain halves. What we tend to call 'functions' (e.g. reading, language, visuospatial orientation) can better be conceived of as functional systems. A system consists of a set of subsystems and a subset will be called upon for processing, the particular set depending on the task demands. This view of the functioning of the brain implies that different measures of laterality are uncorrelated to the extent that they call upon different sets of subsystems. This holds not only for functions that differ to a large extent, e.g. speech perception and music perception, but also for different types of speech perception. Thus, the latter view would predict that the degree of language lateralization may vary according to the way in which it is measured. In the following chapters a number of studies are presented that center around this topic. In the final chapter I will attempt to evaluate the results of these individual studies with respect to this general underlying framework.

4. ON THE THEORY AND MEASUREMENT OF LATERALITY

Paul Eling

In the experimental neuropsychological literature measures of lateralized performance have often been used as primary data for localizing functions. In contrast to traditional localizationists (students of the consequences of focal brain damage to different areas within left and right hemispheres) most authors have restricted themselves to ascribing functions to either the left or the right hemisphere, thereby suggesting that the neuroanatomical fact of a division of the cerebral cortex along the sagittal plane may have particularly important consequences for the representation of function in the brain. The two hemispheres are then described as two more or less independent systems, and functions are attributed to either the left or right hemisphere on the basis of a dichotomous principle. However, an increasing number of researchers have suggested that individuals may vary in their degree of functional hemispheric asymmetry (Jackson, 1915; Zangwill, 1960; Hardyck, 1977). This position implies that homologous areas of the two hemispheres do not represent identical functions with equivalent 'weight', but that there are varying degrees of functional asymmetry between the hemispheres. Several models can explain this variation. First, one class of models claims that in homologous areas similar or identical functions are located, but the neural substrates differ in the efficiency with which they can carry out those functions. The degree to which the two areas differ in functional efficiency could vary. Second, information processing models typically state that several discrete stages are involved in performing tasks that superficially might look quite 'simple'; depending on the stages that are employed and their respective locations, 'observed' laterality can vary as an arithmetic consequence of the lateralization of the subcomponents drawn upon in performing the task. These latter models have become more popular in recent years and may shift the attention of students away from global characterization of left and right hemisphere potentialities (e.g. verbal-nonverbal or analytic-holistic) to a more differentiated view of laterality phenomena.

There are several sources of evidence for the notion of laterality as a continuous phenomenon. First, handedness, a variable frequently believed to be a correlate of brain laterality, may be measured along a continuum. This holds both for hand preference (Oldfield, 1971) and for hand skill as measured, for example, by speech and error rate in a peg moving task (Annett, 1970). Second, it is generally agreed that the consequences of unilateral lesions for the language system may vary between individuals; a proportion of this variation has often been ascribed 'to the degree of dominance of one hemisphere in relation to lateralized processes such as speech production' (Luria, 1966). Furthermore, most experimental studies on laterality have used continuous measures of performance when investigating, for instance, differences between subject groups (e.g. men versus women). Finally, some authors have explicitly included the possibility of varying degrees of laterality in their models of cerebral dominance. Kinsbourne (1975) summarizes his experimental work as follows: Findings are presented "that support the predictions of a model that regarded the two human cerebral hemispheres as being in reciprocal balance. The direction of attention is at any moment the line of the vector resultant of opposing influences originating from the two hemispheres. A lateral shift in the location of the point of focal attention results from an increase of appropriate magnitude in activity of the hemisphere contralateral to the direction of shift and a corresponding decrease in the activity of the ipsilateral hemisphere" (p. 82). Such a model predicts genuine variations of laterality, although individual functions (i.e. the 'atoms' of the system) are localized in either the left or right hemisphere. Another example of authors who regard laterality as theoretically continuous is provided by Hécaen and Albert (1978). In developing a new model of cerebral dominance they write (p. 416): "On reconsideration of the above formulation and taking into account more recent data we believe that this model should be slightly modified. Certain symmetrical regions of the two hemispheres may have similar (instrumental) functions although to different degree". The notion of 'different degree' employed here seems to imply differences in quantitative functional efficiency for qualitatively similar or identical mechanisms.

It is important to note that we can (and perhaps sometimes must) make a distinction between direction and degree of observed laterality in a given situation. It is possible, but not necessary, that both attributes (direction and degree) are coupled to the same underlying mechanism that is responsible for observed laterality phenomena. Although some authors have explicitly pointed to this distinction before and even argued that variations in degree are caused only by extraneous factors (Morgan & Corballis, 1978), it seems from the way experimental data are treated in the literature that many authors currently believe the mechanisms to be indeed unitary.

Sometimes (Hiscock & Kinsbourne, 1977; Bakker, v.d. Vlugt & Claushuis, 1978) differences in degree and direction are separately presented, but only 'as an alternative means of describing the pattern for listening asymmetry' (Hiscock & Kinsbourne, 1978:221). Only very occasionally have separate theoretical analyses of direction (e.g. percentage of subjects having a right ear advantage) and degree (the difference in milliseconds or number correct between ears) been presented (Blumstein, Goodglass & Tartter, 1975). The main question now is "Is variation in degree to be considered a genuine aspect of functional laterality, a reflection of inadequate experimental control or an artifact of measurement?" Theoretical issues will be crucially implicated in any answer to this question.

As mentioned before, with respect to measuring degrees of laterality some theoretical problems have already been noted in the literature. Marshall et al. (1975) argued that if one measures laterality, expressed for instance as the difference between number of items correctly reported from the right and left ear, then this measure will not be statistically independent of overall level of accuracy. Marshall et al. formulate a laterality coefficient that is 'independent' in this respect. Their measure is applicable to recall or recognition scores but it remains unclear what an unbiased measure for reaction times should look like.

Richardson (1976) critically examined the assumptions of Marshall et al. and argued that their premises do not necessarily define a measure at a ratio level. He suggests that because there is no reasonable rich theory about the relationship between left side items correct and right side items correct as accuracy varies, we should look for a theory independent measure of laterality. Although it is difficult to see that such a measure can exist, Richardson nonetheless accepts the idea that laterality can vary by degrees; he regards the ordering of laterality measures as both possible and legitimate.

Colbourn's (1978) reasoning is even more rigorous: he argues that no acceptable theory about laterality variation is available and that therefore we should not draw any conclusions from the mathematical characteristics of the laterality measures correctly used. That is, variations in degree of underlying laterality should not be inferred from the fact that there can be only three outcomes from a laterality experiment: a left side advantage, a right side advantage or no advantage (Colbourn op.cit. p.284).

Colbourn thus argues that until a sophisticated theory of laterality is provided that explains explicitly what 'degree of laterality' means (psychologically and neurologically) we should use only nominal measures of laterality. The difficulty with Colbourn's position is, that as with Richardson, it is not a theory independent position. Of course, in principle it is possible that differences in degree are only artifacts of the measures taken. But if we describe laterality phenomena on a nominal level we restrict ourselves to models of (half) brain functioning that relate more to the putative anatomical substrate than to the psychological processes hypothesized in experimental studies. By analyzing laterality data both with respect to direction and degree of laterality valuable information might be obtained on such problems as: Is laterality a unitary mechanism or a multidimensional phenomenon?

A somewhat different problem with the measurement of laterality has been described by Birkett (1977, 1978). He presents data to show that degree of accuracy varies with degree of lateralization. But rather than correcting for this relation he thinks that it is intrinsic: the system works better the more it is lateralized. This position has a long history in the area of developmental language disorders, especially dyslexia. More studies directed at this hypothesis are needed, but if we are to study such a putative relationship we can hardly restrict ourselves to nominal measures!

Some promising results have been presented that point to the possibility that laterality is not a unidimensional phenomenon at the level of motoric preference and that complex tasks can be decomposed into functional elements that differ in degree and direction of laterality and are not predictable on the basis of motoric preference of skill. Shankweiler and Studdert-Kennedy (1975) have shown in a group of 30 righthanded adults that laterality indices of several manual tasks and a dichotic task have low and often non-significant intercorrelations. Porac and Coren (1979) compared laterality of hand, foot, eye and ear in 701 individuals and concluded "that there is probably more than one mechanism that is responsible for the development and the maintenance of lateral preference behavior (p. 547)".

Also, some new 'systemic' theories have been tentatively discussed by Fowler (1975), Beaumont (1974), and Hardyck (1977). These theories regard the brain as an information processing system, build up of discrete components. The representation and organization of components as well as the actual functioning of a subset of these components may vary across subjects and tasks. So rather than providing an answer to 'what it is that characterizes the specific functions of the right and left hemispheres in the normal adult', these theories intend to explain 'how the commissures act in providing information transfer, between the hemispheres, and in constraining, or modulating the activities in the parallel halves of the brain, in such a way that a functional asymmetry arises and is maintained' (Teuber, 1973:71). If we use 'right', 'left' and 'no-difference' as the only possible outcomes in laterality experiments, much of this work will be hindered. Within-subject variations will be much harder to study if we do not allow for higher levels of measurement. This position implies that current data and ideas do indeed demand new theories that more explicitly relate psychological functions to the (divided or co-operative) working of the two hemispheres (see also Broadbent, 1975; Cohen, 1975). In building theories we must keep in mind that:

- explanations at the psychological level need not necessarily speak to the representation of functions at the neurological level (although they may do so);
- an unambiguous description of what is meant by 'bilateral representation' is badly needed;
- there is an important distinction between direction and degree of laterality;
- more data are needed on the relationship between laterality scores (both recognition and RT measures) and overall performance levels.

In short, laterality research must go further than merely reporting 'right', 'left', or 'no difference' for each function; "neuropsychological investigation should provide us with a factor analysis that will lead to better understanding of the components of complex psychological functions for which the operations of the different parts of the brain are responsible (Luria, 1970:66).

5. THE DEVELOPMENT OF LANGUAGE LATERALIZATION AS MEASURED BY DICHOTIC LISTENING

Paul Eling, John C. Marshall and Gerard van Galen

5.1 Introduction

> -- nous parlons avec l'hemisphère gauche. C'est une habitude que nous prenons dès notre première enfance (Broca, 1865, p. 384) --

On the basis of biological, neurological and neurolinguistic evidence, Lenneberg (1967) concluded that the left hemisphere becomes 'gradually' specialized for language during the period from infancy to sexual maturity. Contrariwise, the right hemisphere's potential to subserve the language process as well as its actual involvement in language progressively decreases until puberty or so Lenneberg assumed. Yet many studies using dichotic listening paradigms have failed to demonstrate an increase in right ear advantage, that would correspond to this purportedly increasing left hemisphere specialization. Satz, Bakker, Theunissen, Goebel and van der Vlugt (1975) have presented an overview of some of these studies. They argued that the 'negative' results were due to methodological and statistical shortcomings. However, it is unlikely that the early results of Kimura (1963) can be explained by a ceiling effect; furthermore later studies (Geffen, 1976; Goodglass, 1973; Berlin et al., 1973) again suggested that the traditional model of progressive lateralization may be inadequate. Similarly, newer techniques that have been applied to study asymmetries in very young children (and even newborns) have suggested that some functional differences between the hemispheres may be present immediately after birth (Marshall, 1980). But almost all studies reported in the literature are cross sectional: the development of hemispheric specialization has been little studied on an intra-individual basis. Changes in lateralization can obviously be better studied in a longitudinal design. Another important aspect shared by all of the aforementioned studies is that none has related the development of lateralization to specific components of psycholinguistic functioning. Most of the studies have presented digits or consonant-vowel syllables as stimuli. However, if we assume that left hemisphere specialization involves only limited aspects of the language system, then one might look for a differentiation of the ear advantage between different language levels during development. This view implies that lateralization should not be regarded as a shift of a complete language system to the left hemisphere. In our view the language system should be regarded not as one unitary function, but rather as a composite of a set of subsystems, that, parallel to the functional development of language of the child, differentiates out of a more global, but asymmetric neurophysiological representation of the basis of language in the brain. That is, not the asymmetry of cerebral structures is subject to lateralization, but the functional differentiation of the language subsystems results in a more pronounced use of the left hemisphere language aspects during development. Such a view is also compatible with the observation of increased differences of the effects of right and left hemisphere lesions during childhood (Lenneberg, 1967).

Such differentiation cannot be observed in laterality studies that use 'global' stimuli and tasks. Thus different tasks should be constructed that relate to the hypothesized differentiation of the language system. In this way it might be possible to show that there is increasing proficiency of the left hemisphere for some aspects of language processing relative to others.

In the present study we have used two dichotic tasks, category monitoring and rhyme monitoring. These tasks, we assume, tap different levels of information processing, 'semantic' and 'phonological' respectively. We have looked at the development of ear advantages in children ranging from 8 until 16 years of age, and we have tested the children three times during a period of half a year. In a preliminary study we presented the two tasks to 40 adults in order to ascertain that both are reliable and valid measures of some left-lateralized system.

5.2 EXPERIMENT 1

5.2.1 Subjects

20 male and 20 female students and members of the Psychological Department participated in this preliminary study. All were completely right handed according to the Annett questionnaire (Annett, 1970). None of the subjects reported any hearing problems.

5.2.2 Tasks

Two dichotic monitoring tasks were developed. In a category monitoring task a number of pairs of words are dichotically presented and subjects are requested to decide whether a word belonging to a pre-specified semantic category occurred. In a rhyme-monitoring task identical material was presented but now the subject was asked to listen for words that ryhmed to a given word.

5.2.3 Stimuli

For the two different tasks we prepared tapes that were identical apart from the instructions. Stimuli were selected from a list of words (Kohnstamm & De Vries, 1969) that had been rated by teachers as 'familiar to kindergarten children'. 10 categories were chosen that we assumed to be similarly familiar to children (fruits, names, furniture, drinks, cities, body parts, animals, colors digits and vegetables). After having selected the categories and appropriate members we picked words that rhymed with members. Thus 'tafel' (= table) belongs to the category 'furniture' but also rhymes with 'wafel' (= waffle). In this way differences between tasks reflect differences in level of processing and not intrinsic stimulus differences. For each category or rhyme word (the instructional targets) five pairs of stimuli were constructed such that either two or three trials contained a positive item. One target word was always presented once to the right ear and once to the left ear. If a third positive pair occurred in a particular block of five a different target was presented either to the left or right ear. These trials were not included in the analyses. Before each group of five items an instruction was given; in the category monitoring task: 'The category is ...' and in the rhyming task: 'The word is ...'. The position of positive pairs within a group was randomly assigned. Thus 10 groups were prepared of five pairs each. These were repeated once, resulting in 100 trials of which 50 were positive, 25 to each ear. All words and instructions were first recorded by a female voice. These were then digitized using a PDP 11/45 computer and the two stimulus tapes were produced according to the prepared design. Between pairs there was a response period of 3 seconds. After the last pair of each group a pause of 10 seconds was inserted, followed by a new instruction and again five seconds of silence. For the preparation of the tapes an instrumentation recorder (SE 7000) was used. On a third channel we put a stimulus-code that could be read by the computer.

5.2.4 Experimental set-up

The whole experiment was performed in a group experiment room. In this room up to 10 subjects can be tested simultaneously. Each subject has his own desk and is separated from his neighbours by sound-absorbing shields. On each desk a head set and a board with two response buttons are mounted. The whole room is controlled by a PDP 11F34 computer. With the help of an audio multiplexer the two channels of the instrumentation recorder can be software connected with the left and right ear of each headphone set. A main program controlled the onsets of stimuli by notifying the codes on the separate channel of the instrumentation recorder. For each subject a separate program was started that connected the two channels to the two ears in a predetermined way and registered choices and response times for each stimulus pair.

5.2.5 Procedure

Subjects were tested in groups of five (or fewer). Half of the subjects started with the category monitoring task, half with the rhyme monitoring task. For half the subjects the connection of the two channels was reversed. The tasks were explained in detail and subjects were told that they had to press as quickly and accurately as possible with their right hand either the yes-button or the no-button (separated from each other by 5 mm) according to whether or not they had heard a target word in the left or right ear. Subjects then practiced for a minimum of 25 trials. Subjects were allowed a short rest between the two tasks and then the second task was explained. Subjects were again asked to respond as quickly and accurately as possible.

5.2.6 Scoring

During the experiment all choices and response times of each individual were recorded and stored in a separate file. If response times were shorter than 100 ms or longer than 2 s. the data were discarded. For the analysis we determined, for each subject and for each task, numbers of correct responses and median and mean RT. No significant difference between median and mean RT scores was detected for any group or condition. We thus present only the results for mean RT here.

5.2.7 Results of the preliminary study

A 2 (Order of tasks) x 2 (Sex) x 2 (Task) x 2 (Ear) analysis of variance was performed on the mean RTs. Order of tasks was not a significant factor nor were there any differences between the sexes. No overall main effect of Task was observed. There was a general practice effect indicated by a significant interaction of Task with Order ($F\ (df=1,36) = 26.2105$, $p < .01$). A right ear advantage of 47 ms was observed which was statistically reliable ($F\ (df=1,36) = 18.4932$, $p < .01$) and did not interact with either of the other main factors.

A similar analysis was performed on the number of correct yes-responses. The Order of tasks was not significant. The females had more correct responses than the males (16.7 vs. 16.1) and this difference, although small in magnitude, was significant ($F\ (df=1,36) = 4.3713$, $p < .05$). 14 out of 20 comparisons between males and females were in the above direction. More correct responses were given in the category monitoring task than the rhyme monitoring task ($F\ (df=1,36) = 41.8334$, $p < .01$). A significant right ear advantage was also observed (right ear 16.8 vs. left ear 16.0) ($F\ (df=1,36) = 16.0278$, $p < .01$) and this effect was more pronounced in the males ($F\ (df=1,36) = 5.8872$, $p < .05$). The interaction between Ear and Task was also significant ($F\ (df=1,36) = 9788$, $p < .01$), indicating that the right ear advantage is relatively smaller in the category monitoring task (17.3 vs. 17.0 for the right and left ear respectively.) than in the rhyme monitoring task (16.4 and 14.9 resp.). Although it is often asserted that reaction times are a more sensitive measure, this interaction, which supported our contention that ear advantages might differ according to the level of language processing could not be demonstrated in the RT results.

Additionally we looked at the mean RTs for the correct _no_ responses. A 2 (Order) x 2 (Sex) x 2 (Task) analysis of variance was performed. Only the interaction between Order and Task was significant ($F\ (df=1,36) = 20.5713$, $p < .01$); this indicates merely that RTs in the second task are somewhat faster than in the first, independent of which task was presented first or second.

To determine the reliability of the results we calculated split half correlations of the mean RTs of correct _yes_ responses on odd and even trials for each ear in both conditions. The corrected values (Spearman Brown formula) for r in the category monitoring task are +0.77 for the right ear and +0.82 for the left ear; in the rhyme monitoring task these values are +0.78 and +0.90 respectively.

From these results we conclude that we have constructed two tasks which produce reliable right ear advantages; there is some (small) indication that the ear advantages differ between the tasks (although the stimuli are identical and verbal).

5.3 The main experiment

5.3.1 Procedure and subjects

The same tapes and procedure were used as in the preliminary study. Four age groups participated in the present experiment: 10 boys and 10 girls of respectively 16, 12, 10 and 8 years of age. All were right-handed. For the 16 year olds this was assertained with the Annett questionnaire (Annett, 1970). For the younger children the judgment of both the teacher and the parents of the children was sought. Each child was tested three times: the second time between one and two weeks after the first session. The third measurement was taken after half a year. All children completed the first two sessions and 13, 14, 17 and 17 children from the 16, 12, 10 and 8 year old groups participated in all three sessions.

As in the preliminary study we determined median and mean RTs for each task. No differences were observed and we again present results based only on the mran RTs.

5.3.2 Results

In Table 1 the mean RTs for right and left ear in both tasks are presented, averaged over subjects within each age group. In Table 2 the results for the number of correct yes responses are given.

These data indicate that cross sectionally no increase in ear advantage can be detected. The most important developmental trend appears to be the large decrease in overall RT and the small increase in correct responses. There are again indications that the right ear advantage in the rhyme monitoring task is sometimes larger than in the category monitoring task.

TABLE 1

	CATEGORY		RHYME	
	RIGHT	LEFT	RIGHT	LEFT
16	577	613	565	618
12	929	957	945	1031
10	960	1035	1132	1149
8	1101	1151	1118	1249

Mean RTs for targets presented to the right and left ear in the category- and rhyme monitoring task in the first session, for the 4 age-groups.

TABLE 2

	CATEGORY		RHYME	
	RIGHT	LEFT	RIGHT	LEFT
16	17.3	15.8	16.0	14.4
12	16.9	16.7	14.8	14.4
10	15.2	14.3	13.2	12.2
8	12.7	11.1	9.9	8.5

Mean number of correctly detected targets for the right and left ear in the category- and rhyme monitoring task in the first session, for the 4 age-groups.

As all children completed the first two sessions a 2 (Sessions) x 4 (Age) x 2 (Task) x 2 (Ear) analysis of variance was performed on the mean RTs. The main effects of Session (F (df=1,152) = 28.5428, $p < .01$), Age (F (df=3,152) = 80.261, $p < .01$), Task (F (df=1,152) = 8.5802, $p < .01$) and Ear (F (df=1,152) = 25.7565, $p < .01$) were significant. Furthermore, there is a significant interaction between Age and Task (F (df=3,152) = 2.8260, $p < .05$) which indicates that the differences between tasks become smaller with age. These results were confirmed by a similar analysis of the number of correct yes responses. Although there was no difference between the first and second session all other main effects were clearly significant. The interaction between Age and Task was also significant (F (df=3,152) = 5.0749, $p < .05$). With increasing age subjects improve in their ability to perform both tasks and there is also a progressively decreasing difference between the tasks. No relationship with ear advantage can be detected, however. Furthermore, cross sectionally at least no significant change in right ear advantage was observed.

In order to study the relationship between ear advantage and tasks in more detail we determined the percentage of subjects who showed a right ear advantage in either of the two tasks and in both tasks. The results (see Table 3) show that the percentage of subjects with a right ear advantage in either of the tasks is closely similar to that reported in other dichotic listening studies (Berlin & McNeill, 1976). The consistency of the ear advantage within subjects across tasks is rather low, however. A similar pattern arises when we calculate the correlations between ear differences in the tow tasks (see Table 4).

TABLE 3

	CATEGORY	RHYME	BOTH	LEA IN BOTH
16	60	90	55	5
12	60	85	50	5
10	80	65	50	5
8	65	80	55	10

Percentage of subjects having a right-ear advantage (defined on mean RT) in the category- and rhyme monitoring task and in both conditions. In the right hand column the percentage of subjects with a LEA in both conditions is presented.

TABLE 4

	1st SESSION	2nd SESSION
16	.40	.24
12	.19	.02
10	-.17	-.42
8	.17	.05

Correlations between ear differences (Left ear RT minus Right ear RT) between the category- and rhyme monitoring task in the first and second session for 4 age groups.

Because the split half reliability of ear scores was relatively good it appears that these results cannot be completely 'explained away' by reference to intrinsic 'noise'. It is true that difference-scores are in principle less reliable than other performance measures but it is possible that our results are partly due to the tasks measuring different components of language-laterality. In this context we note that other authors (Hardyck, 1977; Repp, 1978) have also pointed to the multidimensionality of language-laterality.

In this study we have also looked at the intra-individual changes in ear advantage over a period of half a year. Because not all subjects participated in the third session we performed analyses of variance only on the results of subjects who finished all three sessions. There were unequal numbers of children in each age group and the anovas were therefore carried out on the groups separately. Except for the 8-year olds, all age groups were faster in the third session. The interaction between Ear and Session was not significant for any group, although the ear advantage was somewhat reduced in the third session, especially for the rhyming task. The consistency of strategies and ear advantage was studied in more detail. First we calculated the mean RT over the two ears between the first and third session and correlated these two means for each task. The results (see table 5) show that the reaction times for the rhyming condition do not correlate as highly as for the category monitoring task. Similar correlations were performed on the left minus right difference scores and on various other laterality coefficients (see table 6). The correlations are extremely low and indicate that the reliability of ear differences is very low. These results are confirmed by the percentages of subjects whose ear advantages change in direction between the different sessions and tasks.

TABLE 5

	CATEGORY	RHYME
16	.54	.20
12	.53	.29
10	.81	.46
8	.61	.29

Correlations of mean RT of the category and rhyme monitoring tasks between the first and third session.

TABLE 6

	CATEGORY	RHYME
16	-.09	.53
12	.14	-.02
10	.08	.02
8	.13	.37

Correlations of ear differences in the category and rhyme monitoring tasks of the first and third session.

5.4 Discussion

We have found a significant right ear advantage for two dichotic tasks. This REA did not change systematically in magnitude over the age groups that participated. The finding is consistent with many other studies that have looked cross-sectionally at changes in ear differences. Furthermore, no systematic increase in ear advantage was observed within individuals over a period of half a year. Although six months is not a substantial period of time, this is additional evidence against the claim that increasing lateralization can be reliably demonstrated by dichotic listening tests.

An important aspect of our data is that two different dichotic tests, using the same material, both produce normal patterns of laterality in that between 65 and 70% of the subjects show a right ear advantage; in the first session this REA is in the order of 10%. However, when we look at the consistency of the ear advantage within subjects over tasks, it appears that there is no strong relation between ear advantages in the two tasks. This 'unstability' of ear advantages emerges despite the fact that the right ear advantage is significant and the split half correlations for each ear separately are reasonably reliable. With respect to this particular problem it has to be noted that only a very small number of studies have looked in a detailed manner to the reliability of direction and degree of ear advantage within subjects. Some of these have also revealed that although significant ear advantages may be obtained on different occasions within a group of subjects, there is a large number of subjects showing a reversal of ear advantage (Blumstein et al., 1975; Pizzamiglio et al., 1974; Porter et al., 1975). We suggest that this 'switching' of ear advantage is not merely the result of unreliable measurement augmented by taking difference scores but is rather a genuine aspect of laterality as measured by dichotic listening. The direction of ear advantage is not due solely to the fact that verbal material has been presented. A mechanism like attention switching, that can be easily influenced by other factors, is compatible with our results. To get an impression of the transient character of ear advantages during dichotic listening tasks we performed the following item analysis on the results from the adults. For each task (category- and rhyme monitoring) we determined the mean RT, averaged over all subjects, for each target word (20 targets for each ear). As each pair of targets consisted of identical pairs in reversed order, an ear advantage could be calculated by subtracting the mean RT of the target presented to the right ear from the mean RT of the target presented to the left ear. The results for the twenty target-pairs are plotted in Figure 1.

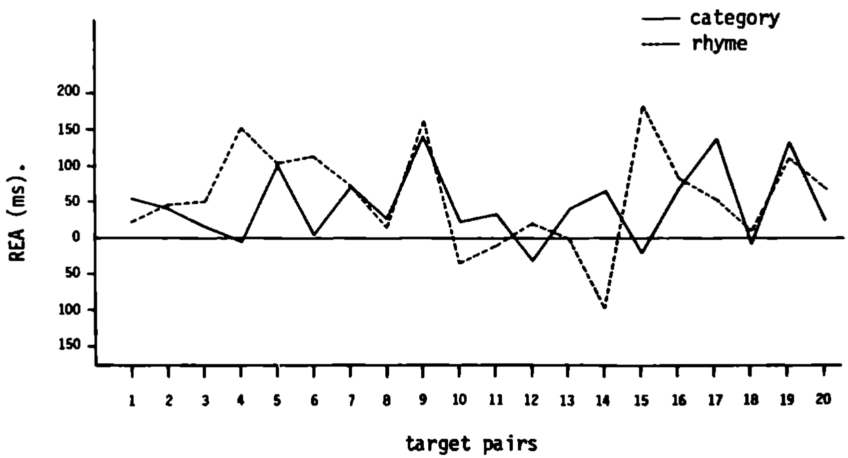

Fig. 1: Fluctuations of the ear advantage for the category- and rhyme monitoring tasks for adult subjects. For further explanation see the text.

It shows that there is an overall right ear advantage that fluctuates during the task. If we compare the fluctuations in the two tasks by calculating the product moment correlation, we find a nonsignificant value for r of +0.11. If the fluctuations had been caused by stimulus factors (for instance, the relative intensity or duration of the target stimulus and its counterpart) one would have expected a significant correlation, as in both task identical material is used. It would seem that other factors, perhaps subject variables, have considerable influence upon ear advantages (Studdert-Kennedy & Shankweiler, 1970).

If, as we have suggested above, lateral advantages as measured by dichotic listening do not simply reflect the fact that the speech processor is located in the left hemisphere, one may ask what the relationship is between dichotic studies on normal subjects and lesion studies. Or, to put it differently, if 'laterality' phenomena in dichotic studies and lesion studies are the result of different mechanisms, can dichotic studies on normal subjects tell us anything about the interpretation of data on the effect of lesions on the right and left hemisphere in adults and children? The answer may be negative (Blumstein et al., 1975; Studdert-Kennedy & Shankweiler, 1970).

Some authors have argued that the two generally accepted models of ear differences in dichotic listening - the structural model of Kimura and the attentional model of Kinsbourne - fail to account for substantial ranges of data (Hayden, Kirstein & Singh, 1979; Bryden, 1978). Nevertheless, no real alternative has so far been produced. It appears that dichotic listening has been used as a tool for investigating other phenomena, and that systematic analyses of the task itself have been relatively neglected. Further research on factors that cause and/or influence the direction and/or the degree of ear advantages might well result in a better understanding of the discrepancies we have mentioned. This in turn might restrain workers from overinterpreting the 'diagnostic' significance of failures to show a right-ear advantage for speech. Nonetheless, insofar as the dichotic listening paradigm is a valid assay of language laterality, it seems that the right ear advantage is constant in size from the earliest ages at which it can be reliably measured.

6. CONSISTENCY OF EAR ADVANTAGE IN TWO VERBAL DICHOTIC TASKS

Paul Eling

6.1 Introduction

A still growing number of neuropsychological studies has employed the dichotic listening technique. A small number of studies has examined the validity and reliability of the dichotic listening paradigm itself. In particular, with respect to the issue of the reliability of ear advantages, the results have been disappointingly low in some studies (Blumstein, Goodglass & Tartter, 1975; Teng, 1981). On the other hand, the monitoring task introduced by Geffen seems to be very promising (Geffen & Caudry, 1981).

In an earlier study (Eling, Marshall & v. Galen, 1981), we used two dichotic monitoring tasks. They differed from the task introduced by Geffen in three aspects. First, subjects did not monitor for a single word (as in the case in Geffen's task). They monitored either for word belonging to a semantic group (e.g. animals, category monitoring) or for words that rhymed to a given word (rhyme monitoring). Secondly, stimuli were presented in blocks of 5 dichotic pairs preceded by an instruction regarding the words that the subject had to monitor. Finally, between pairs, a period of 3 sec. was given for the subject to make a response. Geffen usually presents stimuli at a rate of 1 pair in 750 or 1000 msec. Although our monitoring tasks produced significant right-ear advantages, the laterality scores appeared to be consistent. Moreover, correlations between dichotic tasks as well as the test-retest reliabilities of each task were low.

The present report contains the results of two experiments in which the category- and rhyme monitoring tasks were altered so as to be more similar to the monitoring tasks used by Geffen. Instead of presenting separately introduced blocks of dichotic pairs, only a single instruction was given, followed by a list of 80 dichotic pairs.

6.2 Stimulus material

Four dichotic tapes were prepared that could be used for either task. Target stimuli consisted of 40 common words. There were four groups of semantic categories containing five items each, as well as four groups of rhyming words with five items each. Another 20 common words were used as filler words. From these 60 items, 80 pairs of words were chosen randomly for recording on the tapes, where the two words of each pair were to appear on two different tracks. A selection of the words was achieved with the following restrictions: each word occurred twice on each track, except for the filler words that were presented three times; no pairs of words that belonged to the same group (i.e., to the same category or words that rhymed with the same word) were allowed. Four different random orderings were used. The words were recorded from a female voice. These were then digitized using a PDP 11/45 computer, and the four stimulus tapes were produced according to the prepared design. Between pairs there was a response period of 2 sec. For the preparation of the tapes, an instrumentation recorder (SE 7000) was used. On the tapes, a stimulus-code was entered that could be read by the computer. This code marked the beginning of each pair of words and contained information about which words were to be presented. These tapes were used in two experiments.

EXPERIMENTAL SETTING

The two experiments were performed in a group experiment room. This room is especially designed for testing up to 10 subjects simultaneously. For further details see Eling et al. (1981).

6.3 EXPERIMENT 1

6.3.1 Subjects

Subjects were 10 male and 10 female university students, between 18 and 25 years of age. All were righthanded according to the questionnaire of Annett (1970).

6.3.2 Procedure

Each subject performed the two tasks twice in a completely balanced design. Half the subjects started with the category monitoring task; half the subjects received track I of the tape to the left ear and track II to the right ear; conditions were reversed for the other half. Subjects were requested to press the response button as soon as and only if a target stimulus was detected. Number of correct responses and reaction times were registered. The whole procedure was completed within one hour.

6.3.3 Results

A three-way analysis of variance was performed on the mean reaction time (RT) for correct responses to stimuli presented to the left and right ears. Main factors were Task, Repetition, and Ear. The main effect for Task was significant, $F\ (1,18) = 22.35$, $p < .01$. Responses to right-ear stimuli were significantly faster, $F\ (1,18) = 4.63$, $p < .05$. However, there was a significant Ear x Task interaction, $F\ (1,18) = 7.23$, $p < .05$: in the category condition the REA was 12 msec, while in the rhyme condition it was 67 msec.

A similar ANOVA was performed on the number of correct responses for each ear. In this analysis, the REA was statistically significant, $F\ (1,18) = 13.5$, $p < .01$, but the Ear x Task interaction was not.

The test-retest reliability was calculated for mean RTs. For the category monitoring task, the Pearson product-moment correlation was 0.75 for the right-ear score and 0.64 for the left-ear score, but only 0.22 for the difference score. For the rhyme monitoring task, these results were 0.70, 0.53 and 0.18, respectively.

Consistency of ear advantage on reaction times was studied by examining the number of subjects showing a REA on zero, one, or two tests of each task. The results of this analysis are presented in Table 1. The number of subjects showing a REA on both tests is rather low. If we assume that 70% of the subjects will show a REA on a particular dichotic task, we can expect, on the basis of chance, that approximately one-half of the subjects will show a REA on two occasions when the task is presented twice. In this experiment, the observed number of subjects showing a REA on two tests does not suggest that the REA is consistent.

Table 1: Number of Subjects Showing a REA on Zero, One, Two, Three or Four Trials of the Category Task and Rhyme Task, and a Measure of the Reliability of the Ear Differences.

		0	1	2	3	4	r(1)
Experiment 1 n=20	Category	3	10	7	-	-	.22
	Rhyme	1	8	11	-	-	.18
Experiment II	Category n=10	0	2	3	4	1	.05
	Rhyme n=10	1	3	2	3	1	-.12

(1) In Experiment I, a test-retest correlation between ear differences was calculated; in Experiment II, a split-half correlation was used. See the text for further details.

6.4 EXPERIMENT II

It might be objected that performing two different tasks in a single session produces some confusion for subjects. We therefore performed a second experiment in which we presented only one task to each subject. In this instance, however, each subject was given the same task four times in a single session.

6.4.1 Subjects

Twenty male university students between 18 and 25 years of age participated in this study. All were right-handed according to the questionnaire by Annett (1970).

6.4.2 Procedure

Ten subjects performed on the category monitoring task, and 10 subjects on the rhyme monitoring task. For the four tests, four different tapes were used, and different categories or rhyme words were given to the subject. The order of these category and rhyme words was balanced over subjects. The four tapes were presented in a single session lasting about 40 minutes. Between tests, subjects were allowed a short rest. In other aspects, the procedure was identical to that of the first experiment.

6.4.3 Results

Reaction times on the category monitoring task were faster than on the rhyme monitoring task, F (1,18) = 11.84, $p < .01$. Also, a significant right ear advantage was found, F (1,18) = 9.30, $p < .01$, but, contrary to Experiment I, there was no statistically significant Ear x Task interaction in evidence. In fact, the REA for the category monitoring task appeared to be slightly larger (62 msec for the category task and 20 msec for the rhyme task). This difference, however, was not statistically significant. The main effect of Repetition was not significant, nor were any of the interactions with this factor. However, for both tasks, important fluctuations in ear-advantage were observed. A separate analysis of variance on the number of correct responses corroborated these findings.

Product-moment correlations between mean reaction times of odd and even trials over the four tapes were determined for the right ear, left ear, and difference scores: for the category task the values for r were 0.44, 0.50 and 0.05, respectively. For the rhyme task, these figures were 0.59, 0.53 and -0.12.

We also examined the number of subjects showing a REA on zero, one, two, three and four occasions of task. The results are presented in Table 1. Again, there is no indication that many subjects show a consistent REA in this experiment.

6.5 Discussion

It appears from the results of both experiments that the modification of the dichotic tasks did not produce reliable ear differences. Consistency of ear advantage in the two tasks and the test-retest reliability were low. However, at the same time it must be noted that a significant right-ear advantage was evident in each of the experiments reported here as well as in our earlier study (Eling et al., 1981) that utilized a different procedure. It must be concluded that the use of a monitoring task, even if it produces significant ear advantages, does not guarantee the obtaining of reliable ear advantages.

These results, as well as those of other studies in which the reliability of dichotic tasks has appeared doubtful, suggest that researchers must be careful when comparing dichotic studies in which different tasks have been used. Furthermore, the present results remind us that it may be hazardous to draw conclusions about hemispheric specialization on the basis of dichotic studies. This applies even more so when we consider that, in a large number of studies, dichotic tapes have been used which are either too short (Repp, 1977) or for which no data on reliability are available. Studies designed to show under which conditions reliable estimates of laterality can be obtained by means of the dichotic technique are badly needed.

7. CONSISTENCY OF EAR ADVANTAGE: AN IMPROVEMENT DUE TO INCREASE IN PRESENTATION RATE

Paul Eling

7.1 Introduction

During the past two decades the technique of dichotic listening has been used in a large number of laterality studies. Several tasks have been described in the literature, in which a wide variety of stimuli and of other modes of responding are employed (for a review, see Berlin & McNeill, 1976). For some of these tasks, the reliability of the observed ear advantage has been studied. It appears from these studies that, although occasionally the reliability was quite satisfactory (Geffen & Candrey, 1981), in general they leave much to be desired (Teng, 1981; Blumstein et al., 1975). It has become essential to study under what conditions ear advantages remain consistent.

In earlier studies (Eling, Marshall & v. Galen, 1981; Eling, 1981) we wanted to study ear advantages under two different conditions. On the basis of a report by Geffen, Traub & Stierman, 1978) we decided to use the technique of dichotic monitoring rather than a recall procedure. We developed two dichotic monitoring tasks: category monitoring and rhyme monitoring. In the category monitoring task the subject is asked to respond to words that belong to a prespecified semantic category (e.g. 'fruit'); in the rhyme monitoring task he has to respond to words that rhyme to a prespecified word. We assumed that these tasks would tap different levels of language processing. The results of both studies agree in the sense that a significant right-ear advantage is found, but the consistency of the advantage was very low: the correspondence of ear advantage within subjects between the category and rhyme tasks as well as test-retest comparisons of the same task was at chance level.

This seems remarkable in view of the very promising results obtained by Geffen and Candry, 1981). It could be argued that the number of pairs and the number of targets to which subjects had to respond in our studies was relatively low. This argument, however, is not consistent with the fact that the results for each ear appeared relatively stable. Nevertheless, in another study we presented a list of as many as 200 pairs, containing 40 targets per ear (Eling, 1983). For the category monitoring and rhyme monitoring tasks different lists were prepared. The within-subject correspondence of ear advantage between the two tasks appeared again very low.

Another major difference between the procedure of Geffen et al. (1978) and the one we used in earlier studies, is the length of the response period. She has always used very fast rates of presentation of dichotic pairs, 750 or 1000 ms per pair (Geffen & Candrey, 1981; Geffen et al., 1978). For a number of reasons we had decided to give our subjects more time to respond, about 2 sec.

Geffen (personal communication) argued that this difference in presentation rate was the critical factor. The most obvious explanation would be that with higher rates of presentation subjects are required to attend to the task more carefully and this will result in less variance. In response to Geffen's suggestion we produced new dichotic tapes. Tasks, words and design were identical to those of our last study (Eling, 1983). The rate of presentation, however, was increased. In preliminary observations it was noted that the rate of 750 msec/pair (a rate often used by Geffen), was too high. This can be explained by the fact that we used not only monosyllabic words but also two and three-syllable words. Furthermore, the set of targets in this study is 20, which deviates from Geffen et al. (1978) who asked their subjects to listen for the single word 'dog'. From these preliminary observations we got the impression that a presentation rate of 1.1 sec/pair, although relatively fast, would not make the task impossible to perform and we decided to use this rate in the present study.

7.2 Method

7.2.1 Materials

For each task, category and rhyme monitoring, a practice tape and a test tape were prepared by means of a PDP 11/45 computer. A set of 100 common Dutch words were recorded from a female speaker. The words were one, two, and three-syllable words. Included were 20 names of animals and 20 (different) words rhyming to the Dutch word 'was'. These were digitized and stored on disk. With these 100 tokens, two tapes, each having two tracks, were prepared according to the following design. Two different random orderings of 200 pairs of words were produced. Further restrictions were that each word occurred twice on each track and that the co-occurrence of two words belonging to the same set of targets (animal names or rhyme words) was not allowed. Thus in each task no targets were presented to each ear. For each task separately a pulse marking the beginning of target items was recorded on a third track. Practice tapes consisted of 60 pairs of the appropriate type for each task.

7.2.2 Subjects

Fourty students and staff members of different departments of Nijmegen University participated. Students earned either course credit or a small amount of money. There were 21 female and 19 male subjects. No special demands for participation had been made in order not to restrict the variance. There were 36 subjects who considered themselves righthanded. Four subjects, two male and two female, classified themselves as lefthanded. These subjective classifications were confirmed by the handedness questionnaire of Annett (1970).

7.2.3 Procedure

Subjects were tested individually, seated in a small room, looking at a white wall in order to reduce distraction as much as possible. Every subject performed on two tasks. Each task was explained just before testing. Subjects were told that words would come at a relatively fast rate but they were encouraged not to get confused. It was pointed out that they had to press the response button as soon as they detected a target word and not to try to correct wrong responses. Subjects responded with the preferred hand. Half of the subjects started with the rhyme monitoring, the other half with the category monitoring task. Headphone position was reversed for half the subjects. The two resulting groups will be referred to as group A and group B, wearing the headphones in 'normal' and in 'reversed' position respectively. A second recorder was used for recording the occurrence of the target item pulses on one track and responses made by the subject on a second track. These tapes were analyzed off-line subsequent to the experiment. Each subject was tested again after a period varying from 5 days to three weeks. The same headphone position and the same order of tasks were used in the second session.

7.2.4 Scoring

The tapes on which the occurrences of target words and the responses of the subject had been recorded were analyzed by means of a computer. The number of correct responses and the reaction times were determined for each ear. RTs longer than 1400 msec were discarded. Responses shorter than 300 msec were also rejected unless they could be interpreted as delayed reactions to a target occurring in the preceding pair. This happened very rarely.

7.2.5 Results

ANOVAs were performed both on RTs and on number of correct responses. In the ANOVA on the RTs of the first test a significant main effect for EAR was found (F (df=1,39) = 11.5542, $p < .001$). However, this factor interacted significantly with the factor TASK (F (df=1,39) = 7.3674, $p < .01$). The REA for the rhyming task is 48 ms and larger than that for the category task, where the REA is only 18 ms (see also Table 1).

TABLE 1

	1st session		2nd session	
	CATEGORY	RHYME	CATEGORY	RHYME
R-ear	835 (31.6)	817 (33.0)	799 (34.1)	792 (35.5)
L-ear	853 (29.8)	865 (30.0)	829 (32.8)	823 (33.0)

Mean RTs and mean number of correct responses for targets presented to the right and left ear in the category and rhyme monitoring task in the two sessions.

In the ANOVA on the RTs of the second test only a main effect for the factor EAR was found (F (df=1,39) = 7.1185, $p < .02$). The REA for the category task now is 30 ms; for the rhyme task it is 31 ms.

In the ANOVAs on the number of correct responses the factor EAR was significant in both tests. In the two sessions the REA was larger for the rhyming task than for the category task, but this interaction did not reach significance. On earlier occasions (Eling, 1981) we also observed this interaction showing up at one instance and being absent at others. As yet we cannot explain this phenomenon.

According to current interpretations of hemisphere specialization, one would expect that if two comparable dichotic tasks, both involving verbal material, are presented, the correspondence within subjects of the direction of ear advantage across these tasks will be relatively high, certainly above chance level. In our earlier attempts we failed to find such correspondence. Using a higher presentation rate, we hoped to find more reliable ear advantages. This should then result in more consistent patterns of ear advantage in test-retest comparisons within tasks and a better correspondence of ear advantages between tasks.

To study these two aspects we analyzed the patterns of ear differences using reaction time data and the number of correct responses. A difference between ear-scores was called a right or left ear advantage whenever the difference was larger than zero. The reaction time data demonstrate that 29 out of the 40 subjects (72%) show corresponding ear advantages across tasks in the first test and an identical proportion (though not necessarily the same subjects) in the second test. The corresponding values for the number of correct responses are 70% in the first test and 78% in the second. The values are much higher than in our earlier studies (1, 6) where they were at chance level.

In a similar way, the test-retest consistency of the direction of ear advantage can be studied. The reaction time data reveal that 60% of the subjects show consistent ear advantages in the first and second test of the category task and that 70% are consistent in the rhyme task. For the number of correct responses these values are 72% and 80%.

The reliability of the data was determined more precisely by calculating test-retest correlation coefficients. For the reaction time data the values of r for the right and left ear for the category task are resp. 0.74, 0.67; and for the rhyme task they are 0.80 and 0.75 respectively. The corresponding values for the number of correct responses are 0.64, 0.79, 0.59 and 0.81. Of course, the reliability of the difference scores is of greater importance in this context. Test-retest correlation coefficients of the differences in reaction time on the category task reaches a value of 0.45 and a value of 0.70 on the rhyme task. For the differences in number of correct responses these data are .56 and .73. These results indicate that ear advantages in the present study are much more consistent than in our former studies, in which test-retest correlations were in general very low and statistically not significant.

For several reasons the pattern of reaction times was studied in greater detail. A major consideration was that in an earlier study (Eling et al., 1981) it appeared that the REA shows large variation during a test. Because each target word was presented twice to each ear in the present study, an item analysis can give an indication of the value of measuring individual reactions with an accuracy of one millisecond in the study of ear differences. For a proper understanding of the following analysis two points regarding the composition of the materials must be noted here. Firstly, the four occurrences of the target word were represented on the tape by the same digitized token. Secondly, the word paired with the same target was not held constant over the four occasions. This means that if we compare reaction times to different occurrences of the same target word (either presented to the same ear or to both ears) the acoustical information of the target is identical but that of the configuration as a whole (the simultaneous word pair) is different. Some authors (Kimura, 1967; Kinsbourne, 1970) seem to assume that information presented to each ear is processed independently of the information presented to the other; that is, the speech processor is assumed to receive two messages (one after the other), rather than one, a mixture of both. If this would be the case, one would expect a relatively high correlation of reaction times to the two occurrences of the target words presented to the same ear.

We calculated over subjects mean RTs for each occurrence of a target word. However, we separated the results of the group of subjects wearing the headphones in the normal position (group A) from those wearing them in the reversed position (group B). The reason for this is that only within these groups a specific occurrence of a target word (e.g. first presentation to the right ear) is consonant with respect to the word presented to the other ear.

After calculating the mean RTs for each target word we first looked at the correlation between the first and second occurrence of a target, both presented to the same ear. We did this for each ear and task separately.

They were in general low (see Table 2). We also compared reaction times to the first (and second) occurrence of a target in the left and right ear. Correlations again were rather low. From these results one may get the impression that reaction times to individual target words are not reliable. However, the comparisons we have made are confounded by the fact that target words were paired to different words. In order to compare different targets, holding the stimulus-configuration constant, we have to correlate reaction times to right-sides targets of group A with the reaction times to left-sides targets of group B. The results are striking (see Table 2). They indicate that reaction times to individual target words are reliable as long as the stimulus-configuration is identical.

TABLE 2

			GROUP A	GROUP B
Within ears	CATEGORY	R-ear	-.07	.40
		L-ear	.36	-.26
	RHYME	R-ear	.54	.17
			.24	.71
Between ears	CATEGORY	1st 20	.22	-.10
		2nd 20	.22	.13
Within groups	RHYME	1st 20	.53	.66
		2nd 20	.14	.25
			1st 20	2nd 20
Between ears	CATEGORY	L_A-R_B	.87	.77
		R_A-L_B	.73	.78
	RHYME	L_A-R_B	.78	.90
		R_A-L_B	.87	.88

Comparisons of mean reaction times to targets presented to the right and left ear in the two monitoring tasks. For further explanations, see the text.

7.3 Discussion

Dichotic category and rhyme monitoring tasks were prepared in which relatively short interstimulus intervals were used. From a comparison to the results of earlier attempts, it appears that this manipulation has an important positive influence on the consistency and reliability of ear-advantage scores. This is the major finding of the present study.

From traditional explanations of the REA (Kimura, 1967; Kinsbourne, 1970) no obvious argument can be deduced that would explain why monitoring dichotic pairs at a rate of 1 sec/pair would yield more consistent and more reliable results than monitoring such pairs at a slower rate. The argument that higher rates of presentation reduce the variance is not satisfactory in the sense that it does not point to specific factors relevant to the phenomenon of ear differences in dichotic situations. It is not an explanation.

A second important finding of the present study comes from the item analysis. In the literature a number of inconsistencies with respect to dichotic listening has been reported. The ear advantage found above remained stable over individual targets under certain conditions, namely when the stimulus-configuration as a whole is kept constant. This seems remarkable in view of the fact that this effect is found using the results of two different groups of subjects. Apparently stimulus characteristics appear to determine the observed reaction times to a large degree. This result strongly argues against interpretations suggesting that a large part of the variation observed in ear-differences may be due to differences between subjects in information processing strategies (e.g. Bryden, 1978). This does not mean, of course, that such differences do not exist. However, only very little is known about what such strategies would look like; in contrast, the described stimulus characteristics are much better under experimental control. Therefore it seems most fruitful now to continue performing dichotic studies, but to study in more detail the influence of these variables on ear advantages.

These two observations, viz., the fact that better results are found with a higher rate to presentation and the fact that reaction times in dichotic situations are to a large degree determined by characteristics of the total stimulus-configuration, allow us to view the phenomenon of right-ear advantages in a special light. It may be seen in part as the result of a break-down, not only of the speech processor but of the information processing system as a whole, due to the impossibility to extract enough details for the rapid splitting-up of the stimulus configuration into two separate stimuli. If such an interpretation of the REA would be correct, it would imply that the ear advantage will vary according to the possibilities the information processing system has for separating the stimulus configuration into two messages. In this way it is possible to understand why in dichotic tasks using cv-syllables trials of one pair will suffice in producing a REA, whilst in tasks using digits three of four pairs are needed. Also the differences in magnitude of the REA using pairs consisting of particular types of cv-syllables (Repp, 1977; 1978) can be explained in this way. Such a view could be tested, e.g. by using a second task and by varying the 'mental load' of that task; the REA may vary systematically with the demands of the second task. If spectral overlap of the two stimuli is a major requirement, this would restrict the class of tasks that can be used as the secondary task.

8. COMPARING DIFFERENT MEASURES OF LATERALITY: DO THEY RELATE TO A SINGLE MECHANISM

Paul Eling

8.1 Introduction

The concept of laterality refers to the notion that the two human hemispheres are functionally dissimilar. Broca (1865) was one of the first to draw attention to this phenomenon. He claimed that we talk with our left hemisphere. In response to a remark of a fellow neurologist, who knew of a patient who became aphasic after a right sided lesion. Broca argued that that patient was left-handed. Broca assumed that, in left-handers cerebral dominance was simply reversed. For a considerable length of time after this, hand preference was conceived of as a sign of cerebral dominance or, as we should call it now, of laterality. Hand-preference can be determined in several ways: one may simply ask the subject which hand he prefers for unimanual tasks, most commonly for writing. In an attempt to be more precise, one sometimes presents the subject with a questionnaire or asks him or her actually to perform several unimanual or bimanual tasks. To the latter category belong two tasks that have been used in other laboratory studies as well, viz., the peg-board (Annett, 1970) and tapping tasks (e.g. Peters & Durding, 1978, 1979).

Since the beginning of the 1960s, two new experimental techniques have become available: dichotic tasks (for a review, see Berlin & McNeill, 1977) and visual half-field stimulation (for a review, see White, 1969). These methods have been used widely in laterality research.

In discussions on general issues of laterality - e.g. on whether the left hemisphere is specialized for analytical or sequential processing of information (Bradshaw & Nettleton, 1981) - results obtained by the various empirical techniques (i.e. handedness, dichotic listening, half-field studies) have been used as analogous means of studying laterality. It has been assumed tacitly that laterality scores obtained by dichotic tasks and half-field tests with verbal stimuli are determined by a single mechanism: the speech processor in the left hemisphere (Liberman, 1973). Similarly, the asymmetries observed in these experimental techniques are generally related to the effects of lesions of one hemisphere. It is an empirical fact that, although a majority of the population shows a right-ear or right half-field preference, the proportion of subjects showing this effect has always remained far below the proportion of subjects showing language distortion after left rather than right hemisphere lesions. This discrepancy has received too little attention.

In some studies, the relationships between laterality scores for handedness, dichotic listening, and half-field stimulation have been studied (Fennell, Bowers & Satz, 1976; Zurif & Bryden, 1969). The results of this studies do not demonstrate convincingly that the asymmetries observed are all due to a single factor. On the contrary, they suggest that laterality scores of different modalities are at best marginally related (Zurif & Bryden, 1969).

Several factors may be responsible for these results. First, difference scores include the variance of both the right and left side scores. It would seem probable that these are more unreliable than the right and left side scores themselves (Eling, Marshall & v. Galen, 1981; Provins & Cunliffe, 1972). Second, an examination of the studies in which dichotic tasks are compared with half-field tests indicates clearly that the tasks used are often dissimilar. For instance, Zurif & Bryden (1969) presented digits in their dichotic tasks and letters in their half-field task. Fennell, Bowers & Satz (1977) have used a different visual half-field task that appeared to be rather similar to the dichotic task. There is, however, a striking difference between the two techniques that is hard to overcome. When a single pair of ordinary words is presented dichotically, both of these can usually be identified correctly. However, for half-field tasks, it is generally argued that words must be presented tachistoscopically with stimulus presentation times of less than 150 ms. This is to prevent eye-movements. Recognition scores under these conditions are usually low, at any rate much lower than with dichotic presentation. It thus appears that stimulus material and task requirements are, in general, different for the two measures of laterality.

These two arguments would lead one to expect that, under proper conditions, the correlations of laterality scores should increase. However, a third and simple alternative remains possible, viz., that the low association may be due to the fact that there is little relationship between the kinds of asymmetry measured by the different procedures. At the present time, this explanation would be based merely on a lack of positive evidence to the contrary. But the explanation cannot be ruled out, and it deserves some attention. The strongest evidence for a dissociation of asymmetry scores comes from studies showing that the majority of left-handers have language represented in the left hemisphere (Goodglass & Quadfasel, 1954; Milner, 1974; Penfield & Roberts, 1959).

Because in most studies interrelations among laterality scores in relatively large groups of subjects, either dichotic and half-field tasks are not included (Porac, Coren, Steiger & Duncan, 1980), or the assessment of differential performance by the right and left hand is lacking (Zurif & Bryden, 1969), we decided to gather data from a group of normal adults, using a handedness questionnaire, several motor tasks, three dichotic and two half-field tasks. This was done in order to be able to compare performances on tasks within and across modalities. Although some further issues that have been dealt with in various other studies are also involved in the present study, this paper will mainly concentrate on the problem of interrelationships among laterality scores. Certain important and interesting details of individual tasks and of subgroups of subjects will be dealt with in a later publication.

8.2 Method

8.2.1 Subjects

In the present study, 126 students from several University departments participated. They received either course credit or a small amount of money for their participation. There were 58 males and 68 females. Originally, subjects were not selected with respect to handedness. When it was discovered after 110 subjects that the number of left handers remained too low for meaningful comparisons of handedness groups, we specifically invited left handers to participate. None of the subjects reported special problems with either hearing, vision, or the use of either hand.

Hand preference for each subject was determined with Annett's questionnaire (Annett, 1970a). Subjects were considered either right-handers or left-handers when they answered 'right' or 'left' respectively to all of the first six questions. Otherwise they were considered to have a mixed preference. In an additional question, subjects were asked to give information about the occurrence of left-handedness in their (biological) family members. The proportion of right-, mixed-, and left-handers for the different subgroups (males vs. females; with and without familial lefthandedness) is represented in Table 1. It can be observed that the proportion of mixed- and left-handers is higher in females and when familial left-handedness is present.

Table 1: Number of Right-, Mixed-, and Left-Handed Males and Females With and Without Familial Left-Handedness

		Right-handers	Mixed-handers	Left-handers	total
Familial +	Males	7	11	2	20
	Females	6	12	5	23
Familial -	Males	25	11	2	38
	Females	23	17	5	45
Total		61	51	14	126

8.3 Tasks

8.3.1 Dichotic listening tasks

Three dichotic listening tasks were prepared, which we will call category monitoring, rhyme monitoring, and voice monitoring. The tasks are similar, though not identical, to those used in Eling (1981b). Lists of common words are presented dichotically at a rate of 1 pair per 2.5 sec. Subjects are requested to react as fast as possible to target stimuli by pressing a response button with the index finger of the preferred hand. For the category task, target stimuli consisted of 20 different names of animals. Targets for the rhyme task were 20 different words (all different from the animal names) that rhymed with the Dutch word 'was'. Apart from these 40 items, 60 common words were used as fillers. With these 100 items, three random orderings of 200 pairs were constructed with the following restrictions: each word occurred twice on each channel; two targets were not allowed to form a pair. All words were spoken once by a female voice and once by a male voice. Their recording was digitized using a PDP 11/45. Dichotic tapes were prepared according to the three designed orderings using the digitized tokens.

For the voice monitoring task, 20 words were appointed as targets and, for these targets, tokens spoken by the male voice were used. This task was used as a control task. It can be 'solved' using acoustic information and, therefore, we did not expect systematic ear-differences to occur (Wood, 1975). For each of the three tasks, one tape was produced that included a block of 60 practice trials. On a separate track, a digital code was entered that could be read by the computer during the experiment. This code was used as the starting point for reaction time measurement and for the identification of the words involved.

8.3.2 VHF-tasks

A serious problem for studies that have tried to compare laterality scores of dichotic and half-field tasks is that usually the two kinds of tasks differ in various important aspects. We have tried to overcome this problem by using exactly the same tasks and stimuli for the half-field tasks (no visual analogue was produced for the voice monitoring task). Using the same random orderings, pairs of words were presented bilaterally on a television screen. The words were preceded by a star-like character in the centre of the screen. This remained visible for 1 sec. and was followed by a pair of words. Because the words varied in length from 3 to 8 letters, we used the following procedure for presenting them bilaterally. Words were positioned such that the first letter of a word in the left visual field was 8 cm from the centre and, in the right field, 5 cm from the centre. This causes starting points of words to be fixed and the middle of a word to be approximately 3 degrees from the fixation point in both hemifields. This procedure was chosen because words were of unequal length. Presentation time was 140 msec. In a preliminary experiment with 40 subjects who did not participate in the present study, it was ascertained that this half-field task produces the traditional right visual field superiority effect.

8.3.3 Tapping tasks

Peters & Durding (1978, 1979) have performed a number of laterality experiments using tapping tasks. We modelled the tapping tasks after theirs. Six conditions were used: tapping with right and left index finger, tapping alternatingly with index and middle finger of each hand, tapping synchronously with the index and middle finger of each hand. The instruction was always to tap at maximum speed. For each 10 sec. period of tapping, a mean tap-interval was calculated.

8.3.4 Peg-board

One of the most reliable and valid measures of differences in manual skill is the peg-board as developed by Annett and her co-workers (Annett, 1970b; Annett, Hudson & Turner, 1974). The subject is requested to place 10 pegs standing in a row at the bottom of the board into 10 holes at the top. Time is measured from the starting signal of the experimenter until the last peg is in the hole at the top row. The subject starts at random with either the right or the left hand, and then uses the other hand. This is repeated five times, and mean performance times are determined for each hand.

8.3.5 Dynamometer

For measuring the power of each hand, a dynamometer was used. Subjects started with the preferred hand, followed by the other; each hand was tested twice.

8.4 Procedure

All the tasks were performed in the Group Experimental Room in the Psychological Laboratory at the University of Nijmegen. As many as 4 subjects participated simultaneously. The six types of tasks were presented in blocks - dichotic listening, visual half-field, tapping, peg-board, dynamometer, and questionnaire - all in a random order. Within a block, the ordering of conditions was also randomized.

Subjects were seated at a desk and separated from others by sound absorbing shields. Except for the peg-board, the dynamometer and the questionnaire, all instructions were presented on television screens that were mounted on the desks. Subjects were encouraged to tell the experimenter whenever they did not understand the instruction.

Before each dichotic and half-field task, the subjects practiced for 60 trials. On a separate screen near the terminal of the experimenter, the performances of each subject could be monitored. Information on task, trial, reaction time and number of errors for each subject were available. Whenever a subject showed relatively long reaction times or many errors during practice trials, the experimenter explained the task again to that subject and told him to react as fast as possible. Due to technical and practical problems (available time for testing subjects) not all subjects performed all the tasks. In Table 2 the number of subjects who completed each of the tasks is presented.

Table 2: Number of Subjects that Completed the Different Laterality Tasks. Subjects are split up according to Familial Left-Handedness and Hand-Preference (Right, Mixed, Left)

		Familial +			Familial -		
Handedness		Right	Mixed	Left	Right	Mixed	Left
Dichotic	Category	13	20	7	47	47	7
	Rhyme	12	22	7	41	25	7
	Voice	12	19	7	45	25	7
VHF	Category	13	22	7	48	28	7
	Rhyme	13	22	7	48	28	7
Tapping		11	15	7	43	22	7
Peg-Board		13	19	7	47	24	7
Dynamometer		13	22	5	47	26	3

8.4.1 Results

The main object of this study was to determine the interrelations among laterality scores of different tasks. Before examining these relationships, it will be useful to see whether the tasks used are compatible to those described by others, especially with respect to left-right differences.

To that end, these results are described first.

For each dichotic and half-field task, mean RTs for correct responses and the number of correct responses for targets presented to the right and left side (i.e., ear for dichotic listening and half-field in the half-field task) were determined for each subject (see also Table 3).

Table 3: Mean Scores for Right-, Mixed-, and Left-Handers for Right and Left Side in the Laterality Task

	Right Handers		Mixed Handers		Left Handers	
Side of presentation	Right	Left	Right	Left	Right	Left
Dichotic listening						
Category (ms)	766	795	771	793	744	757
Rhyme (ms)	794	805	786	819	792	821
Voice (ms)	534	535	531	535	543	540
Category (n.c.)	25	24	25	24	27	24
Rhyme (n.c.)	26	22	27	22	26	19
Voice (n.c.)	37	37	38	38	38	38
Visual Half Field						
Category (ms)	643	650	641	651	647	622
Rhyme (ms)	618	643	644	659	657	642
Category (n.c.)	16	15	17	14	14	19
Rhyme	23	16	21	15	22	17
Tapping						
1st trial 1 Finger	167	202	172	177	232	189
(ms) 2 Fingers alt.	168	182	172	169	219	217
2 Fingers syn.	215	260	238	237	315	299
2nd trial 1 Finger	161	198	183	178	212	180
(ms) 2 Fingers alt.	152	175	168	161	208	187
2 Fingers syn.	204	266	222	243	346	262
Peg-board (sec)	9.03	9.80	9.35	9.25	10.18	9.30
Dynamometer 1st trial	34	32	22	31	29	32
(kg) 2nd trial	33	29	31	30	30	33

Separate MANOVA's were performed on the mean RTs as well as on the number of correct responses for the dichotic and the half-field tasks, using Handedness as a between-subjects-factor and Tasks as repeated measures factor together with Side of presentation. The results of the voice monitoring task were not included in this analysis. The reason for this was that we did not want an interaction between Side and Task to show up because of a task that cannot properly be considered to measure laterality. It may be observed in Table 3 that for the voice monitoring task no difference between right and left ear targets was found for any of the different groups of subjects in this task. This is in accordance with other studies that investigated different levels of auditory processing in relation to laterality (e.g. Wood, 1975).

The results of the analysis on the dichotic reaction time data are as follows (see also Table 3). The main factor of Side of target was significant ($\underline{F}$ (1,111)= 21.88; $\underline{p} < .01$) indicating that these tasks produce the traditional right ear advantage. There was also a significant difference between the mean reaction times for the category task and that for the rhyme task ($\underline{F}$ (1,111) = 24.06; $\underline{p} < .01$). Subjects were slightly faster in the category monitoring task. The interaction between Task and Handedness was significant ($\underline{F}$ (1,111) = 3.83; $p < .05$), indicating that left-handers were faster than both other subject groups in the category task. No other main effects or interactions were significant.
In the analysis on the number of correct responses we found main effects for Side of target ($\underline{F}$ (1,111) = 18.41; $\underline{p} < .001$). The interaction between Task and Side of target was also significant ($\underline{F}$ (1,111) = 21.59; $p < .001$). The laterality effect was larger in the rhyme condition, mainly due to lower scores for the left ear targets. We have studied this interaction in other experiments (Eling, 1981b) and have observed a similar effect. The phenomenon is, however, not very stable; it is, for example, absent in the present reaction time analysis. It may be concluded that these tasks yield measures of laterality that are comparable to those obtained in many other dichotic listening studies.

Similar analyses were carried out on the data of the half-field task. For the reaction time data, only a significant main effect of Side of target was observed ($\underline{F}$ (1,126) = 4.07; $p < .05$), confirming our assumption that subjects would react faster to right sided targets. In the analysis of the number of correct scores, again a significant effect of Side of presentation was found (F (1,126) = 20.99; $p < .001$). Furthermore, a significant main effect of Task was observed (F (1,126) = 71.19; $p < .001$) as well as a significant interaction between Side of presentation and Task (F (1,126) = 37.90; $p < .001$). The difference between recognition scores of the two half-fields was larger in the rhyme monitoring tasks.

We studied right-left differences in the peg-board task with t tests for each of the handedness-groups separately. The results are very clear. For right-handers, the right hand was significantly faster than the left (t = 9.46; df = 59; $p < .001$). In the mixed group, only a small non-significant difference of 10 msec was found. Left-handers are significantly faster with their left hand (t = 6.46; df = 13; $p < .001$), while the between-hand difference was roughly of the same magnitude as was that of the right handers.

On the mean tap-intervals a MANOVA was performed, with Handedness as a between-subjects factor and Hand, Conditions and Trial (1st vs. 2nd) as repeated measures. There was a main effect for Handedness (F (2,90) = 8.15; $p < .01$) that interacted with the factor Hand (F (2,90) = 27.55; $p < .001$). The main effect for Hand was also significant (F (1,90) = 23.41; $p < .001$). Furthermore, right-left differences were not of equal magnitude in the different conditions: they were smallest in the condition where subjects had to tap with their index and middle finger in alternation. The interaction between Conditions and Hand was statistically significant (F (2,89) = 5.07; $p < .01$). The three-way interaction between Handedness, Conditions and Hand was also significant (F (4,178) = 3.19; $p < .004$). Neither the main effect for Trial nor any of the interactions with this factor were significant. This suggests that the observed effects were relatively stable.

For each subject, strength of right and left hand was determined by using a dynamometer. Each hand was tested twice. A MANOVA was carried out on the results with Handedness as a between-subjects factor and Hand and Trial (1st vs. 2nd) as repeated measures. There was a significant main effect for Hand (F (1,118) = 27.60; $p < .001$). However, this effect interacted with the factor Handedness (F (2,118) = 7.71; $p < .01$) and Trial (F (1,118) = 6.33; $p < .05$). The pattern of between-hand differences was in agreement with traditional assumptions and the picture was somewhat accentuated in the second test in the sense that the between-hand difference were somewhat larger for the right handers.

In summary, we may conclude that the laterality tasks that we have used tap laterality in a fashion similar to tasks that have been described in the literature. One interesting finding may be singled out here: right-left differences appear to interact with handedness only in some tasks, namely, the peg-board and tapping tasks. This interaction does not show up in the dichotic and visual half-field analyses. In the half-field data, there were indications that the different groups of subjects do not have a comparable preference for the same side. But, while mixed-handers showed insignificant differences between the right and left hand in manual tasks, their preference in the dichotic and half-field tasks were more comparable to that of the right-handers.

Although it is possible to compare our results with other studies with respect to the effects of other variables like sex and familial left-handedness (e.g. Searleman, 1980; Zurif & Bryden, 1969), we will not elaborate this theme, since the primary aim of this paper is the investigation of the interrelationships among these measures of laterality.

We compared, over subject groups, the difference scores of all pairs of tasks. For the dichotic and half-field tasks, we used the L-R difference of the reaction times as well as of the number of correct responses. Pearson correlation coefficients were calculated between difference scores of all possible pairs of tasks (see Table 4).

Although the correlations in general were low, it must be noted that some coefficients were statistically significant. We also calculated the C of contingency, which is a non-parametric measure of correlation. The resulting pattern of interrelations closely resembles the analysis using the Pearson correlation coefficient. Furthermore, there appears to be an interesting picture of three different clusters. A hierarchical cluster analysis (Johnson, 1967) was performed on the product-moment correlations to study this pattern of interrelations. Using the maximum method, which is conservative with respect to the number of clusters that will be detected, three clusters were found: dichotic scores, half-field scores, and handedness scores. From this analysis,

Table 4. Pearson Correlation Coefficients of Laterality Scores among the Different Tasks.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
DICHOTIC	1. Category RT	*	.46	.21	.37	.39	.06	.15	.08	-.07	-.11	.09	.19	.02	.00	.03	-.03	.01	.08
	2. Rhyme RT		*	.45	.45	.65	.17	-.05	.00	-.07	-.11	.17	.00	-.01	-.11	-.23	-.06	-.07	.03
	3. Voice RT			*	.32	.28	.20	-.09	-.05	-.07	-.70	.00	.06	.00	.03	-.03	.02	.08	-.08
	4. Category n.c.				*	.42	.01	.06	.00	-.16	.03	-.06	.02	.03	-.03	-.18	-.07	-.08	-.04
	5. Rhyme n.c.					*	.19	.05	.00	-.04	-.07	.08	.01	-.07	-.11	-.18	-.07	-.17	.01
	6. Voice n.c.						*	.02	.03	.01	-.05	.09	.05	.03	-.11	-.01	-.05	-.01	.00
V.H.F.	7. Category RT							*	.25	.34	.22	-.07	.17	.09	.05	-.07	-.13	-.10	.15
	8. Rhyme RT								*	.28	.43	.09	.11	.05	.03	-.01	.12	-.07	.05
	9. Category n.c.									*	.52	.09	.11	.07	.13	-.06	-.12	.07	.10
	10. Rhyme n.c.										*	.03	.00	.12	.21	.02	-.01	.10	.04
	11. Peg.											**	.42	.42	.40	.19	.23	.26	.42
	12. Dynamometer												*	.31	.08	.13	-.01	.31	.42
TAPPING	13. 1 Finger													*	.33	.19	.24	.27	.40
	14. 2 Fingers alt.														*	.02	.21	.29	.24
	15. 2 Fingers syn.															*	.31	.32	.10
	16. 1 Finger																*	.20	.33
	17. 2 Fingers alt.																	*	.37
	18. 2 Fingers syn.																		*

one may conclude that the interrelations among laterality scores were not equally strong for all possible comparisons. However, an additional analysis was necessary to test whether the clusters found by the hierarchical cluster analysis were statistically independent. This was done by calculating canonical correlations. In this analysis, each pair of clusters of laterality scores was tested for independence. Independence here means that all canonical correlations between two clusters are not significantly different from zero. All comparisons resulted in non-significant $\underline{p}$ values. Therefore, we must conclude that the three clusters are independent from each other. These findings lend support to the hypothesis that the laterality scores of the three clusters were determined by three functions which are lateralized independently of each other.

8.5 Discussion

In this study, we measured laterality using techniques that are well known in the literature. The pattern of interrelationships that emerges in this study suggests that there is considerable 'discordance' between the different laterality scores, with respect to the direction as well as the magnitude of differences. This lack of agreement between laterality scores cannot easily be explained by arguing that there is too much noise in the data. An important argument against such an interpretation is the fact that we find three clusters of laterality scores. The fact that the tasks forming a cluster belong to the same domain (e.g. all manual tasks in one cluster) suggests that the pattern of interrelations is not due to random factors but points to a systematic dissociation of laterality scores. That is, although laterality scores may be interrelated, the relationship is apparently not as strong as has been assumed in the past.

It is possible that task characteristics are responsible for this pattern of interrelationship among the laterality scores. In this context it may be noted that the group of mixed-handed and left-handed subjects showed a REA on the dichotic tasks, comparable to that of the right-handed subjects. Similarly, the half-field tasks also did not yield a significant interaction between the factors Side of presentation and Handedness groups. Because this is contrary to the results of some studies reported in the literature (for an overview, see Hardyck, 1977), one might question the procedures we have used. It is unclear, however, how our tasks could have 'reversed' laterality effects only for the mixed- and left-handed subjects. Nevertheless, we cannot exclude the possibility that task characteristics not only express themselves in the raw data for the right and left side but also in the difference scores. That is, they might contribute to the magnitude of the right-left differences as well as to the proportion of subjects observed to show laterality effects. Such an interpretation of our data would raise to the interesting question as to which task would be a 'pure' measure of laterality, and whether a comparison of different tasks can be made at all. According to this line of reasoning, it can be argued that it has not been shown that the 'single mechanism' hypothesis is untenable.

On the other hand, there is no strong evidence supporting this hypothesis. As yet, empirical results of studies on patients and normals have not led us cogently to generalize, as Broca (1865) did, that distinct types of right-left differences reflect the working of a single mechanism. On the contrary, it appears from the results of our study, as well as from those of others (Fennell et al., 1977; Zurif & Bryden, 1969), that the notion of "laterality" may be misleading if it is taken to refer to a single mechanism underlying all of the right-left differences that have been studied.

It seems that this study, rather than presenting new answers, poses two new questions: to what extent are the mechanisms producing right-left differences in the different domains independent of each other and what is the nature of the common factor underlying laterality scores within clusters? A way to find answers to these questions is to make a thorough study of the relative contribution of specific task characteristics to laterality scores.

9. GENERAL DISCUSSION

In this discussion I wish to take up the general issues formulated in the first chapter of this thesis and underlying the theoretical and empirical studies reported in the chapters 4 to 8. The thesis addresses the issue of the interpretation of laterality phenomena. Traditionally, phenomena such as differential effects of left and right-sided lesions and handedness have been used as a means of localizing functions. Whereas phrenologists and physiological psychologists attempted to localize particular functions at specific sites on the cerebral cortex, researchers in the area of laterality have tried to relate a particular function more generally, to either the left or the right hemisphere. A second important aspect involved in the study of laterality phenomena is the issue of the relation between anatomical form and physiological function. There is a general 'law' which in general terms states that: organs have their particular form in order to perform a particular function optimally. It would be in conflict with this law to find that two organs with the same form performing different functions. Precisely this conflict seems to arise in the case of the two cerebral hemispheres, at least in human beings. At first glance they seem to have the same form, yet they appear to 'house' different functions. These two factors, the more global (and therefore 'more acceptable') way of localizing functions and the 'physiological paradox', have attracted the interest of many researchers. This has led to a vast literature on the three basic questions of laterality: what are the differences between the two hemispheres; why is there a difference; and how did it evolve?

In the present thesis I have addressed two issues, namely degree of lateralization and the relationship between different measures of laterality. Let us first turn to the issue of degree of laterality. One of the most fundemantal features of research on laterality has been the emphasis on the view of the brain as consisting of two more or less independently working systems. Consequently many lateralization phenomena have been interpreted as demonstrating the functioning of only one of the hemispheres. Despite the warnings expressed by Broadbent (1974) the study of the integration of the working of different parts of the brain has been relatively neglected. The tendency to split up the brain into a left and a right hemisphere can still be observed in many theories on laterality that have been developed during the last decade. These theories typically claim that each hemisphere is specialized in processing a particular type of material or in processing material in a particular way (independent of the kind of material).

The notion of variation in degree of lateralization seems to be incompatible with this type of theory. Nevertheless, it has often been observed that many signs of lateralization are not present to the same degree in all types of subject populations. For instance, left-handed subjects are commonly considered to be less lateralized; this is demonstrated e.g. by studies on the effects of unilateral brain damage and on handedness.

The issue of degree of lateralization is addressed in the chapters 4 to 7, albeit in a slightly different way. It is argued that variation in degree of lateralization cannot only be observed between subjects but also within a single subject. My standpoint is based on Luria's (1973) view on function as a dynamic functional system. According to this view functions cannot simply be localized as centers in the brain, as the classical neurological theories have done. Rather, the 'localization' of a function is dependent on the task required from the subject on the one hand and on the strategy adopted by the subject to perform that task on the other. The set of sub-systems involved in different tasks will vary and the observed measure of laterality will vary accordingly.

In order to collect evidence in support of this view I developed two dichotic tasks, category monitoring and rhyme monitoring. The same verbal material is used for constructing the dichotic tapes. According to the generally accepted views on the interpretation of asymmetries observed under dichotic conditions a right ear advantage is expected for both tasks. There is no reason why the advantage should be different in extent in thse two tasks. However, I would predict that an interaction between ear advantage and task will appear. Indeed, on several occasions I have found such an interaction, indicating that the ear advantage for the rhyme monitoring task may be somewhat larger. However, this phenomenon does not seem to be very stable.

I have not found data suggesting a possible explanation for this phenomenon. Nevertheless, it is my impression that during the experiment subjects change their strategy of performing the rhyme monitoring task. Whereas it seems difficult in the beginning to 'neglect' the semantic information, resulting in relatively long reaction times, in the course of the experiment the subject learns to attend more to the phonetic information which is all that is required for his decision in this task.

The prediction of inter-individual variation of degree of lateralization also seems to be capable of explaining the observation in the literature that unilateral lesions do not affect children and adults in a comparable manner. It is generally argued that the adult pattern of lateralization is not yet present in children. In children functions seem to be represented bilaterally, that is, double. Lenneberg's monograph (1967) has been the most influential work in this area and he describes the development of lateralization as a kind of shift from bilateral to unilateral control of functions. According to him this process should be completed around puberty. By now, it has been demonstrated by many authors that lateralization is established long before puberty, at the age of five or even two. Currently, one can even say that the evidence does not suggest any development at all. The sources on which Lenneberg based his view have been shown to be unreliable and insufficient. However, at the time we undertook our study of the development of laterality it was still commmonly assumed that development of lateralization should be demonstrable with dichotic tasks.

In contrast to the shift hypothesis of Lenneberg, we argued that an increase in lateralization is the result of the development of an information processing system which is more and more capable of processing particular types of information. The more the system specializes, the clearer lateralization effects will be. Thus in our study as reported in chapter 5, we did not only predict an interaction between task and ear advantage, but we also predicted that this effect should be larger in older groups of children than in younger groups. We also argued that the best way of testing this type of developmental hypothesis was to use a longitudinal design rather than a cross-sectional design as nearly all studies have done. We failed to find any developmental trends with respect to laterality. The first and simplest objection one can make is that the age groups involved in this study are too old. The only response I can give to this objection is that children younger than those who participated in this study were not able to perform the tasks properly. A more serious drawback was the fact that we found that the ear advantage did not appear to be such a robust phenomenon as has often been suggested. Within a sample of twenty subjects approximately 70% showed a right ear advantage. On retesting this group we again found a statistically significant advantage which was observed in 70% of the subjects but the overlap between the two groups showing the ear advantage at the two occasions was at chance level. This came rather as a surprise, since dichotic tasks have been used in an overwhelming number of studies and hardly any doubts about the realiability and validity of the technique have been expressed.

We have made several attempts to improve our tasks; the procedure described in chapter 7 seems to provide more reliable results with respect to the ear advantage. In that study we presented the stimuli at a fairly high rate. We did this in response to a suggestion made by Geffen (personal communication) who introduced the monitoring technique and also used very high presentation rates. It is obvious from reports of the subjects that this task is demanding; the subjects have to concentrate hard in order to cope with the task. This suggests that using a high presentation rate reduces the variance considerably. However, this is hardly an explanation for the fact that under these conditions individual ear scores as well as the ear advantage are reliable while under other conditions only the individual ear scores are reliable.

Another explanation can be given, although it may be doubted whether it is any more satisfying than the preceding one. One could say that the more complex or difficult the dichotic task is the clearer the ear advantage will be. This can be demonstrated as follows. It is virtually impossible to obtain ear advantages with monaural presentation. It is possible to get ear advantages with single pairs of (normal) words but in that case one has to measure response latencies. No asymmetries will be observed if a free recall procedure is used. However, if only pairs of cv-syllables are used, one finds ear advantages even with free recall. In this situation the subjects hear two perfectly aligned stimuli with a similar structure, a consonant and a vowel, while the difference between the two stimuli is restricted to small discrepancies in the first 30 msec of the stimili. If one uses a dichotic task in wich pairs of digits are presented, one can see that the ear advantage is most clear and reliable when four pairs of digits are presented in 2 sec. Thus stimulus characteristics and time pressure seem to be important factors in obtaining reliable effects. With respect to the last factor, there is no indication why this should be so. It seems necessary to develop models of the effect of ear advantage in which processing demands also play a certain and not inconsiderable role. With respect to these models, which are still to be developed, I would like to add the following. The models as described by Kimura and Kinsbourne have conceived of the two words presented under dichotic conditions as two independent messages which had to be interpreted by some general processor. However, the results of the item analysis of chapter 7 suggest that this view might be wrong. In the analysis I looked at reaction times to individual target words. Each target was presented four times, twice on each side. However, it was paired with different words on these four occasions. By looking at the results of two groups of subjects, those wearing the headphones in the normal position and those wearing the phones in the reversed position, responses to a target word presented to the right ear and the left ear could be studied, keeping the stimulus-configuration constant. It appears that very stable reaction times can be obtained as long as the stimulus-configuration as a whole is stable. Thus, it is not the case that first one stimulus, preferably the one coming from the right ear, is processed first and the other one only after that. Together, they seem to form a single stimulus-configuration, which the processor is able to separate into two, while in general information about the side of presentation is retained. This view does not explain the right ear advantage. Nevertheless, I think that this picture does give a representation of what is going on under dichotic presentation, that should be taken as a starting point when theorizing about ear advantage.

Summarizing the evidence with respect to my prediction about variations in degree of lateralization I can say that there are only a few indications that two dichotic tasks using the same material produce different degrees of lateralization. Even with the improved procedure I could not demonstrate this effect unambiguously. However, I have found a statistically significant effect on different occasions and therefore it should not be interpreted as a chance finding.

Now I wish to turn to the second issue, the question of whether different measures of laterality can be assumed to reveal the same underlying principle of organization of functions in the brain. In the literature many ways of determining laterality have been described such as lesion studies, handedness and experimental techniques like dichotic listening and visual half field stimulation. These methods are generally believed to measure the same thing: laterality. This can be seen best in papers reviewing the literature in order to evaluate the value of a particular theory of laterality: very often all sources of evidence collected with the various methods mentioned above are treated as qualitatively similar. To put it more concretely: a right ear advantage expresses the same thing as a right visual half field advantage and as aphasia due to left-hemisphere damage, namely left-hemisphere specialization for language. Although this is not generally held to imply that all aspects of language processing are localized in the left hemisphere, at least one very fundamental aspect such as the 'speech processor' of Liberman (1974) is assumed to be lateralized. The localization of this processor is again determined by a general principle which governs the localization of all functions into the left and right hemisphere. This principle is what is generally implied by the concept 'laterality'. In the first chapter I have described an alternative interpretation of laterality phenomena. I there stated that laterality as observed in a particular situation is dependent on the set of subsystems involved in performing a particular act. In that view, laterality measures will only correlate with each other to the extent that there is overlap in the set of subsystems tapped with each of these procedures.

Results casting doubt on the traditional position described above come from a small number of studies that have compared a number of laterality measures often within small samples of subjects. I believe that the study described in chapter 8 provides strong evidence against the traditional interpretation. The fact that measures of dichotic listening, visual half field stimulation and handedness are independent of each other, can hardly be interpreted within the usual framework. These results are in line with the model of laterality as presented in the first chapter. According to this model measures of laterality will only correlate to the extent that the different conditions call upon the same subsystems.

One problem with this type of evidence is that it is 'negative' in the sense that the correlation, predicted by the traditional conception, was not found. However, the fact that within the different tasks, i.e., dichotic tasks, visual half field tasks and handedness tasks, significant correlations are found and form independent interpretable clusters is counterevidence to a strong objection. This objection would be that no significant correlations were obtained due to sloppy experimentation. Apart from the data which argue against the interpretation of laterality tasks as tapping a single mechanism, there is, to my knowledge, actually very little evidence in support of such a notion. It does not seem fair to reject negative evidence if there is no strong positive empirical basis for maintaining a particular theoretical position.

A number of further conclusions which are based on the experiments presented in this thesis are stated in the relevant chapters. They need not be reformulated here. Instead, I would like to draw two general conclusions based on my experience with the literature on laterality and on the experiments presented in this thesis. The flavour of them is fairly negative but at the same time they imply what type of research is badly needed for a better understanding of laterality phenomena.

Firstly, what is most striking is the fact that there are only very few studies on the reliability and validity of the different techniques used to measure laterality. This is even more amazing if one realizes how unnatural some of these procedures are. If we look at dichotic listening, it is clear that only for a very limited number of tasks any data on reliability of ear advantage are described in the literature. It is also apparent that within a group of subjects a statistically significant ear advantage can be found, even though the effect is not a reliable indicator of lateralization for any particular subject. Certain tasks show relatively reliable effects, others do not. However, there is insufficient insight into the conditions which have to be fulfilled in order to design a suitable task. Such an understanding of course, would not only be helpful in preparing dichotic material, but it would also contribute to our understanding of laterality.

The second conclusion is related to the first. In view of the fact that so little is known on the reliability of the procedures used in laterality research, it is remarkable to see how easily many results have been accepted and interpreted. Most theories that have been formulated reach far beyond the relevant data. It is only during the last few years that some scepticism is being expressed. It appears that one has been overenthusiastic and over-optimistic about the possibilities of laterality research given the theoretical and empirical means that are presently available.

SUMMARY

In this thesis a number of studies are presented directed at several theoretical and empirical issues. In the first chapter the traditional interpretation of laterality phenomena is described. It is argued that too much emphasis has been placed on the view of the brain as consisting of two more or less independent systems. The class of dichotomous models, related to this view, do not leave room for the possibility that laterality varies in degree, between as well as within subjects. Furthermore, it is pointed out that the traditional approach usually assumes (implicitly) that the different measures of laterality all tap a single mechanism. An alternative view of laterality is described based on the notion of 'functional system' of Luria (1973). Functions are not considered to be something similar to the 'centers' as described in the classical neurological literature. Rather they are seen as a set of subsystems, whereby the make-up of the set is dependent on the nature of the task to be performed and the strategy chosen by the individual. Within this approach variation of degree of lateralization can be expected and different measures of laterality do not necessarily have to correlate.
In the chapters 2 and 3 a review of the clinical and experimental literature with respect to relevant issues is given. Perhaps the single most important issue in the clinical studies with respect to laterality is the relationship between side of lesion causing aphasia and handedness. Although it is generally assumed that these two variables strongly correlate, it appears from the studies on large samples in particular that in fact this correlation is very weak. The major reason for this is that in approximately 70% of the lefthanded aphasics language is represented in the left hemisphere. In chapter 4 the position of Colbourn (1978) with respect to the permitted level of measurement of laterality is questioned. He claimed that the use of data higher than the nominal level is unwarranted since there is no theory that can handle differences in degree of laterality. However, in the literature almost all experimental studies use scores that are at an ordinal or interval level. It appears that many authors believe that observed differences in degree of laterality between subject groups can be of major importance in our understanding of laterality phenomena. Therefore it is argued that although good models of laterality in which the notion of degree of laterality is incorporated in a satisfactory way it would nevertheless not be sensible to restrict ourselves to nominal measures of laterality. In chapter 5 an experimental study on the development of laterality is presented. For that purpose two new dichotic

tasks, category monitoring and rhyme monitoring, were developed. No increase in laterality was observed. However, it appeared that the ear advantage measured with our tasks was fluctuating to an unexpected large extent. In the chapters 6 and 7 experiments are described in which attempts have been made to produce more reliable ear advantages. It is shown that an increase of the rate at which dichotic pairs of words are presented result in reliable laterality effects. An item analysis looking into the reaction times to individual target words demonstrated that responses to a particular word are influenced by stimulus characteristics of the word presented to the other ear. This is interpreted as indicating that the two stimuli presented under dichotic conditions are not processed as two independent stimuli but rather seem to merge into a single stimulus configuration. This view, if correct, could serve as a basis for a better interpretation for the right ear advantage. Although the interaction of task by ear, indicating differences in degree of laterality, was observed on some occasions, the effect was not stable. It is possible that by developing specific strategies, subjects change the way of processing the information that is presented and that this change is reflected in the observed laterality scores.

In chapter 8 a study is described in which different measures of laterality are compared in a relatively large sample. The measures studied appeared to split up in three independent clusters: dichotic scores, visual half field scores, and handedness scores. These results are interpreted as evidence against the traditional interpretation of laterality scores as tapping a single mechanism. In chapter 9 the results of the empirical studies are discussed with respect to the general framework presented in the first chapter. It is concluded that the evidence for the notion of variation of degree of lateralization is rather weak. Nevertheless, some significant results were obtained on independent occasions and cannot simply be regarded as chance findings. The evidence with respect to the second issue, the relation of different measures of laterality, was more convincing. It is argued that before general statements on laterality can be formulated, more reliable instruments for measuring laterality are badly needed. Furthermore, it is claimed that findings obtained using a particular procedure to study laterality cannot simply be generalized to other areas.

SAMENVATTING

Dit proefschrift bevat een aantal studies, die betrekking hebben op enkele theoretische en empirische vraagstukken op het gebied van lateraliteit. Het begrip lateraliteit verwijst in het algemeen naar de opvatting dat de twee hersenhelften funktioneel van elkaar verschillen, hetgeen zich uit in bijvoorbeeld handvoorkeur. In het eerste hoofdstuk wordt een beschrijving gegeven van de traditionele, meest gangbare verklaring van lateraliteitsverschijnselen. Naar de mening van de auteur wordt bij die interpretatie te zeer de nadruk gelegd op een visie, waarin de hersenhelften worden opgevat als twee onafhankelijke systemen. De klasse van dichotome modellen, die aan deze visie is gekoppeld, staat niet toe lateraliteit te beschouwen als een continuum, waarbij verschillen in mate van lateraliteit zowel tussen individuen als binnen een individu, mogelijk zijn. Bovendien wordt erop gewezen dat de traditionele opvatting er vanuit gaat dat de verschillende methoden om lateraliteit te meten één en hetzelfde mechanisme betreffen.

In hoofdstuk 1 wordt een andere visie op lateraliteit gepresenteerd, die vooral steunt op het begrip 'funktioneel systeem', dat onder meer door Luria is beschreven. Daarbij worden funkties niet opgevat als 'centra', zoals in de klassieke neurologische literatuur wel gebeurt. Veeleer worden ze gezien als een verzameling van deelsystemen, waarbij de samenstelling van de verzameling zowel afhankelijk is van de aard van de taak die uitgevoerd moet worden als van de werkwijze die het individu kiest.

Bij deze benadering zijn gradaties in lateraliteit mogelijk en interpreteerbaar, maar ook behoeven verschillende maten van lateraliteit niet noodzakelijkerwijs met elkaar te correleren.

In de hoofdstukken 2 en 3 wordt een overzicht gegeven van de klinische en experimentele literatuur met betrekking tot vooral die punten, die relevant zijn voor de in hoofdstuk 1 geformuleerde vraagstukken. In hoofdstuk 4 wordt de positie van Colbourn (1978) ter discussie gesteld. Deze auteur is van mening dat, gezien de aard van de ontwikkelde theorieën over lateraliteit, alleen op nominaal niveau gemeten mag worden. Door ons wordt echter gesteld dat het, gezien het feit dat veel vooraanstaande onderzoekers van mening zijn dat graduele verschillen in lateraliteit zinvol geïnterpreteerd zouden kunnen worden, niet juist zou zijn onszelf door de door Colbourn voorgestelde beperking op te leggen, hetgeen niet wegneemt dat aangepaste theorieën ontwikkeld dienen te worden.

Hoofdstuk 5 beschrijft een experimentele studie over de ontwikkeling van lateraliteit. Voor dat onderzoek zijn twee nieuwe dichotische taken ontwikkeld, categorie-monitoring en rijm-monitoring. Hierbij worden reeksen paren van woorden aan een proefpersoon aangeboden, aan elk oor één woord, en de proefpersoon moet reageren zodra hij een woord hoort dat tot een voorafgespecificeerde categorie behoort (bv. 'fruit'), of dat rijmt op een bepaald woord. De verschillen in de aantallen gedetecteerde woorden en in de reactietijd daarvoor nodig tussen stimuli aangeboden aan het rechter- en linkeroor (het oorvoordeel) is een maat voor lateraliteit. Er werd geen toename in lateraliteit gevonden, die gerelateerd was aan leeftijd. Hoewel beide taken significante oorverschillen aantoonden die vergelijkbaar waren met in de literatuur gerapporteerde resultaten bleek het echter dat het oorvoordeel in grote mate fluctuaties vertoonde. In de hoofdstukken 6 en 7 worden experimenten gerapporteerd waarin gepoogd is de meetprocedure zo te veranderen dat de oorverschillen stabieler zouden worden. In deze experimenten bleek onder andere dat de resultaten wat betreft de oorverschillen redelijk betrouwbaar zijn wanneer de stimuli snel achter elkaar worden aangeboden. Een item-analyse, waarin de reactie-tijden op individuele woorden zijn bekeken, toonde aan dat een respons op een bepaald woord systematisch beinvloed wordt door stimuluskenmerken van het woord dat tegelijkertijd wordt aangeboden aan het andere oor. Dit wordt geinterpreteerd als een aanwijzing dat de twee stimuli, die dichotisch worden aangeboden niet onafhankelijk van elkaar verwerkt worden. Er lijkt veeleer sprake te zijn van één stimulus-configuratie. Deze visie kan, als zij correct blijkt te zijn, dienen als een uitgangspunt voor een betere interpretatie van het oorvoordeel.

Ofschoon de interactie tussen taken en oorvoordeel, die - indien aanwezig - duidt op gradaties van lateraliteit, enkele malen aangetoond kon worden, was het effect niet stabiel. Het is mogelijk dat individuen door bepaalde strategieën te ontwikkelen de manier waarop ze de aangeboden informatie verwerken kunnen veranderen en dat deze verandering in de geobserveerde lateraliteitsscores gereflecteerd wordt.

In hoofdstuk 8 wordt een studie beschreven waarin bij een relatief grote steekproef lateraliteit op verschillende manieren werd vastgelegd. Het bleek dat de gebruikte maten uiteenvielen in drie onafhankelijke clusters: dichotische scores, visuele halfveld scores en handvoorkeur scores. Deze resultaten worden geinterpreteerd als gegevens die strijdig zijn met de traditionele opvatting dat allerlei maten één en hetzelfde lateraliteitsmechanisme meten.

In hoofdstuk 9 worden de resultaten van de empirische studies besproken tegen de achtergrond van de algemene uitgangspunten zoals die in hoofdstuk 1 zijn weergegeven. Een eerste conclusie is dat de empirische ondersteuning van de opvatting van gradaties van lateraliteit matig te noemen is. De resultaten uit het onderzoek naar de relatie tussen de verschillende lateraliteitsmaten zijn veel overtuigender. Het is evenwel noodzakelijk om meer betrouwbare meetinstrumenten te ontwikkelen, alvorens meer algemene uitspraken over lateraliteit te kunnen doen. Tenslotte wordt gesteld dat resultaten die verkregen zijn met een bepaalde meetmethode niet eenvoudig gegeneraliseerd kunnen worden naar andere terreinen. Zo kunnen ideeën over lateraliteit die gebaseerd zijn op de effekten van hersenbeschadigingen niet gemakkelijk vertaald worden naar de werking van het intacte brein en kan onderzoek over handvoorkeur niet direkt gerelateerd worden aan resultaten van dichotische experimenten.

REFERENCES

Ajuriaguerra, J. de & Tissot, R. (1969) The apraxias. In: P.J. Vinken & G.W. Bruyn (eds.), Handbook of Clinical Neurology, Vol. IV. Amsterdam: North Holland Publishing Company.

Akelaitis, A.J. (1944) The study of gnosis, praxis, and language following section of the corpus callosum and anterior commisure. Journal of Neurosurgery, 1, 94-102.

Annett, M. (1970a) A classification of hand preference by association analysis. British Journal of Psychology, 61, 303-312.

Annett, M. (1970b) The growth of manual performance and speed. British Journal of Psychology, 61, 545-558.

Annett, M. (1978a) Genetic and nongenetic influences on handedness. Behavior Genetics, 8, 227-249.

Annett, M. (1978b) A single gene explanation of right and left-handedness and brainedness. Coventry: Polytechnic.

Annett, M. (1982) Handedness. In: J.G. Beaumont (ed.), Divided visual field studies of cerebral organisation. London: Academic Press.

Annett, M., Hudson, P.T.W. & Turner, A. (1974) The reliability of differences between the hands in motor skill. Neuropsychologia, 12, 527-531.

Bagnara, S., Boles, D., Simion, F. & Umilà, C. (1982) Can an analytic/holistic dichotomy explain hemispheric asymmetries? Cortex, 18, 67-78.

Bakker, D.J., Van der Vlugt, H. & Claushuis, M. (1978) The reliability of dichotic ear asymmetry in normal children. Neuropsychologia, 16, 753-757.

Basser, L. (1962) Hemiplegia of early onset and the faculty of speech with special reference to the effects of hemispherectomy. Brain, 85, 427-460.

Bastian, H.C. (1887) On different kinds of aphasia with special reference to their classification and ultimate pathology. The British Medical Journal, 5, 931-936.

Beaumont, J.G. (1974) Handedness and hemispheric function. In: S. Dimond & J.G. Beaumont (eds.), Hemispheric function in the human brain. London: Paul Elek.

Beaumont, G. (1982) (ed.), Divided visual field studies of cerebral organisation. London: Academic Press.

Beaumont, J.G. (1982) Introduction. In: J.G. Beaumont (ed.), Divided visual field studies of cerebral organisation. London: Academic Press.

Berlin, C.I. (1977) Hemispheric asymmetry in auditory tasks. In: S. Harnad, R.W. Dowty, L. Goldstein, J. Jaynes & G. Krauthamer (eds.), Lateralization in the nervous system. New York: Academic Press.

Berlin, C.I. & McNeill, M.R. (1976) Dichotic listening. In: N.J. Lass (ed.), Contemporary issues in experimental phonetics. New York: Academic Press.

Berlin, C.I., Hughes, L., Lowe-Bell, S. & Berlin, H.L. (1973) Dichotic right ear advantage in children 5 to 13. Cortex, 9, 394-401.

Bertelson, P. (1981) The nature of hemispheric specialization: Why should there be a single principle? The Behavioral and Brain Sciences, 4, 63-64.

Birkett, P. (1977) Measures of laterality and theories in hemispheric process. Neuropsychologia, 15, 693-696.

Birkett, P. (1978) Hemispheric differences in the recognition of nonsense shapes: cerebral dominance or strategy effects? Cortex, 15, 245-249.

Blumstein, S., Goodglass, H. & Tartter, V. (1975) The reliability of ear advantages in dichotic listening. Brain and Language, 2, 226-236.

Bonin, G. von (1961) Anatomical asymmetries of the cerebral hemispheres. In: V.B. Mountcastle (ed.), Interhemispheric Relations and Cerebral Dominance. Baltimore: Johns Hopkins.

Bossy, J.G. (1970) Morphological study of a case of complete, isolated and asymptomatic agenesis of the corpus callosum. Archives of Anatomical and Histological Embryology, 53, 289-340.

Boyd, R. (1861) Tables of the weights of the human body and internal organs in the sane and insane of both sexes at various ages arranged from 2114 post-mortem examinations. Philosophical Transactions, 151, 241-262.

Bouillaud, J.B. (1825) Recherches cliniques propres â demontrer que la perte de la parole corresponds â la lêsion des lobales antêrieurs en cerveau. Archives Gênêral Mêdecin, 8, 25-45.

Bradshaw, J.L. (1980) Right hemisphere language: familial and nonfamilial sinistrals, cognitive deficits and writing hand position in sinistrals and contrete abstract, imageable and nonimageable dimensions in word recognition. A review of interrelated issues. Brain and Language, 10, 172-188.

Bradshaw, J.L. & Nettleton, N.C. (1981) The nature of hemispheric specialization in man. The Behavioral and Brain Sciences, 4, 51-93.

Bramwell, B. (1899) On crossed aphasia. Lancet, 8, 1473-1479.

Braune, C. (1891) Die Gewichtsverhältnisse des rechten zur linken Hirnhälfte beim Menschen. Archiv für Anatomie und Physiologische Anatomie. Abst. 253.

Broadbent, D.E. (1974) Division of function and integration of behavior. In: F.O. Schmitt & F.G. Worden (eds.), The neurosciences: Third study program. Cambridge: M.I.T. Press.

Broca, P. (1861) Perte de la parole. Ramollisement chronique et destruction partielle du lobe antêrieur gauche du cerveau. Bulletin de la Sociêtê d'Anthropologie, 2, 330-357.

Broca, P. (1965) Sur le siêge de la facultê du langage articulê. Bulletin de Sociêtê Anthropologie, 6, 377-393.

Broca, P. (1875) Instructions craniologiques et craniomêtriques de la Sociêtê d'Anthropologie de Paris. Bulletin de la Sociêtê d'Anthropologie de Paris, 6, 377-393.

Bryden, M.P. (1964) Tachistoscopic recognition and cerebral dominance. Perceptual and Motor Skills, 19, 686.

Bryden, M.P. (1978) Strategy effects in the assessment of hemispheric asymmetry. In: G. Underwood (ed.), Strategies of information processing. London: Academic Press.

Bryden, M.P. & Zurif, E.B. (1970) Dichotic listening performance in a case of agenesis of the corpus callosum. Neuropsychologia, 8, 371-377.

Chamberlain, H.D. (1928) The inheritance of left-handedness. Journal of Heredity, 19, 557-559.

Clark, E. & Dewhurst, K. (1972) An illustrated history of brain function. Berkeley: University of California Press.

Cohen, G. (1975) Hemispheric differences in the utilization of advance information. In: P. Rabbitt and S. Dornic (eds.), Attention and Performance, V. London: Academic Press.

Colbourn, C.J. (1978) Can laterality be measured? Neuropsychologia, 16, 283-289.

Connolly, C. (1950) External morphology of the primate brain. Springfield: Charles C. Thomas.

Conrad, K. (1949) Über aphasische Sprachstörungen bei hirnverletzten Linkshändern. Der Nervenarzt, 20, 148-154.

Corballis, M. & Morgan, M. (1978) On the biological basis of human laterality. I. Evidence for a maturational left-right gradient. The Behavioral and Brain Sciences, 1, 261-269.

Cunningham, P.J. (1892) Contributions to the Surface Anatomy of the Cerebral Hemispheres. Cunningham Memoirs No VII. Dublin: Royal Irish Academy.

Damasio, A. & Damasio, D. (1977) Musical faculty and cerebral dominance. In: M. Critchley & R.A. Henson (eds.), Music and the brain. London: William Heineman Medical Books Ltd.

Davidoff, J. (1982) Studies with non-verbal stimuli. In: J.G. Beaumont (ed.), Divided visual field studies of cerebral organisation. London: Academic Press.

Dennis, M. & Kohn, B. (1975) Comprehension of syntax in infantile hemiplegics after cerebral hemidecortication: left hemisphere superiority. Brain and Language, 2, 472-482.

Dennis, M. & Whitaker, H.A. (1976) Language acquisition following hemidecortication: linguistic superiority of the left over the right hemisphere. Brain and Language, 3, 404-433.

Dejerine, J. (1892) Contributions à l'étude anatomique et clinique des différentes variétés de cécité verbale. C.R. Société Biologie, 4, 61-90.

Dimond, S.J. (1972) The double brain. London: Churchill-Livingstone.

Eberstaller, O. (1890) Das Stirnhirn. Wien und Leipzig: Urban und Schwarzenberg.

Economo, C. von & Horn, C. (1930) Über Windungsrelief, Masse und Rindenarchitektonik der Supratemporal Flache. Zeitschrift der Gesamte Neurologie und Psychiatrie, 130, 678-757.

Egeth, H. & Epstein, J. (1972) Differential specialisation of the cerebral hemispheres of sameness and difference. Perception and Psychophysics, 12, 218-220.

Eling, P. (1981a) On the theory and measurement of laterality. Neuropsychologia, 19, 321-324.

Eling, P. (1981b) Consistency of ear advantages. Paper presented at the INS-Conference, Bergen, July.

Eling, P. (1982) Relaties tussen maten van lateraliteit. (Report No. 82FU10.) Nijmegen: Katholieke Universiteit, Department of Experimental Psychology, November, 1982.

Eling, P. (1983) Comparing different measures of laterality: do they relate to a single mechanism? Journal of Clinical Neuropsychology, 5,

Eling, P., Marshall, J.C. & van Galen, G. (1981) The development of language lateralization as measured by dichotic listening. Neuropsychologia, 19,

Ettlinger, G., Jackson, C. & Zangwill, O. (1956) Cerebral dominance in sinistrals. Brain, 79, 569-588.

Ferrier, D. (1886) The functions of the brain. London: Smith Elder & Co. (2nd edition).

Fennell, E.B., Bowers, D. & Satz, P. (1977) Within modal and cross-modal reliability of two laterality tests. Brain and Language, 4, 63-69.

Fowler, C. (1975) A systems approach to the cerebral hemispheres. Haskins status report on speech research, SR-44.

Fritsch, G. & Hitzig, E. (1870) Ober die elektrische Erregbarkeit des Grosshirns. Archive für Anatomische Physiologische und Wissenschaftliche Medizin, 37, 300-332.

Galaburda, A. & Kemper, T. (1979) Cytoarchitectonic abnormalities in developmental dyslexia: a case study. Annals of Neurology, 6, 94-100.

Galaburda, A., leMay, M. & Kemper, T. (1978) Right-left asymmetries in the brain. Science, 199, 852-856.

Gall, F. & Spurzheim, J.C. (1809) Recherches sur le système nerveux en gênêral, et sur celui du cerveau en particulier. Mémoire présentê â l'Institut de France, Paris.

Gazzaniga, M.S. (1970) The Bisected Brain. New York: Appleton-Century-Crofts.

Gazzaniga, M.S. & LeDoux, J. (1977) The Integrated Mind. New York: Plenum Press.

Geffen, G. (1976) Development of hemispheric specialization for speech perception. Cortex, 12, 337-346.

Geffen, G. & Caudrey, D. (1981) Reliability and validity of the dichotic monitoring test for language laterality. Neuropsychologia, 19, 413-423.

Geffen, G., Traub, E. & Stierman, J. (1978) Language laterality assessed by unilateral ECT and dichotic monitoring. Journal of Neurology, Neurosurgery and Psychiatry, 41, 354-360.

Geschwind, N. (1974) Late change in the nervous system: an overview in plasticity and recovery of function in the central nervous system. In: D. Stein, J. Rosen & N. Butters (eds.), Plasticity and recovery of function in the central nervous system. New York: Academic Press.

Geschwind, N. & Levitsky, W. (1968) Human brain: left-right asymmetries in temporal speech region. Science, 161, 186-187.

Gesell, A. & Ames, L. (1947) The development of handedness. The Journal of Genetic Psychology, 70, 155-175.

Goodglass, H. (1973) Developmental comparison of vowels and consonants in dichotic listening. Journal of Speech and Hearing Research, 16, 744-752.

Goodglass, H. & Quadfasel, F.A. (1954) Language laterality in left-handed aphasics. Brain, 77, 521-548.

Hardyck, C. (1977) A model of invididual differences in hemispheric functionning. In: H. Whitaker & H.A. Whitaker (eds.), Studies in neurolinguistics, Vol. III. New York: Academic Press.

Hardyck, C. & Petrinovitch, L. (1977) Left-handedness. Psychological Bulletin, 84, 385-404.

Hardyck, C. (1983) Seeing each other's points of view: visual perceptual lateralization. In: J.B. Hellige (ed.), Human Cerebral Asymmetry: Method, Theory and Application. New York: Praeger.

Harris, L.J. (1980) Left-handedness: early theories, facts and fancies. In: J. Herron (ed.), Neuropsychology of left-handedness. New York: Academic Press.

Hécaen, H. (1969) Aphasic, apraxic, agnostic syndromes in right and left hemisphere lesions. In: P.J. Vinken & G.W. Bruyn (eds.), Handbook of Clinical Neurology, Vol. III. Amsterdam: North Holland Publishing Company.

Hécaen, H. (1976) Acquired aphasia in children and the ontogenesis of hemispheric functional specialisation. Brain and Language, 3, 114-134.

Hécaen, H. (1979) Aphasias. In: M.S. Gazzaniga (ed.), Handbook of Behavioral Neurology, Vol. II. New York: Plenum Press.

Hécaen, H. & Albert, M. (1978) Human Neuropsychology. New York: John Wiley & Sons.

Hécaen, H. & Dubois, (1969) La naissance de la neuropsychologie du langage, 1825-1865. Paris: Flammarian.

Henschen, S. (1926) On the function of the right hemisphere. Brain, 49, 110-123.

Hicks, R. & Kinsbourne, M. (1976) On the genesis of human handedness: a review. Journal of Motor Behavior, 8, 257-266.

Hicks, R. & Kinsbourne, M. (1978) Lateralized concomitants of human handedness. Journal of Motor Behavior, 10, 83-94.

Hiscock, M. & Kinsbourne, M. (1977) Selective listening asymmetry in preschool children. Developmental Psychology, 13, 217-224.

Hoadley, M.F. & Pearson, K. (1929) On measurement of the internal diameter of the skull in relation (I) to the prediction of its capacity (II) to the "preeminence" of the left hemisphere. Biometrika, 21, 85-117.

Hudson, P.T.W. (1975) The genetics of handedness - a reply to Levy and Nagylaki. Neuropsychologia, 13, 331-339.

Hudson, P.T.W. & Marshall, J.C. (1978) Is a unified (cross species) theory of asymmetries feasible? The Behavioral and Brain Sciences, 1, 300.

Inglis, J. & Sykes, P.H. (1967) Some sources of variation in dichotic listening performance in children. Journal of Experimental Child Psychology, 5, 480-488.

Jackson, H. (1915) On the nature of the duality of the brain. Medical Press Circular, 1874, reprinted in Brain, 38, 80-86.

Jackson, J.H. (1932) Selected Writings of John Hughlings Jackson (ed. by J. Taylor). New York: Basic Books.

Johnson, S.C. (1967) Hierarchical clustering scheme. Psychometrika, 32, 241-254.

Jordan, H.E. (1911) The inheritance of left-handedness. American Breeders Magazine, 2, 19-29; 113-124.

Kimura, D. (1961) Cerebral dominance and the perception of verbal stimuli. Canadian Journal of Psychology, 15, 166-171.

Kimura, D. (1963) Speech lateralization in young children as determined by an auditory test. Journal of comparative physiology and psychology, 56, 899-902.

Kimura, D. (1967) Functional asymmetry of the brain in dichotic listening. Cortex, 3, 163-178.

Kimura, D. (1975) The asymmetry of the human brain. In: Progress in Psychobiology - Reading from Scientific American. San Francisco: W.H. Freeman & Co.

Kimura, D. (1975) Cerebral dominance for speech. In: D.B. Tower (ed.), Human Communication and its Disorders, Vol. III. New York: Raven Press.

Kinsbourne, M. (1970) The cerebral basis of lateral asymmetrics in attention. Acta Psychologica, 33, 193-201.

Kinsbourne, M. (1975) The mechamism of hemispheric control of the lateral gradient of attention. In: P. Rabbitt & S. Dornic (eds.), Attention and Performance V. London: Academic Press.

Kinsbourne, M. & Hiscock, M. (1977) Does cerebral dominance develop? In: S. Segalowitz & F. Gruber (eds.), Language Development and Neurologic Theory. New York: Academic Press.

Kohnstamm, G.A. & De Vries, A.K. (1969) Streeflijst Woordenschat bij de overgang van kleuteronderwijs naar basisonderwijs. Ijmuiden: Vermande Zonen.

Krashen, S. (1973) Lateralization, language learning and the critical period Some new evidence. Language Learning, 23, 63-74.

Lecours, A.R. (1981) Morphological maturation of the brain and functional lateralization for verbal skills. In: Y. Lebrun & O. Zangwill (eds.), Lateralization of Language in the Child. Lisse: Swets & Zeitlinger.

Leleux, C. & Lebrun, Y. Language development in Two cases of left hemispherectomy. In: Y. Lebrun & O. Zangwill (eds.), Lateralization of Language in the child. Lisse: Swets & Zeitlinger.

Lenneberg, E.H. (1967) Biological foundations of language. New York: Wiley.

Levy, J. (1973) Lateral specialization of the human brain: behavioral manifestations and possible evolutionary bases. In: J. Kiger (ed.), The Biology of Behaviour. Corvallis: The Oregon State University Press.

Levy, J. & Nagylaki, T. (1972) A model for the genetics of handedness. Genetics, 72, 117-128.

Levy, J. & Reid, M.L. (1978) Variation in cerebral organization as a function of handedness, handposture in writing and sex. Journal of Experimental Psychology: General, 107, 119-144.

Levy, J. & Trevarthen, C. (1969) Metacontrol of hemisperic function in human split-brain patients. Journal of Experimental Psychology: Human Perception and Performance, 2, 299-312.

Liepmann, H. (1965) Die linke Hemisphäre und das Handeln. Münchener Medischer Zeitschrift, 49, 2375-2378.

Liberman, A.M. (1974) The specialization of the language hemisphere. In: F.O. Schmitt & F.G. Worden (eds.), The Neurosciences, third study program. Cambridge: MIT Press.

Luria, A.R. (1966) Higher cortical functions in man. New York: Basic Books.

Luria, A.R. (1970) The functional organization of the brain. Scientific American, 222, 66-78.

Luria, A.R. (1973) The working brain. London: Penguin.

Marshall, J.C. (1980) On the biology of language acquisition. In: D. Caplan (ed.), Biological studies of mental processes. Cambridge: MIT Press.

Marshall, J.C. (1981a) Lateral and focal organization in the human brain. In: Y. Lebrun & O. Zangwill (eds.), Lateralization of language in the child. Lisse: Swets & Zeitlinger.

Marshall, J.C. (1981b) Hemispheric specialization: What, how, and why. The Behavioral and Brain Sciences, 4, 72-73.

Marshall, J.C., Caplan, D. & Holmes, J.M. (1975) The measure of laterality. Neuropsychologia, 13, 315-321.

McKeever, W. (1981) On laterality and dichotomania. The Behavioral and Brain Sciences, 4, 73-74.

Milner, A.D. & Jeeves, M.A. (1979) A review of behavioral studies of agenesis of the corpus callosum. In: J. Steele Russell, M.W. van Hof & G. Berlucchi (eds.), Structure and function of cerebral commissures. London: The MacMillan Press.

Milner, B. (1974) Hemispheric specialization: Scope and limits. In: F.O. Schmitt & F.G. Worden (eds.), The Neurosciences, third study program. Cambridge: MIT Press.

Milner, B., Taylor, L. & Sperry, R. (1968) Lateralized suppression of dichotically presented digits after commissural section in man. Science, 161, 184-185.

Mishkin, M. & Forgays, D.G. (1952) Word recognition as a function of retinal locus. Journal of Experimental Psychology, 43, 43-48.

Molfese, D.L. (1978) Left and right hemisphere involvement in speech perception: Electro-physiological correlates. Perception and Psychophysics, 23, 237-243.

Monakow, C. von (1914) Die Lokalisation im Grosshirn und der Abbau der Funktionen durch corticale Herde. Wiesbaden: Bergmann.

Morais, J. (1975) The effects of ventriloquism on the right side advantage for verbal material. Cognition, 3, 127-129.

Morgan, M.J. & Corballis, M.C. (1978) On the biological basis of human laterality: II. The mechanism of inheritance. The Behavioral and Brain Sciences, 1, 270-276.

Newcombe, F. & Ratcliff, G. (1973) Handedness, speech lateralization and ability. Neuropsychologia, 11, 399-407.

Oldfield, R.C. (1971) The assessment of handedness: The Edinburgh inventory. Neuropsychologia, 9, 97-111.

Penfield, W. & Roberts, L. (1959) Speech and brain mechanisms. Princeton: Princeton University Press.

Peters, M. & Durding, B.M. (1978) Handedness measured by finger tapping: A continuous variable. Canadian Journal of Psychology, 32, 257-261.

Peters, M. & Durding, B.M. (1979) Left-handers and right-handers compared on a motor task. Journal of Motor Behavior, 11, 103-111.

Pfeiffer, R.A. (1918) Beobachtungen an Rechts und Linkshänderschrift von anscheinend weittragender Bedeutung. Zeitschrift für die gesamte Neurologie und Psychiatrie, 45, 301-315.

Pfeiffer, R. (1922) Die rechte Hemisphäre und das Handeln. Zeitschrift für die gesamte Neurologie und Psychiatrie, 77, 471-508.

Pizzamiglio, L., DePascalis, C. & Vignati, A. (1974) Stability of dichotic listening test. Cortex, 10, 203-205.

Porac, C. & Coren, S. (1976) The dominant eye. Psychological Bulletin, 83, 880-897.

Porac, C. & Coren, S. (1979) Individual and familial patterns in four dimensions of lateral preference. Neuropsychologia, 17, 543-548.

Porac, C., Coren, S., Steiger, J.S. & Duncan, P. (1980) Human laterality: A multidimensional approach. Canadian Journal of Psychology, 34, 91-96.

Porter, R.J., Troendle, R. & Berlin, C.I. (1975) Effects of practice on the perception of dichotically presented stop-consonant-vowel syllables. Journal of the Acoustical Society of America, 57, 483-496.

Provins, K.A. & Cunliffe, P. (1972) The reliability of some motor performance tests of handedness. Neuropsychologia, 10, 199-206.

Ramaley, F. (1913) Inheritance of left-handedness. American Naturalist, 47, 730-738.

Rasmussen, Th. & Milner, B. (1977) The role of early left-brain injury in determining lateralization of cerebral speech functions. In: S.J. Dimond & D. Blizard (eds.), Evolution and Lateralization of the Brain. New York: New York Academy of Sciences.

Rife, D.C. (1940) Handedness with special reference to twins. Genetics, 25, 178-186.

Repp, B. (1977) Measuring laterality effects in dichotic listening. Journal of the Acoustical Society of America, 62, 720-737.

Repp, B.H. (1977) Dichotic competition of speech sounds: the role of acoustic stimulus structure. Journal of Experimental Psychology: Human Perception and Performance, 3, 37-50.

Repp, B.H. (1978) Stimulus dominance and ear dominance in the perception of dichotic voicing contrasts. Brain and Language, 5, 310-330.

Richardson, J.T. (1976) How to measure laterality. Neuropsychologia, 14, 135-136.

Roberts, L. (1955) Handedness and Cerebral Dominance. Transactions of the American Neurological Association, 80, 143-147.

Rubens, A.B., Mahowald, M.W. & Hutton, J.T. (1976) Asymmetry of the lateral (sylvian) fissures in man. Neurology, 26, 620-624.

Satz, P. (1973) Pathological left-handedness: an explanatory model. Cortex, 8, 121-135.

Satz, P. (1977) Laterality tests: an inferential problem. Cortex, 13, 208-212.

Satz, P., Bakker, D.J., Teunissen, J., Goebel, R. & Vlugt, H. v.d. (1975) Developmental parameters of the ear asymmetry: a multivariate approach. Brain and Language, 2, 171-185.

Searleman, A. (1977) A review of right hemisphere linguistic capabilities. Psychological Bulletin, 84, 503-528.

Searleman, A. (1980) Subject variables and cerebral organization for language. Cortex, 16, 239-254.

Searleman, A., Tweedy, J. & Springer, S.P. (1979) Interrelationships among subject variables believed to predict cerebral organization. Brain and Language, 7, 267-276.

Semmes, J. (1968) Hemisphere specialization: a possible clue to a mechanism. Neuropsychologia, 6, 11-26.

Seron, X. (1981) Children's acquired aphasia. Is the initial equipotentiality theory still tenable? In: Y. Lebrun & O. Zangwill (eds.), Lateralization of language in the child. Lisse: Swets & Zeitlinger.

Shankweiler, D. & Studdert-Kennedy, M. (1975) A continuum of lateralization for speech perception? Brain and Language, 2, 212-225.

Shellshear, J.L. (1937) The brain of the Aboriginal Australian. A study in cerebral morphology. Philosophical Transactions of the Royal Society, Ser B., 227, 293-409.

Sperry, R., Gazzaniga, M.S. & Bogen, J.E. (1969) Interhemispheric Relationships: The Neocortical Commissures; Syndromes of Hemisphere Disconnection. In: P.J. Vinken & G.W. Bruyn (eds.), Handbook of Clinical Neurology, Vol. III. Amsterdam: North Holland Publishing Company.

Stone, M.A. (1980) Measures of laterality and spurious correlation. Neuropsychologia, 18, 339-345.

Studdert-Kennedy, M. (1975) Two questions. Brain and Language, 2, 123-130.

Teng, E.L. (1981) Dichotic ear difference is a poor index for the functional asymmetry between the cerebral hemispheres. Neuropsychologia, 19, 235-240.

Teuber, H.L. (1974) Why two brains? In: F.O. Schmitt & F.G. Worden (eds.), The Neurosciences: third study program. Cambridge: MIT Press.

Thurnham, J. (1866) On the weight of the brain and the circumstances affecting it. Journal of Mental Sciences.

Van Wagenen, W. & Herren, R. (1940) Surgical division of commissural pathways in the corpus callosum. Archives of Neurology and Psychiatry, 44, 740-759.

Wada, J.A., Clark, R. & Hamm, A. (1975) Cerebral hemispheric asymmetry in humans. Archives of Neurology, 32, 239-246.

Wagner, H. (1864) Massbestimmungen der Oberfläche des grossen Gehirns. Cassel und Göttingen: Wiland.

Weber, E. (1905) Ursache und Folgen der Rechtshändigkeit. Halle: Carl Marhold.

Wernicke, C. (1874) Der Aphasische Symptomencomplex. Breslau: Cohn und Weigert.

White, M.J. (1969) Laterality differences in perception: a review. Psychological Bulletin, 72, 387-405.

White, M.J. (1973) Does cerebral dominance offer a sufficient explanation for laterality differences in tachistoscopic recognition? Perceptual and Motor Skills, 36, 479-485.

Witelson, S.F. (1977) Anatomical asymmetry in the temporal lobes: its documentation, phylogenesis, and relationship to functional asymmetry. In: S.J. Dimond & D. Blizard (eds.), Evolution and Lateralization of the Brain. New York: New York Academy of Sciences.

Witelson, S.F. & Pallie, W. (1973) Left hemisphere specialization for language in the newborn: neuroanatomical evidence of asymmetry. Brain, 96, 641-646.

Wood, C. (1975) Auditory and phonetic levels of processing in speech perception. Journal of Experimental Psychology - Human Perception and Performance, 104, 3-20.

Woods, B. & Teuber, H.L. (1978) Changing patterns of childhood aphasia. Annuals of Neurology, 3, 273-280.

Young, A.W. (1981) Asymmetry of cerebral hemispheric function during development. In: J. Dickerson & H. McGurk (eds.), Brain and Behavior: a developmental perspective. Glasgow: Blackie.

Young, A. (1982a) Methodological and theoretical bases of visual hemifield studies. In: G. Beaumont (ed.), Divided visual field studies of cerebral organization. London: Academic Press.

Young, A.W. & Bion, P.J. (1980) Absence of any developmental trend in right hemisphere superiority for face recognition. Cortex, 16, 213-221.

Zangwill, O.L. (1960) Cerebral dominance and the relation to psychological function. Edinburgh: Oliver and Boyd.

Zurif, E.B. & Bryden, M.P. (1969) Familial handedness and left-right differences in auditory and visual perception. Neuropsychologia, 7, 179-187.

CURRICULUM VITAE

De schrijver van dit proefschrift is geboren op 24 december 1951 te Nijmegen. Na het behalen van het gymnasium alpha diploma studeerde hij psychologie in Nijmegen. Tevens was hij als student-assistent gedurende enkele jaren werkzaam bij de vakgroep Funktieleer en was als zodanig betrokken bij onderzoek naar visuele waarneming. Het doktoraalexamen met als hoofdrichtig psychologische funktieleer legde hij af in 1977. Sedertdien is hij werkzaam geweest op het onderzoeksproject 'Ontwikkeling van lateraliteit van taal en spraakfunkties binnen de Interfacultaire Werkgroep Taal- en Spraakgedrag en de vakgroep Funktieleer.
Naast onderzoek op het gebied van lateraliteit publiceerde hij ook enige studies op het gebied van lees- en leerstoornissen. Tevens was hij betrokken bij het prekandidaats praktikum-onderwijs van de vakgroep Funktieleer en verzorgde hij de doktoraalkursus lateraliteit vanaf 1978. Na beëndiging van het onderzoeksproject in 1981 is hij als wetenschappelijk medewerker verbonden aan het Max-Planck-Institut für Psycholinguistik te Nijmegen. Daar verricht hij psycholinguistisch onderzoek op het gebied van de afasie. In 1982-1983 verzorgde hij binnen de vakgroep Funktieleer de doktoraalkursus Neuropsychologie.

STELLINGEN

1. Het is onjuist te veronderstellen dat meten op nominaal niveau theorie-onafhankelijk zou zijn en daarom meer geschikt voor onderzoek naar lateraliteit dan meten op hogere niveaus.

Colbourn, C.J. Can laterality be measured? *Neuropsychologia*, 1978, *16*, 283-289.

Eling, P. On the theory and measurement of laterality. *Neuropsychologia*, 1981, *19*, 321-324.

2. De stelling dat lateraliteit zich ontwikkelt wordt niet door empirische gegevens ondersteund.

Eling, P., Marshall, J.C. & v. Galen, G.P. The development of language lateralization as measured by dichotic listening. *Neuropsychologia*, 1981, *19*, 767-773.

3. Broca heeft expliciet gesteld dat er geen reden is om aan te nemen dat handvoorkeur en hemisfeer-specialisatie voor taal gerelateerd zijn; dit in tegenstelling tot wat algemeen wordt beweerd over Broca's opinie aangaande dit vraagstuk (bijvoorbeeld Goodglass en Quadfasel, 1954).

Goodglass, H. & Quadfasel, F. Language laterality in lefthanded aphasics. *Brain*, 1954, *97*, 521-548.

4. Onderzoek naar de relatie tussen verschillende indicatoren van lateraliteit zoals afasie, handvoorkeur, oorvoordeel en visueel halfveldvoordeel, suggereert dat allerlei funkties - al dan niet betrekking hebbend op de verwerking van taal onafhankelijk van elkaar gelateraliseerd kunnen zijn.

Eling, P. Comparing different measures of laterality: do they relate to a single mechanism? *Journal of Clinical Neuropsychology*, 1983, *5*, 135-147.

5. Ofschoon het perceptueel centrum van een gesproken woord vrij nauwkeurig bepaald kan worden, is het nog onduidelijk welke rol dit centrum speelt in de auditieve woordperceptie.

Morton, J., Marcus, S. & Frankish, C. Perceptual centres (P-centres). *Psychological Review*, 1976, *83*, 405-608.

Eling, P., Marshall, J.C. & v. Galen, G.P. Perceptual Centres for Dutch Digits. *Acta Psychologica*, 1980, *46*, 95-102.

6. Het is voor de meeste dichotische taken niet relevant of de paren woorden gesynchroniseerd zijn op fysische beginpunten dan wel op perceptuele centra. De wijze van synchronisatie is mogelijk van belang voor dichotische stimuli bestaande uit paren stopkonsonant - klinker syllaben.

Eling, P., Marshall, J.C. & v. Galen, G.P. How synchronous should listening tapes be? A comparison of p-centre and onset-alligned tapes. *Internal Report* 79 FU 14.

7. Het begrip 'MBD' (minimal brain damage/dysfunction) dat wel wordt gebezigd ter aanduiding van een diversiteit van symptomen bij verschillende auteurs varierend in aantal en aard, kan niet opgevat worden als een syndroom.

Eling, P. & Renier, W.O. MBD: what is in a name? *Tijdschrift voor Orthopedagogiek en Kinderpsychiatrie*, 1981, *6*, 85-94.

8. Ten onrechte wordt geprobeerd ontwikkelingsdyslexie te verklaren op basis van 'organische' onvolkomenheden zoals een afwijkend lateraliteitspatroon. Een steekhoudende verklaring zal zich echter baseren op specifieke kenmerken van het leerproces bij kinderen met een dergelijke stoornis.

Eling, P. & v. Grunsven, M. Dyslexie en leren lezen. *De Psycholoog*, 1980, *15*, 221-226.

9. De intonatiepatronen bij patienten met een zogenaamde Wernicke-afasie vertonen afwijkingen; het is vooralsnog onduidelijk of de oorzaak ervan gelegen is in een afwijkende syntaktische planning van de uiting dan wel in conceptuele problemen bij deze patienten.

Danly, M., Cooper, W. & Shapiro, B. Fundamental frequency, language processing and linguistic structure in Wernickes Aphasia. *Brain and Language*, 1983, *19*, 1-24.

10. Omdat wetenschappelijk onderzoek geen inherente richting heeft is het onmogelijk te spreken over 'vooruitgang in de wetenschap'. Vooruitgang en achteruitgang kunnen slechts vastgesteld worden aan de hand van maatschappelijke doelstellingen. Zo is het mogelijk een bepaalde wetenschappelijke ontwikkeling te beschouwen als een vooruitgang met betrekking tot de ene doelstelling en tegelijkertijd als een achteruitgang met betrekking tot een andere.

Deze stellingen horen bij het proefschrift:
Paul Eling, Studies in laterality: Controversial issues in the approach of hemisphere specialization. Katholieke Universiteit Nijmegen, 2 december 1983.