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Dale Dagenbach

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HEMISPHERIC ASYMMETRIES ON LANGUAGE PROCESSING: EFFECTS OF SUBJECT CHARACTERISTICS AND PERCEPTUAL MODALITY

By

Dale Dagenbach

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ABSTRACT

HEMISPHERIC ASYMMETRIES IN LANGUAGE PROCESSING:
EFFECTS OF SUBJECT CHARACTERISTICS AND PERCEPTUAL MODALITY

By

Dale Dagenbach

The effects of handedness, sex, familial sinistrality, and handwriting posture on auditory and visual language processing asymmetries were determined using noninvasive measures. These effects varied with modality, and several interactions between subject variables were found, suggesting that the effects of any particular variable may be modified by others. The correlation between auditory and visual language processing asymmetries was moderate overall, but varied widely as a function of subject characteristics. The results suggest that methodological considerations may explain a considerable amount of the variance in the literature describing the relationship between subject variables and cerebral organization, but also suggest that cerebral asymmetries for language processing are likely to be modality specific and task specific. This points to the need for more precise understanding of the mechanisms that underlie perceptual asymmetries, including specification of the role of attentional factors, and determination of exactly which components or stages of language processing are lateralized.

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TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

Since Broca (1861) originally reported that speech was governed by an area located within the left cerebral hemisphere, the phenomenon of cerebral functional lateralization has been the focus of a considerable amount of research and speculation. The usual aim of this research has been to generate a model of the human brain which details its organization, whether localized or diffuse, for different types of functioning. This has been paralleled, especially of late, by efforts to identify individual and group differences in cerebral organization and to meaningfully integrate these variations with existing general models. Obviously, the success of either of these research programs depends in part upon the success of the other, and although both have yielded a substantial body of literature, a number of questions fundamental to each goal remain unresolved.

One resolved issue is the determination of the exact nature of the relationship between certain subject variables and apparently divergent patterns of cerebral organization for language functioning. It is generally accepted that subject characteristics such as handedness and familial sinistrality are correlated with patterns of cerebral functional lateralization. Indeed, it has been suggested that the current versions of a general model of cerebral functional lateralization, which postulate left hemisphere dominance for language-related functioning and right hemisphere dominance for certain types of visuospatial processing, apply fully only to those individuals who are dextral males without left-handed relatives and who experienced no birth stress (Levy, 1980). But although a relationship between various subject characteristics and distinct patterns of cerebral organization may be acknowledged, the detailing of those patterns is still far from complete. Evidence from clinical and experimental investigations of this issue has been highly contradictory, as will be seen below.

The sources of these contradictions in findings are numerous. There are, for example, many unresolved issues inherent in the assessment of lateralized cerebral functions in clinical or normal populations, and many unresolved issues related to the measurement of some of the subject variables of interest as well. Certainly, much of the variance in results can be attributed to the use of different experimental techniques, instructions, and sampling procedures in the various studies which have been performed. Even more relevant may be the role of an unclear understanding of the basic phenomenon of cerebral functional lateralization itself, which obscures determination of exactly what is being assessed in various measures of cerebral asymmetry, and especially confounds comparing the results of different studies using slightly different procedures. Finally, interactions among the relevant subject variables may also contribute to the confusion surrounding this question; the effects of some variables may be suppressed or enhanced in the presence of others.

The problems mentioned above have not proved easy to redress, partly because they entail both methodological and theoretical considerations. The way to more accurately and more consistently depict the relationship between subject variables and cerebral organization may be to adopt a different interpretation of the results obtained using various procedures, or to adopt different or standardized procedures for the assessment of cerebral organization. Advances in both theory and method probably will be required before a consistent and accurate depiction becomes possible.

A second unresolved question pertinent to considerations about the nature of cerebral functional lateralization in general, and to considerations about individual differences in such lateralization, is the extent to which asymmetrical processing of language varies within subjects as a function of modality. Studies of the relationship between auditory and visual language processing asymmetries typically report small positive correlations (e.g., Zurif & Bryden, 1969), no correlation, or even negative correlations (Smith & Moscovitch, 1979). There are several reasonable interpretations of such findings. The lack of correlation may reflect the inadequacy of the assessment procedures used to determine cerebral organization; neither dichotic listening tests nor divided visual field measures of language processing asymmetries are assumed to correlate perfectly with underlying cerebral asymmetries, and the correlation of two imperfect measures may magnify their inadequacies.

More likely, such findings may reflect the actual dissociation of visual and auditory language processing. This dissociation could arise in two ways--first, although it is convenient to speak of language lateralization, language per se may not be lateralized. One can instead conceive of language as being the product of a succession of information processing stages performed on a certain class of stimuli. Within this framework, hemispheric specialization may be for a particular type of encoding or recoding operation used in processing when the stimulus is linguistic, but not necessarily used only in the processing of linguistic stimuli (Moscovitch, 1979). A similar view suggests that language processing can be described as requiring a number of component mental operations. According to this view, lateralization may be the result of hemispheric specialization for one of those component operations rather than for language processing in general. Either view suggests that any particular task using linguistic stimuli would result in lateralized processing only to the extent that it demands the use of the particular component operation of information processing stage that is lateralized (Cohen, 1982). The operations or stages that are lateralized in such models may contribute unequally to auditory and visual language processing. Alternatively, linguistic stimuli may constitute a unique class of stimuli, and auditory and visual language processing may be lateralized because of hemispheric specialization for that type of stimuli rather than for some more general mental operation. Auditory and visual language processing may nevertheless be lateralized independent of one another due to adaptations necessitated by their utilization of different kinds of sensory input. (See Bradshaw & Nettleton, 1981, for a recent review of the basis of hemispheric specialization.)

The extent to which the correlation between visual and auditory language processing varies as a function of subject characteristics is largely unexplored, although a few studies have provided data for some subject groups (e.g., Smith & Moscovitch, 1979; Hines & Satz, 1974). Studying the interaction of subject variables with the strength of association of asymmetries in visual and auditory language processing may provide yet another piece of evidence about the nature and degree of hemispheric specialization, and may further document the influence of subject variables.

With this in mind, the aim of the current study was to evaluate the relationship between cerebral organization for language processing within the auditory and visual domains and the subject variables of sex, handedness, strength of hand preference, family handedness history, and handwriting posture. A further aim, given the variability in previous findings, was to employ procedures for the assessment of cerebral organization which were more rigorous, and, it was hoped, more valid, than the procedures used in many previous studies. For this reason, procedures were chosen that theoretically minimize the influence of factors not directly related to cerebral asymmetry, such as choice of strategy or selective attention to one side, that may have contributed to variance in other studies. A large sample of left-handers was used, ensuring that the resulting characterizations of visual and auditory language processing asymmetries were based on data from more than a few cases for most subject variable interactions. The sample size permitted study of the cerebral organization of the left-handed population, using noninvasive procedures, to a greater extent than has been previously reported. In particular, it provided an opportunity to examine cross-modal correlations in language processing asymmetries within this group. A large sample size is important in studying the left-handed population because they form a more heterogeneous group than right-handers with respect to cerebral organization. Finally, the effects of the subject variables were assessed both independently and in combination with each other to control for the effects of interactions.

In sum, the current study was an attempt to perform the best possible investigation, using noninvasive measures, of the relationship between subject variables and cerebral asymmetries in auditory and visual language processing. The degree to which such methodological efforts to resolve previous contradictions can succeed provides an estimate of the degree to which theoretical reconsiderations are also necessary. The rationale guiding the exact selection of procedures and methods used in the current study may be understood by considering several bodies of literature. These are reviewed below.

LITERATURE REVIEW

Cerebral Functional Lateralization

Although it has been accepted for over a century that the left and right cerebral hemispheres subserve different functions in man, the reasons for such specialization, the exact nature and degree of the division of functioning between the hemispheres, and the mechanisms by which it is effected have been investigated systematically only in recent years, and only to a limited extent thus far. From these investigations have come some new conceptions of cerebral functional lateralization which suggest that previous characterizations may have been simplistic. A brief review of changing conceptions of the phenomenon will illustrate how an unclear understanding of asymmetrical hemispheric functioning has contributed to the confusion surrounding the effects of subject variables on cerebral organization. It also may clarify the causes of previous failures to find strong correlations between auditory and visual measures.

The model of differential hemispheric functioning that emerged from the nineteenth century acknowledged the role of the left hemisphere in verbal functioning and in higher order thought processes in general, but failed to specify or elaborate the role of the right hemisphere despite Jackson's (1876) suggestion of a special function in perception. Similarly, reports of specific functional losses following unilateral right hemisphere injury in the first half of this century failed to undermine a consensus that the left hemisphere completely dominated thought and controlled behavior (Levy, 1980).

The publication of the split-brain research of Sperry and his colleagues during the 1960s and 1970s quickly destroyed that consensus. Assessment of left and right cerebral hemisphere capabilities following their surgical isolation by severing of the corpus callosum indicated that both hemispheres were specialized for different functions. This body of research undoubtedly formed most of the foundation of current conceptions of cerebral functional lateralization in normal individuals as well as split-brain patients. But the influence of the split-brain research has also been misleading at times. The early characterizations of hemispheric specialization which emerged from this research may have been overly simple and led researchers to ask inappropriate questions.

According to Zaidel (1978), three distinct periods of research guided by different models of cerebral lateralization are discernible in the split-brain studies: During the first period, cerebral functional lateralization was conceived of as the unilateral competence of the left or right hemisphere for performing tasks in different cognitive domains. Thus, the left hemisphere was needed for tasks requiring language processing, and the right hemisphere was necessary for certain spatial tasks. During the second period, the domain of right hemisphere skills was expanded, but the concept of unilateral competence was maintained. A more significant alteration of thinking occurred during the third period when the notion of unilateral control for certain tasks began to supplant that of unilateral competence. It was suggested that the nature of the task might induce one hemisphere to assume control of processing even though the other hemisphere might be even more capable of performing it. Thus, the absolute division of functioning along some language/visuospatial dichotomy was weakened.

The third period of split-brain research also yielded the various alternative dichotomous characterizations of hemispheric specialization that epitomized the last decade of research and theory: The left hemisphere is specialized for analytical propositional thought, the right hemisphere for appositional holistic forms of thought (Bogen, 1969a; 1969b); or the left hemisphere is a serial information processor, the right hemisphere a parallel information processor (Cohen, 1973); or more recently, the left hemisphere is specialized for fine temporal sequential ordering of information, the right for spatial processing (Bradshaw & Nettleton, 1981). Presumably, such dichotomies are more fundamental than the previously suggested verbal/visuospatial division of functioning. However, there are reasons to doubt the attempt to dichotomously characterize cerebral functional asymmetry at all (e.g., Bertelson, 1981; Bryden, 1982; Cohen, 1981; Marshall, 1981; McKeever, 1981; Wyke, 1981).

The conceptions that have guided the split-brain research have served to guide investigations of the cerebral organization of normal subjects as well, creating certain problems as well as inspiring numerous studies. First, the extent to which the functioning of the isolated hemispheres of split-brain patients can be generalized to describe functioning in normal individuals can itself be questioned (Bryden, 1982). More importantly, the early conceptions of unilateral competence for some globally defined function rather haphazardly combined the nature of the stimuli, the modality of presentation, and the processing requirements of the task. Extensions of these conceptions to investigations of normal subjects may have resulted in the use of inappropriate measures of cerebral asymmetry and in inappropriate comparisons of studies that were in fact assessing very different processes.

Fortunately, the evolving characterization of cerebral functional lateralization seen in the split-brain research has been paralleled, and perhaps even surpassed, in studies of normal subjects using noninvasive procedures. Beginning with Kimura's (1961) original observation of a relationship between ear advantages on dichotic listening tasks and speech lateralization as measured by the Wada test, and continuing through a vast literature detailing visual field and ear advantages for processing different types of stimuli under different conditions, a catalogue of apparent hemispheric differences in processing competencies or propensities has been constructed (see Bradshaw & Nettleton, 1981). Such research has fairly reliably found right ear and right visual field advantages for processing language-related stimuli, and more variable left visual field and left ear advantages for certain classes of nonlinguistic stimuli. These advantages are usually interpreted as an indication of contralateral hemispheric specialization. Such studies, findings, and interpretations of them are consistent with notions of unilateral competence such as those developed in the early split-brain research.

However, the use of noninvasive paradigms to assess cerebral organization in normal subjects has also yielded a large body of data indicating that whereas such visual field and ear advantages may be reliably obtained, their magnitude and direction vary as a function of factors such as task difficulty (Jonides, 1979), memory load (Hellige, Cox, & Litvac, 1979), stimulus set size (Cohen, 1973), and the nature of preceding stimuli (Klein, Moscovitch, & Vigna, 1976). The data from visual and auditory tasks also are somewhat in conflict with clinical findings--for example, whereas clinical data indicate that nearly 100% of male dextrals have speech production lateralized to the left hemisphere, dichotic listening tests typically classify only about 50% as left hemisphere dominant for speech perception using significance criteria, and approximately 20-30% show left ear advantages. The variability of findings under different conditions, both between studies and between subjects, and within subjects (Ward & Ross, 1977), and the failure of many subjects to show the expected asymmetry suggest that visual field and ear advantages can not be understood entirely in terms of differential hemispheric competence.

Results of this nature have prompted a closer examination of perceptual asymmetries and their relationship to any underlying hemispheric specialization. One approach to explaining variance or conflicts in noninvasive studies of cerebral organization is to isolate the methodological or procedural differences which may have produced them. In a similar vein, procedures can be devised to minimize the role of factors not directly related to the specialized functioning of the cerebral hemispheres. An alternative approach is to study the mechanisms by which visual field and ear asymmetries are mediated, and to incorporate such elements within models of cerebral functional lateralization. From this latter perspective, factors that might be biasing according to some theories, such as a tendency towards selective attention to one side under certain conditions, or the use of one strategy instead of another, may instead be intrinsic components of cerebral asymmetries in information processing. Considerations of both types are appropriate and will be reviewed briefly. Because the current study employed only divided visual field and dichotic listening tasks, only the literature relevant to these two types of procedures will be considered.

The methodology used in noninvasive studies of cerebral functional lateralization has customarily been to present stimuli to the left and right ear simultaneously, or to the left and/or right visual field for a brief amount of time. The differential accuracy or speed of processing as a function of the side of presentation is then determined. Use of these procedures assumes that contralateral connections from the ears and visual fields to the cerebral cortex are more direct than ipsilateral connections. In studies of language lateralization, this has meant that words, letter strings, pseudowords, and letters have been presented in dichotic listening and divided visual field tasks with the expectation that performance would be better for stimuli presented to the right ear or right visual field for most individuals.

Early dichotic listening studies (e.g., Kimura, 1961) relied on the presentation of lists of word pairs, one word to each ear simultaneously, followed by recall of as many items as possible. Such a procedure, although typically resulting in a right ear advantage for groups of subjects, also allowed interactions with factors such as selective attention to one ear, or biases in order of report. These strategic components of performance on dichotic listening tasks can, in turn, influence the magnitude of asymmetry found (Satz, Achenbach, Pattischall, & Fennell, 1965; Morais & Bertelson, 1973). Investigations of the effect of stimulus type have also shown that not all linguistic stimuli yield equal processing asymmetries--for example, vowels tend to produce small ear advantages (Studdert-Kennedy & Schankweiler, 1970); stop consonants produce relatively large ones (Studdert-Kennedy & Schankweiler, 1975). Such factors, together with low test-retest reliabilities for most dichotic procedures, have raised questions about the validity of dichotic listening procedures as an index of cerebral functional lateralization (e.g., Teng, 1981; Colburn, 1978; Berlin, 1977; Satz, 1977).

Dichotic listening procedures have been revised repeatedly in efforts to overcome these shortcomings, and these efforts have been successful to some extent. For example, current versions of dichotic tests frequently use single pairs of stop consonants on each trial, since stop consonants produce larger asymmetries, allowing classification of more subjects, and since single pair presentations reduce memory effects. Efforts to control for the effects of selective attention biases, including instructions to attend to only one side per block of trials (Hayden, Kirstein, & Singh, 1979), or the use of fusion techniques which result in only one stimuli per trial being heard despite the presentation of two (Repp, 1977), have given encouraging results suggesting that selective attention alone cannot account for perceptual asymmetries. Using a dichotic monitoring procedure, in which the subject responds when a target word is detected on either channel, Geffen and Caudrey (1981) reported high test-retest reliabilities, relatively high rates of subject classification, and most importantly, nearly perfect agreement with invasive assessment of speech lateralization. Thus, cautions about the validity and reliability of dichotic listening tests as a measure of cerebral organization are in order, but advances in the methodology suggest that such cautions should not be taken so strongly as to exclude the evidence from all dichotic listening studies. Instead, each study using dichotic listening might need to be evaluated individually, with attention paid especially to the issue of how valid the particular procedures used were likely to be.

The divided visual field research can be criticized in a similar fashion. Presentations of words or letters or letter strings to the right visual field typically yield more accurate or faster recognition or identification than presentations to the left visual field. The exact type of stimulus, the manner of presentation, and the use of various forms of response may all interact to affect the degree of asymmetry in performance obtained (see Beaumont, 1982; and Young, 1982 for recent reviews of this literature as it pertains to asymmetries in language processing). Thus, for any particular divided visual field task, it is unclear to what extent asymmetrical performance reflects the differential specialization of the cerebral hemispheres, other factors that may be relevant to cerebral functional asymmetry such as attentional biases, or unrelated factors such as left-to-right scanning tendencies resulting from reading practice. Schwartz and Kirsner (1982) have argued that the visual field asymmetries in their study could be accounted for entirely by consideration of attentional allocation, without invoking the concept of hemispheric specialization. Others have argued that visual field asymmetries are the result of scanning tendencies learned in left-to-right reading rather than cerebral specialization (e.g., White, 1973). It has also been suggested that visual field asymmetries represent the interaction of attentional biases and allocation with hemispheric specialization (e.g., Moscovitch & Klein, 1980). In any case, a simple notion of visual field asymmetries in performance resulting from direct entry of the stimulus to the hemisphere that is capable of processing it, as opposed to having to cross the corpus colossum, does not seem warranted.

However, as the literature reviewed by Beaumont (1982) and Young (1982) also reveals, a right field advantage is obtained for linguistic stimuli fairly reliably under most conditions. This, together with the fact that visual field tasks frequently do discriminate between handedness groups, suggests that cerebral specialization may be at least one component of the effect. As in the case of the dichotic listening literature, one might want to judge each study independently instead of dismissing the methodology completely. For the methodology to be valid as an index of language processing asymmetries, one might want to argue that it should yield asymmetries in the expected direction for dextral male subjects, and that it should discriminate between handedness groups to some extent. Moreover, as Bryden (1982) cautions, one would want a considerable amount of data about a particular task before making very strong assertions about that task's exact relationship to language lateralization.

At the risk of some redundancy, summarizing Cohen's (1982) review of theories of perceptual asymmetry will be worthwhile. Cohen notes that an adequate theoretical account of perceptual asymmetries should be able to account for both the standard types of asymmetries observed, and for the lability of such findings; the considerable variance found between studies, between subjects, and within subjects suggests that an adequate theory of asymmetrical performance on divided visual field and dichotic listening tasks must address changes in asymmetries as well as the asymmetry itself.

Cohen suggests that current theories tend to espouse either structural or dynamic models of cerebral functional lateralization. Structural models explain asymmetrical performance on noninvasive measures of cerebral organization as a consequence of more direct access by the stimulus to the hemisphere appropriate for that type of processing. Structural models can further be distinguished among themselves in terms of the degree and nature of specialization proposed. Cohen argues that absolute specialization is not supported by the data, at least in terms of such globally defined functions as language processing, whereas models that advocate relative specialization are so flexible that testing strong predictions is unfeasible. Various theories of hemispheric specialization are reviewed by Bradshaw and Nettleton (1981), who advocate left hemisphere specialization for temporal sequential processing. Commentary on their article suggests that the evidence for this is also inconclusive (Bertelson, 1981; Brownell & Gardner, 1981; Bryden & Allard, 1981; Cohen, 1981; Marshall, 1981; McKeever, 1981). The nature of hemispheric specialization can also be characterized as a stage of processing distinction rather than a type of processing one; Moscovitch (1979) suggests that asymmetries in processing arise at late points in the processing sequence--memory rather than perceptual components result in asymmetrical performance. Cohen (1977) employs a similar information processing analysis but argues that components of verbal processing rather than a particular stage of processing are lateralized to one hemisphere--for example, laterality effects might arise from left hemisphere phonological analysis rather than left hemisphere language processing in general.

Dynamic models of perceptual asymmetries incorporate a flexible attentional component which interacts with structurally based specialization of the cerebral hemispheres to produce the types of asymmetries found in dichotic listening and divided visual field measures. Kinsbourne (1973; 1975) has developed one such model that suggests hemispheric specialization produces small and stable asymmetries, while the larger and more variable asymmetries typically found using non-invasive procedures reflect the differential allocation of attention to the cerebral hemispheres. Increased allocation of attention to one cerebral hemisphere results in increased processing capacity and in perceptual selection for stimuli contralateral to that hemisphere. Cohen (1982) argues in favor of a dynamic model of perceptual asymmetry but notes that the evidence is far from conclusive (e.g., Boles, 1979).

By now, it should be clear that cerebral functional lateralization is probably a vastly more complex phenomenon than early conceptions of it implied, and that the behavioral manifestations of any hemispheric specialization may reflect a number of intermediate factors as well. Thus, attempts to compare various findings regarding subject variables and cerebral organization will undoubtedly result in some confusion. As Bryden (1982) observes: "If one has a rubber yardstick, and is not even really sure what one is measuring, it is not surprising that attempts to relate the measure to other variables are not terribly successful" (p. 221). Early lack of appreciation of this complexity resulted in the use of dubious procedures to determine the influence of various subject characteristics.

It also should be clear that there is no strong theoretical basis for presuming that visual and auditory language processing asymmetries must correlate strongly, or that failures to find strong correlations reflect inadequacies of the noninvasive measures. As noted previously, given uncertianty as to the nature of hemispheric specialization, it is unclear to what extent visual and auditory language processing share whatever components, stages, or types of processing that are lateralized, and to what extent attentional factors might influence each type of measure differently. Assessment of the correlation of auditory and visual language perceptual asymmetries under different conditions does, on the other hand, provide one mean of addressing just these questions--by comparing what procedures or conditions yield strong correlations with those that do not, one may begin to address the question of what features auditory and visual language processing asymmetries have in common.

Despite the difficulties noted in the preceding review, a copious literature exists that relates subject variables to various dichotic listening and divided visual field measures of cerebral asymmetry. Similarly, a number of correlational studies of auditory and visual perceptual asymmetries for language processing have been reported. Studies of both types are potentially flawed for the reasons noted above, but these investigations have contributed to knowledge of the influence of subject variables on cerebral organization, and to knowledge about cerebral functional lateralization in general.

Subject Variables and Cerebral Functional Lateralization

A number of subject characteristics have been related to cerebral functional asymmetry for language processing as research on the phenomenon has grown. Among these are handedness, strength of handedness, handwriting posture, sex, age, degree of birth stress experienced, and mental health. Often one has been considered as a means of unconfounding the literature detailing another; for example, one might consider the effects of strength of hand preference as a means of addressing the variance in studies that considered only the direction of handedness. The literature for the five subject variables relevant to the current study will be reviewed briefly below.

Handedness

Both clinical data on the consequences of unilateral lesion damage and other forms of unilateral cerebral trauma, and experimental data from dichotic listening and divided visual field tests with normal subjects indicate a complex relationship between handedness and cerebral asymmetries for language processing. Right-handers, and especially right-handed males, give evidence of language processing in general being lateralized to the left hemisphere. Left-handers form a more heterogeneous population. Cerebral organization within left-handers is considerably more diverse than within the dextral population. Beyond this generalization, however, the characterization of sinistrals becomes more obscure. There are suggestions that left-handers may differ from right-handers in the degree of lateralization of language processing, the direction of such lateralization, or both.

Clinical data detailing the effects of left and right hemisphere lesions in mostly male subjects (Goodglass & Quadfasel, 1954) and describing the results of sodium amytal tests of cerebral organization for language functioning (Rasmussen & Milner, 1977) indicate that oral language functions are lateralized to the left hemisphere in the vast majority of right-handers, but only in around 60-70% of left-handers. The remainder of the left-handed population may be characterized by either a reversed pattern of lateralization for oral language processing, or by a more bilateral representation of such functioning (Levy, 1974). Satz (1979) reviewed published studies citing cases of unilateral lesions and arrived at slightly different figures; he estimated that 40% of left-handers have unilateral speech production in the left cerebral hemisphere, 20% have unilateral speech production localized in the right cerebral hemisphere, and the remaining 40% have some degree of bilaterally distributed speech functioning. Still other studies suggest that left-handers as a group are less laterally differentiated for at least some aspects of language functioning (Hecaen & Sauget, 1971; Hecaen, DeAgostini, & Monzon-Montes, 1981). Uncertainty as to the exact proportion of left-handers with bilateral speech production or other language-related functioning, and the preponderance of males in the clinical samples, suggest that such estimates of cerebral organization for sinistrals as a group are tentative.

The experimental data comparing left and right-handers also clearly indicate that left-handers and right-handers have different cerebral organization for language-related functioning when considered as groups, but beyond that generalization the data become confusing. Specifically, it has been suggested that left-handers in general are less lateralized for language processing than right-handers, since they show smaller asymmetries in divided visual field measures (Bradshaw, Gates, & Nettleton, 1977; Bryden, 1973; Hines & Satz, 1974; McKeever, VanDeventer, & Suberi, 1973; Piazza, 1980; Zurif & Bryden, 1969), and dichotic listening procedures (Briggs & Nebes, 1977; Curry, 1967; Curry & Rutherford, 1967; Higenbottam, 1973; Satz et al., 1965; Zurif & Bryden, 1969). Other studies have noted greater variance in the direction of ear asymmetries (Geffen & Traub, 1980; Knox & Boone, 1970; Lishman & McMeekan, 1977; Satz, Achenbach, & Fennell,1967) and visual field asymmetries (Cohen, 1972; Schmuller & Goodman, 1980) in left-handed samples. However, many other studies have found no effects based solely on handedness using noninvasive measures of asymmetrical language processing (McKeever & VanDeventer, 1977; Searleman, 1981), and the positive findings listed above vary greatly in strength.

Discrepancies in the characterization of the left-handed population based on measures of perceptual asymmetries have been addressed in a number of ways, as have those based on clinical data. These include noting the influence of various factors other than cerebral asymmetry that may bias perceptual asymmetries, suggestions that language-related processes are likely to be even more dissociated in left-handers than right-handers, which would magnify the inherent variance of noninvasive procedures, and efforts to more carefully define and measure handedness itself. Similarly, attention has been given to discovering characteristics of left-handers who demonstrate anomalous patterns of cerebral organization.

Strength of Hand Preference

One explanation of the variance in studies of handedness and cerebral organization for language processing is that such studies have frequently defined handedness only loosely, often relying on self-reported handedness for subject classification. More serious consideration of the phenomenon of handedness reveals that the definition and assessment of handedness are complex problems.

Defining handedness has proved to be difficult, since it is unclear whether handedness consists of some single factor varying in degree from strong left preference to strong right preference, as factor analysis approaches have suggested (Bryden, 1977; Richardson, 1978), or whether it is a multidimensional attribute. Annett (1982) suggests that handedness should be understood in terms of the presence or absence of a factor which biases an individual strongly towards left-hemisphere speech, and incidentally increases the likelihood of a dextral preference. In the event of the absence of that factor, both handedness and cerebral asymmetry for speech production are determined by chance. No consensus appears to have emerged from the various theories which have been put forth as to the nature of handedness.

Assessment of handedness has also proved to be complex, no doubt partly due to the inadequate definition of the term. Satz et al. (1965) provided early evidence that self-reports of handedness and performance measures did not agree well. The use of performance measures of handedness in research has been regretably limited, however. More common has been an effort to control for variations in the degree of handedness by administering hand preference inventories that allow graded responses to questions about hand usage in various activities. Bryden (1977) advocated the use of a five item questionnaire, based on factor analysis results suggesting that those particular items were most closely related to a unitary dimension of handedness. Bryden reasoned that including more variable items might yield misleading results. Provins, Milner, & Kerr (1982) have recently taken exception to Bryden's claim; they suggest that while right-handedness is a robust phenomenon unlikely to be sensitive to the assessment procedures used, left-handedness is highly sensitive to the items used for assessment. They argue that because the aspects of hand usage that correlate well with cerebral lateralization of speech are unknown, research on this topic should examine a variety of handedness criteria.

The studies that have explicitly examined the relationship between an individual's strength of hand preference and cerebral asymmetries have failed to produce a consistent set of findings. For example, using dichotic listening tests, Dee (1971) reported that strongly left-handed subjects showed a significant right ear advantage but weakly left-handed subjects did not. In contrast, Knox and Boone (1970) and Satz et al. (1967) both found that strongly left-handed subjects were the ones who failed to show a right ear advantage. Although inadequately investiagted thus far, measures of the strength of hand preference have not yet resolved the general variance found between studies of handedness and perceptual asymmetries for language processing, or provided a means for indicating which nonright-handers are likely to show divergent patterns of cerebral organization.

Familial Sinistrality

Another subject variable frequently examined in attempts to better understand the relationship between handedness and cerebral asymmetries for language processing is familial sinistrality (FS). Clinical studies have suggested in some instances that individuals with a positive history of familial sinistrality (FS+) tend to have more bilateral distribution of speech than those without left-handed relatives, based on the consequences of unilateral lesions (Hecaen & Sauget, 1971). Conflicting reports have come from studies of war traumas (Newcombe & Ratcliff, 1973) and unilateral electroshocks (Warring & Pratt, 1973). More recently, Hecaen & DeAgostini, and Monzon-Montes (1981) have reexamined the question using a larger sample and wider array of language assessment procedures. They conclude that familial sinistrality is related to a greater degree of bilateral representation of language skills, although the effect is not manifested in all language-related functions. They also report no effects due to strength of hand preference.

Studies of familial sinistrality and cerebral organization in normal subjects using noninvasive procedures have yielded contradictory findings. Using dichotic listening tasks, Briggs and Nebes (1976) and Searleman (1980) have reported finding no effects due to familial sinistrality. Higenbottam (1973) also reported no effects--neither left-handers with or without familial sinistrality showed a significant right ear advantage. Lishman and McMeekan (1977) reported that FS+ was associated with smaller degrees of right ear advantage. Zurif and Bryden (1969) reported the opposite finding--they found significant right ear advantages for those with positive histories of familial sinistrality, whereas FS- individuals showed no ear advantage. Geffen and Traub (1980), using their dichotic monitoring procedure, found that FS+ subjects showed significant right ear advantages more often than FS- subjects, who were more diverse in the direction of asymmetry. Even more complex interactions have been reported: McKeever and VanDeventer (1977) found an interaction of sex and FS, with only left-handed FS- males failing to show a right ear advantage in their study. Lake and Bryden (1976) also reported an interaction of sex and familial sinistrality, but in their study it was females with a history of familial sinistrality who showed perceptual asymmetries of smaller magnitude.

A similar array of discordant findings exists for studies using divided visual field measures. The following data describing the effects of familial sinistrality in left-handers illustrates this: Bryden (1965) originally reported that familial sinistrality was associated with a left visual field advantage, whereas subjects with no history of familial sinistrality showed no visual field advantage. Zurif and Bryden (1969) found no visual field advnatgae in FS+ subjects and a right visual field advantage in FS- subjects. Higenbottam (1973) and Piazza (1980) reported finding right field advantages for both FS+ and FS- subjects, while Bryden (1973) found no visual field advantage for either group. McKeever, VanDeventer, and Suberi (1973), McKeever and VanDeventer (1977), McKeever (1979), and Bradshaw and Taylor (1979) have all suggested that FS+ individuals show a greater degree of right field advantage on tasks of language processing than FS- subjects, who show small field preferences or none at all. Andrews (1977) conversely reported that FS+ was associated with smaller degrees of visual field advantage.

Obviously, the data are confusing and fail to resolve the issue. As in the case of handedness, even the measurement of familial sinistrality is somewhat uncertain. Most studies have considered the presence of at least one left-handed member in an individual's immediate family to be the criterion for familial sinistrality, and relied on either subject report or self-report for assessment of handedness in the immediate family. McKeever and VanDeventer (1977) argue in favor of consideration of the extended family as well. Perhaps more relevant to the extreme degree of contradictions in the literature is Bishop's (1981) suggestion that family size and familial sinistrality interact, since larger families allow more opportunity for left-handedness to be expressed. Bishop suggests that future studies should compare only parental handedness to eliminate this bias. Most relevant to understanding this confusion may be the finding by Hecaen et al. (1981) that the effects of FS are not manifested for all measures of language functioning, suggesting that experimental studies find or fail to find similar effects as a function of the particular aspect of language processing which they assess. The contributions of other sources of variance than differential hemispheric specialization are also undoubtedly manifested in the literature.

Sex

The occasional reporting of sex differences in cerebral organization has led to increased consideration of this variable as well. McGlone (1980) recently reviewed the literature on sex differences in cerebral asymmetry and concluded that both clinical studies (e.g., McGlone, 1977) and noninvasive assessments using dichotic listening tests (Lake & Bryden, 1976) and divided visual field measures (Bradshaw & Gates, 1978; Levy & Reid, 1978) have provided support for the idea that females may be less lateralized for language functioning than males. Certainly many more studies have looked for such effects and failed to find them, as McGlone notes. McGlone concludes tentatively that there is sufficient evidence to uphold the idea of sex differences in cerebral organization, although others commenting on her review (Annett, 1980; Kinsbourne, 1980; McGuiness, 1980) have found the evidence less convincing. Perhaps the most perspicacious stance at present is to note that the evidence which does exist to support the idea of a sex difference in cerebral organization is nearly unanimous in indicating that males are more lateralized than females for language processing, but such evidence needs strengthening and further investigation.

Handwriting Posture

Levy and Reid (1976; 1978) have suggested that a new variable be considered as an index of cerebral asymmetries in language processing. In a series of studies, they have presented compelling evidence that the hand position one adopts while writing is indicative of cerebral organization; those who use a so-called inverted posture have language functioning lateralized ipsilaterally to their writing hand; those who use a normal handwriting posture have language functioning localized in the cerebral hemisphere contralateral to their writing hand. Thus, right-handers with a normal hand posture and left-handers who write with an inverted posture would be characterized by left hemisphere dominance for language processing, and right-handed inverters and left-handers with normal handwriting posture would be characterized by right hemisphere dominance for language processing.

While Levy and Reid's research, using a divided visual field measure of cerebral organization, strongly supported this claim, several other attempts to verify their findings have been less conclusive. Weber and Bradshaw (1981) and Levy (1982) have recently reviewed the literature relating handwriting posture and cerebral organization and have arrived at conflicting conclusions. Weber and Bradshaw claim that little support for Levy and Reid's theory has come from other laboratories, noting failures to confirm their findings using divided visual field measures (Bradshaw & Taylor, 1979; McKeever, 1979; McKeever & VanDeventer, 1980) and dichotic listening tests (Beaumont & McCarthy, 1981; McKeever & VanDeventer, 1980; Smith & Moscovitch, 1979). Partial support for Levy and Reid's theory was found using a verbal tachistoscopic task similar to the one used in their studies (Smith & Moscovitch, 1979). Levy's (1982) reading of the same literature suggests that although the Levy and Reid theory as originally stated is not supported, within the domain of visual language processing there is evidence indicating a difference between individuals who use normal and inverted handwriting posture. Levy notes that Smith and Moscovitch (1979) replicated the Levy and Reid (1978) findings for the verbal task. Some support for a difference between individuals with normal and inverted handwriting posture has also come from EEG measures of cerebral organization for processing visual language (Herron, Galin, Johnstone, & Ornstein, 1979). Levy argues that visual and auditory language are strongly dissociated in left-handers, and that even more dissociations between various aspects of language functioning within the visual and auditory domains are likely.

Interactions Among Subject Variables

In the literature reviewed thus far on the effects of subject characteristics on cerebral organization, a number of interactions between subject variables have been noted. Such interactions have led many researchers to suggest that effects attributed to one subject variable may instead be the manifestation of another unassessed one. Likewise, the failure to control for one subject variable may account for some of the discrepancies in the literature describing another. To counter this, recent studies have tended to assess a number of subject variables rather than one or two. The literature would become even more overwhelming if one were to consider all reports of all interactions among subject variables, however. Therefore, the results of just three studies selected for their relevance to the current study will be described.

McKeever and VanDeventer (1977) suggested that the disarray in the literature describing subject variables and cerebral organization was partly from uncontrolled interactions, and therefore decided to systematically assess the effects of handedness, strength of handedness, familial sinistrality and sex on a dichotic listening test and a divided visual field measure. On the visual task, which involved letter recognition, no main effects of any of the subject variables were found, but significant interactions occurred between handedness and familial sinistrality, and handedness and sex. FS+ left-handed subjects showed a greater right visual field advantage than FS- subjects, and right-handed females showed a greater right visual field advantage than right-handed males. On the dichotic listening task, a main effect of handedness was found due to greater right ear advantages in right-handed subjects. Comparisons between self-reported handedness and performance measures of handedness indicated that the former was a better predictor of cerebral organization than the latter.

Searleman (1980) compared the effects of handedness, strength of handedness, sex, familial sinistrality and handwriting posture on asymmetries obtained from a dichotic listening test using consonant-vowel syllable pairs. No significant main effects of any of these variables were reported when the magnitude of the asymmetry was used as the dependent variable. A handedness X strength of handedness interaction was reported in which the strongly left-handed subjects showed smaller asymmetries than weakly left-handed subjects, whereas strength of handedness had the opposite influence in right-handers. When analyzed for the direction of asymmetry rather than the magnitude, the data showed no effects of any of these variables and no significant interactions.

A third study by McKeever and Hoff (1982) reveals the importance of considering the interactions of subject variables. Using right-handed subjects, they measured vocal reaction times to name drawings of objects and to make lexical decisions in a divided visual field experiment, and assessed the effects of sex and familial sinistrality. For the object naming task, a sex by FS interaction was found which indicated that FS- males showed a greater right field advantage than FS+ males, but FS- females showed smaller right visual field advantages compared to FS+ females. In the lexical decision task, FS+ subjects showed larger right visual field advantages for words, and FS- subjects showed greater right visual field advantages for nonwords. McKeever and Hoff suggest that previously reported findings of sex differences (e.g., Bradshaw & Gates, 1978) in studies which used only FS- subjects may have been due to the sex by FS interaction rather than a straightforward effect of sex.

Clearly, using an array of subject variables may prevent one from drawing misleading conclusions in some cases. It also presents some problems for interpretation due to the complex patterns of findings which may result. McKeever and Hoff's (1982) finding of a sex by FS interaction, for example, may explain previous reports of sex differences on object naming tasks. The effect may be task-specific, however, since they did not find it on the lexical decision task. It suggests that only when many such studies have been performed and the commonality and lack of commonality in effects can be assessed systematically can adequate interpretations of such findings be made.

The Relationship of Auditory and Visual Language Processing Asymmetries

As noted earlier, attempts to compare auditory and visual language processing asymmetries, based on data from dichotic listening and divided visual field studies, have generally found only small correlations. More specifically, Bryden (1965) and Zurif and Bryden (1969) reported small positive correlations of dichotic listening and divided visual field asymmetries for linguistic stimuli using combined samples of left and right-handers. Smith and Moscovitch (1979) reported negative correlations of -.36 for right-handers with normal handwriting posture, -.26 for left-handers with normal handwriting posture, and -.10 for left-handers with an inverted handwriting posture. Bryden (1973) also reported nonsignificant negative cross-modal correlations. Fennell, Bowers, and Satz (1977a; 1977b) correlated the recall of stimuli presented to the right ear and the right visual field, and the left ear and left visual field, and found small, varying nonsignificant correlations for left and right-handers tested separately, although directional concordance for the asymmetries in each task increased with practice. Finally, in contrast to the results summarized above, Hines and Satz (1974) reported significant cross-modal correlations for right-handed subjects with and without familial sinistrality ($r = .34$, and $r = .39$, respectively), and essentially no cross-modal correlation for left-handed subjects ($r = .02$).

The generally small degree of correlation reported, and the variance in these results, may result from any of several different underlying factors that have already been discussed (see p. 3). Component operations or processing stages required to different degrees by auditory and visual language processing may underlie hemispheric specialization, and changes in the degree of correlation found may reflect the extent to which the tasks are similar or dissimilar in their demands. Another possibility is that measures of perceptual asymmetries are woefully inadequate as indicators of underlying cerebral specialization, and there is little reason to expect high correlations from measures which are so labile. Finally, the endeavor to correlate auditory and visual language processing asymmetries may be inherently flawed; Colburn (1978) has argued that attempts to quantify the cerebral lateralization present in any task are without foundation, and that analysis should be based solely on the presence or absence of a significant left or right side advantage for any individual subject, rather than on the magnitude or such advantages.

The systematic assessment of the interaction of subject variables with such correlations may be enlightening. One could argue that if a pattern of relatively small correlations were pervasive regardless of subject characteristics, then indeed the noninvasive measures used may have been inadequate. But if the pattern of correlation varied systematically as a function of subject variables, then the results would be reflecting the association or dissociation of auditory and visual language processing. Of course, it would also be of interest to determine the extent to which various subject groups are more or less equally lateralized for processing auditory and visual language.

OVERVIEW OF THE CURRENT STUDY

The current study assessed the effects of the subject variables of handedness, strength of hand preference, familial handedness history, sex, and handwriting posture, and the various possible combinations of these factors, on cerebral organization for auditory and visual language processing. It further examined the relationship between auditory and visual language processing asymmetries as a function of the above named subject variables.

In addition to concurrently assessing the effects of this combination of subject variables on measurements of perceptual asymmetry in two modalities, the current study endeavored to distinguish itself from earlier studies of this type by using more valid measures of cerebral organization. The dichotic listening and divided visual field tasks used in the current study were selected based on indications that they were relatively less insensitive to strategy factors. Both contained procedures designed to control for selective attention to one side or the other.

The dichotic listening tape used consisted of fused rhymed word pairs. Fusion techniques in dichotic listening have been shown to result in only one stimulus being experienced on a trial, and to be unaffected by selective attention to one side or the other in terms of the responses selected (Repp, 1976). The particular dichotic tape used has been found to produce right ear advantages in right-handed subjects more often than nearly all other dichotic tests, to produce left ear and right ear advantages in left-handed subjects in approximate agreement with clinical estimates of speech dominance in that population, and to have relatively high test-retest reliability ($r = .85$). It is currently being assessed to determine its relationship to invasive measures of cerebral organization (Wexler & Halwes, Note 1).

The visual task used was an adaptation of the procedures used by Levy and Reid (1978), who reported that it correctly classified nearly 100% of their dextral male pilot subjects as being left hemisphere dominant for language processing. In pilot studies, the adaptation of the task used in the current study classified approximately 90% of the dextral male subjects as left hemisphere dominant for language processing, based on individually determined significant right visual field advantages ($p < .10$). Following Levy and Reid, the particular procedures used included a central fixation digit and short individually determined exposure durations of the stimuli to preclude eye movements to either side. Because visual field procedures have not been subjected to the same scrutiny as dichotic listening techniques by clinicians, no particular task has been shown to concur with invasive measures of speech dominance or asymmetries of visual language processing. Since this ideal criterion for validity cannot be met, the Levy and Reid task would appear to be one of the set of best possible alternatives; it does fulfill the criteria of classifying a large percentage of subjects on an individual basis and classifying right-handed males in accordance with what one would expect based on the clinical norms.

Assessment of the cross-modal correlation between the visual and auditory asymmetries provides data which potentially address a number of issues. First, as already noted, the fundamental nature of cerebral specialization is unclear at the present time. If left hemisphere specialization is for language processing, then one would expect to find moderate correlations or even strong correlations between auditory and visual tasks requiring it. If, however, it is some specific aspect or component of language processing which underlies apparent left hemisphere verbal specialization, then it becomes unclear what extent of correlation one should expect to find, since its differential contribution to the auditory and visual task would be uncertain. The lack of correlation reported by previous studies suggests the latter, or that if language per se is lateralized, it is nonetheless dissociated in the visual and auditory modalities. However, the procedures used in previous reports of cross-modal correlations have seldom been scrutinized for their validity, and there is always the possibility that more valid and more reliable measures of cerebral organization would produce stronger correlations.

Assessment of the interaction of subject variables and cross-modal correlations also addresses the issues of the nature of specialization, and the pervasiveness of anomalies in cerebral organization for individual subjects. One can ask, for example, whether or not subjects with anomalous patterns of cerebral organization in one modality show the same pattern in the other modality as well. A failure to observe directional concordance between modalities would suggest that, at least for those subjects, the dissociation between the brain structures mediating auditory and visual language processing is extreme.

METHOD

Subjects: Subjects in the current study were 26 self-reported right-handed males, 25 self-reported right-handed females, 100 self-reported left-handed males, and 100 self-reported left-handed females. All subjects reported having normal or corrected-to-normal vision and hearing, and reported being native English speakers. Subjects were recruited from introductory psychology classes at Michigan State University and received course credit for their participation.

Procedures: Each subject was first asked to fill out a questionnaire describing preferred hand use for six manual activities--writing a letter, drawing a picture, throwing a ball to hit a target, holding a racquet, hammering a nail, and holding a toothbrush. Subjects responded to each item by checking the appropriate description of hand usage from the following: always left, usually left, both hands equally, usually right, or always right. The short questionnaire was used in reference to Bryden's (1977) suggestions about assessment of hand preference.

Subjects were then asked to copy the following phrase: "The great tragedy of science; the slaying of a beautiful hypothesis by an ugly fact". They were instructed to copy the first part of the phrase without moving the paper, which was positioned at midline perpendicular to the table edge which they were directly facing. They were then told to copy the second part of the phrase with the paper positioned however they would normally place it. Subjects were instructed to use cursive unless they always printed. The experimenter noted the position of the writing hand and the pen for each position of the paper, scoring these as being normal or inverted according to the drawings provided in Levy and Reid (1976).

Family handedness history was measured according to both subject report and self-report by members of the immediate family: Subjects were instructed to list, by relationship, all members of their immediate family excluding step-relatives and relatives by adoption. A similar listing of the members of the subject's parents' families was also obtained. Subjects were asked to indicate the handedness of each member of their immediate family listed, and to indicate those individuals whom they knew to be left-handed in their extended families. They were given a handedness questionnaire for each member of their immediate family, and instructed to have them filled out and to return them by campus mail to the experimenter. The subjects' parents were asked to indicate the handedness of the members of their own immediate families on the back of their questionnaires.

Subjects were then given the divided visual field task and the dichotic listening task, which are described below.

Divided Visual Field Task

As already noted, the divided visual field task was an adaptation of the procedures described by Levy and Reid (1978). The present procedures differed from theirs chiefly in the use of black stimuli presented against a white background, as opposed to white stimuli against a black background, and in the illumination levels used.

Stimuli: The stimuli consisted of 60 consonant-vowel-consonant nonword trigrams, presented unilaterally with the letters vertically arrayed and with a number at the center. The CVC trigrams were composed from the letters A,D,E,F,G,K,O,P,S, and T, and presented on slides constructed using Artype Alternate Gothic #2 6 pt. transfer lettering for letters and 8 pt. transfer lettering for numbers on matte acetate. Each CVC trigrams was centered 1.25 inches (3.175 cm.- approximately 2^{o} cf visual angle) to the left or right of the centered fixation digit when projected onto the screen. The trigrams subtended 1.15 inches (2.92 cm) in height (approximately 1.8^{o} of visual angle). Each trigram was shown once in each visual field.

Procedures: Subjects were positioned with their head centered 36.5 inches (92.71 cm) from the fixation point, which was an "x" drawn on the projection screen. An exposure duration was individually determined for each subject initially, using trials with single letters projected unilaterally and a digit at the fixation point. Subjects were instructed to focus on the fixation point, where a number would appear, along with a letter to the left or the right, and without moving their eyes, to report first the number and then the letter. Single-letter trials were in blocks of five. On the first trial, the stimuli were shown for 60 msec., followed by a visual noise mask for 200 msec. The stimulus exposure duration was increased or decreased in 10 msec. increments on each block of trials until the subject correctly identified 80% of the letters.

Subjects then received 12 practice trials using CVC stimuli, which were shown for 60 msec. longer than the above-determined exposure duration, followed by a visual noise mask for 200 msec. This procedure allowed approximately 50% correct stimuli identification according to Levy and Reid (1978). A ceiling of 150 msec. was used, since exposure durations longer than this would have allowed eye saccades from the fixation point. Subjects were instructed to report the fixation digit first and then the CVC trigram, pronouncing it as a syllable rather than letter by letter. The 120 CVC trials used in the analysis were then presented using the same instructions and exposure duration. All the trigrams were presented randomly, with half appearing in each visual field overall, for the first 60 trials. Subjects were then given a three-minute rest period, followed by the final 60 trials, in which the trigrams were presented to the visual field opposite of that which they previously appeared in, again in a random order. All responses were recorded.

Dichotic Listening Test

The dichotic listening test was administered using a Revox A700 stereo tape recorder and Sharpe stereo headphones. The dichotic tape was obtained from Haskins Laboratories (New Haven, CT.), where it was developed by Wexler and Halwes.

The tape consisted of fused rhymed word pairs. All of the stimuli were monosyllabic words beginning with one of the six stop consonants b, d, g, k, p, and t. On any trial, the members of each pair presented differed only in the initial stop consonant; i.e., pill was presented with bill, or boy with toy, etc... Fifteen word pairs of approximately equal frequency were constructed in this fashion, with each pair presented eight times during the test.

The dichotic tape was created by digitizing natural speech recordings of the words, and then cross-splicing the initial distinctive portion of each word onto the other. The procedures used resulted in the fusion of the dichotic pairs, resulting in a single auditory stimulus being experienced. More detailed descriptions of the tape's construction are available in Wexler and Halwes (Note 1).

Subjects were initially allowed to hear each of the 30 words used as stimuli presented binaurally to familiarize them with the tape. They were instructed to check the corresponding word on the first page of the answer sheet used if that was what they had heard. The words on the tape were identical to and in the same order as the words printed on that page. The same binaural presentation was then repeated, but this time the subject had to select the word he or she heard from four choices on the answer sheet; the four choices included the correct word, the word it was paired with on dichotic trials, and two other words differing from the correct word only in terms of the first consonant. The foils were also words of approximately the same frequency, and all began with one of the stop consonants.

Subjects then received 120 dichotic trails following the same format of choosing the word heard from the four alternatives on the answer sheet. The headphones were reversed twice during this period to ensure equalization of the channels. As already noted, this tape has been found to have a high test-retest reliability for dichotic measures (r = .85), to meet a number of criteria in classifying subjects which may indicate validity, and is being assessed to determine its correlation with invasive measures of speech organization.

Scoring

For purposes of analysis, the following scoring procedures were used: Responses on the handwriting questionnaire were assigned values of 1 to 5, with 5 indicating the right hand was always used, resulting in a total possible score of 30. Subjects who scored from 6 to 14 were classified as left-handed; those who scored from 15 to 21 were labeled ambidextrous; those who scored from 22 to 30 were considered right-handed. This somewhat arbitrary classification procedure also served as the measure of strength of hand preference.

For analysis, the handwriting posture indicated by the pen position when the paper was perpendicular to the table edge was used as the final measure. According to Fudin and Lembessis (1982), this appears to have been the final criterion used in the Levy and Reid (1978) study, and some of the conflicts in results regarding this measure may be due to the use of other criteria based on the incomplete descriptions in Levy and Reid (1976).

Familial sinistrality was scored using McKeever and VanDeventer's (1977) suggestion that subjects should be considered to have a positive history of familial sinistrality if one member of their immediate family or two members of their extended family are left-handed. The questionnaires completed by members of the immediate family were used as the first basis of classification when possible; if the questionnaires were not returned, then the subject's description of family handedness was substituted.

The scoring of the divided visual field and dichotic listening task results was considerably more complex due to the disputes regarding analysis of lateralized performance data. Briefly, two issues are being debated: First, is any form of index or comparison of lateralized data between subjects appropriate? Secondly, what should the particular form of index or analysis for comparison purposes be given that one feels justified in using one?

Colburn (1978) has suggested that there is no theoretical justification for using any form of lateralization index with data from purported measures of hemispheric asymmetries. He instead argues that each individual subject can be classified as left hemisphere dominant, right hemisphere dominant, or unclassified for the task performed based on the data, but that comparisons of subjects, groups of subjects, or tasks are not yet possible due to our ignorance of the underlying phenomenon. Using such an approach with a modest significance criterion ($p = .10$, one-tailed), Wexler, Halwes, and Heninger (1981) reported that classifications of right-handed subjects inconsistent with the neurological data on cerebral organization for this group declined almost completely; the subjects who were classified nearly all showed a right ear advantage on the task, suggesting at least one advantage of this approach.

The alternative argument suggests that one can consider differences in the degree of lateralized performance, and the issue then becomes how best to do so. One can employ an analysis of variance using visual field or ear of presentation as a within-subjects variable, and look for interactions between this and other factors. However, this avoids dealing with the question of how one compares data from very different levels of performance, as one often obtains in these tasks. Various indices of lateralized performance have been proposed which consider this to one extent or another; most show some constraint at some level of performance, however. Two such indices do appear to be unconstrained at all levels of performance--the "e" index (Halwes, 1969), and the lambda index (Bryden & Sprott, 1981). Any such index constitutes a theory of how performance and the underlying cerebral specialization contributing to asymmetries in a task interact, and therefore caution in the application of indices is certainly well advised (see Repp, 1977; and Bryden & Sprott, 1981, for detailed discussions).

The data in the current study were scored and analyzed using the lambda index, as described by Bryden and Sprott (1981), and by using visual field and ear of presentation as within-subjects measures in analyses of variance. The lambda index was chosen because it has the intuitively appealing qualities of being unconstrained at all levels of performance, and of being relatively nondisjoint as it goes from positive to negative values. In other words, it assumes that cerebral asymmetries and overall performance level should not be related. It also allows determination of the significance of individual subject scores, and analysis of group data.

The formula

$$u(\lambda) = (\ln XR\,(n-XL)/XL\,(n-XR))/\sqrt{1/XR+1/(n-XR) + 1/XL + 1/(n-XL)}$$

where XR and XL equal correct right and left side responses respectively, and (n-XR) and (n-XL) equal total number of right side trials minus correct right side responses, and total number of left side trials minus left side responses, was used to calculate an individual standardized score for each subject on the visual task. For the dichotic listening task, the formula

$$u(\lambda) = (\ln XR/(n-XR))\,/\sqrt{1/XR + 1/(n-XR)}$$

was used to calculate the individual standardized scores. The numerator in each of these equations represents the subject's lambda score and the denominator represents the standard deviation of that score. Similarly, group estimates of lambda were obtained using the formula

$$\lambda = \Sigma\ \hat{\lambda}i/\sigma\lambda_1^2/\Sigma 1/\sigma\lambda_1^2$$

for each of the subject groups.

Analysis

The individual standardized scores obtained for each subject, as described above, were tested for significance using the very modest criterion of $P < .30$, since research by Wexler and Halwes (Note 1) indicates that subject misclassification is infrequent even at this very undemanding level, but increases radically at higher levels of probability. Groups defined by subject variables were then characterized according to the number of subjects showing significant left or right visual field, or left or right ear advantages, as Colburn (1978) suggested. Groups defined according to subject variables were also characterized by determining the group lambda score for the visual and dichotic listening task.

A four-way analysis of variance, using sex, handedness, history of familial sinistrality, and handwriting posture as the factors and the individual standardized scores based on the lambda index as the dependent variable was performed separately on the auditory task data and the visual task data. The same analyses were performed using the absolute values of the individual standardized scores to assess effects due to the magnitude of lateralization regardless of the direction.

Analyses of variance using handedness, sex, and familial sinistrality as between-subjects factors and visual field and ear of presentation as within-subjects factors were also performed, to allow for more direct comparison of the results with other studies in the literature. Handwriting posture was not included as a factor in these analyses because the absence of right-handed inverted handwriting posture created too many empty cells for the BMDP2V program to perform a repeated measures analysis of variance. Similar repeated measures analyses were performed using just the left-handed and ambidextrous subjects' data and all four factors of handedness, sex, familial sinistrality, and handwriting posture.

The cross-modal correlations between the auditory and visual task as a function of subject variable characteristics were detailed in two ways: First, the Pearson product-moment correlation for the overall sample and for each of the subject variable combinations present in the sample were computed. An analysis of variance was also performed using between-subjects factors of handedness, sex, and familial sinistrality, and a within-subjects factor of modality of presentation, using the lambda indices as the dependent variable.

RESULTS

First, a description of the subject population obtained using the sampling procedures described earlier will be given. The right-handed group included all 51 self-described right-handers and 9 self-described left-handers who wrote with their left hands but performed most other activities with their right hand. The four inverted handwriting posture subjects in the right-handed group come from this latter subject. A more detailed characterization of the right-handed sample is presented in Table 1. (Subjects for whom the data is incomplete are not included in that table.)

The ambidextrous subjects included 19 subjects who showed a weak left-handed preference, 13 who showed no preference at all, and 6 who showed a weak right-handed preference. Again, more detailed description of this group and of the left-handed group, all of whom showed a strong left-hand preference and wrote with their left hand, is available in Table 1.

The breakdown of the current sample by the subject variables assessed is in approximate agreement with the normative data reported by Searleman, Tweedy, and Springer (1979). In the present study, 32% of the right-handers, 58% of the ambidextrals, and 49% of the left-handers have a positive history of familial sinistrality, whereas in that study the percentages of subjects with familial sinistrality were 40, 44, and 54%, for right-handed, ambidextrous, and left-handed

TABLE 1

Breakdown by Subject Variables

Hand	Sex	FS	Handwriting Posture	N	Hand	Sex	FS	Handwriting Posture	N
right	male	+	normal	6	right	female	+	normal	9
right	male	+	inverted	1	right	female	+	inverted	0
right	male	-	normal	17	right	female	-	normal	14
right	male	-	inverted	2	right	female	-	inverted	1
ambi	male	+	normal	4	ambi	female	+	normal	9
ambi	male	+	inverted	5	ambi	female	+	inverted	3
ambi	male	-	normal	2	ambi	female	-	normal	4
ambi	male	-	inverted	6	ambi	female	-	inverted	3
left	male	+	normal	8	left	female	+	normal	31
left	male	+	inverted	32	left	female	+	inverted	6
left	male	-	normal	14	left	female	-	normal	25
left	male	-	inverted	24	left	female	-	inverted	11

subgroups, respectively. More interesting are the highly significant sex differences in the use of normal and inverted handwriting posture (x^2 = 38.02, p. < .001) for left-handed and ambidextrous subjects. Most left-handed and ambidextrous males use an inverted handwriting posture, whereas most left-handed and ambidextrous females use a normal posture. This is not an artifact of the particular scoring system used; although the proportions vary as a function of the scoring criterion used to a small extent, the effect was highly significant whether hand or pen position was used to determine handwriting posture, and whether the paper was fixed in a perpendicular position or the subject was allowed to slant it. This sex difference has been reported previously by a number of authors (Searleman et al., 1979; McKeever & VanDeventer, 1980; Parlow & Kinsbourne, 1981), although in previous reports it has usually not been as strongly shown as in the current study.

The subject groups are further classified in Tables 2 and 3, which show the number of subjects with significant left or right visual field or ear advantages using the very weak criterion of p. < .3, following the suggestion of Wexler and Halwes (Note 1) that accurate classification of subjects is possible at this level. These tables also provide the standardized estimate of each group's lateralization based on the lambda indices of group members. Inspection of the data shows that all groups had right visual field advantages, and that only four subjects had a significant left visual field advantage. The dichotic listening task produced much weaker advantages overall, and produced weak left ear advantages in three subject groups--ambidextrous females with familial sinistrality and inverted handwriting posture, left-handed males with

TABLE 2

Divided Visual Field Task Data

Handedness	Sex	FS	Handwriting Posture	N with Significant Visual Field Advantage (p.<.3) left	none	right	(λ)
right	male	+	xxxxxx	0	3	4	.697
right	male	-	xxxxxx	0	7	12	.791
right	female	+	xxxxxx	0	1	8	.887
right	female	-	xxxxxx	0	1	14	1.132
ambidextrous	male	+	normal	0	1	0	1.261
ambidectrous	male	+	inverted	0	0	4	1.561
ambidextrous	male	-	normal	0	0	2	1.323
ambidextrous	male	-	inverted	0	1	6	1.150
ambidextrous	female	+	normal	0	1	8	1.069
ambidextrous	female	+	inverted	0	1	2	.751
ambidextrous	female	-	normal	0	1	3	.702
ambidextrous	female	-	inverted	0	0	3	1.638
left	male	+	normal	1	2	5	.658
left	male	+	inverted	1	4	27	.999
left	male	-	normal	0	3	10	1.096
left	male	-	inverted	0	0	22	1.371
left	female	+	normal	1	4	27	.985
left	female	+	inverted	0	1	5	1.346
left	female	-	normal	0	3	22	1.127
left	female	-	inverted	1	3	7	.756

VISUAL LANGUAGE PROCESSING

LAMBDA

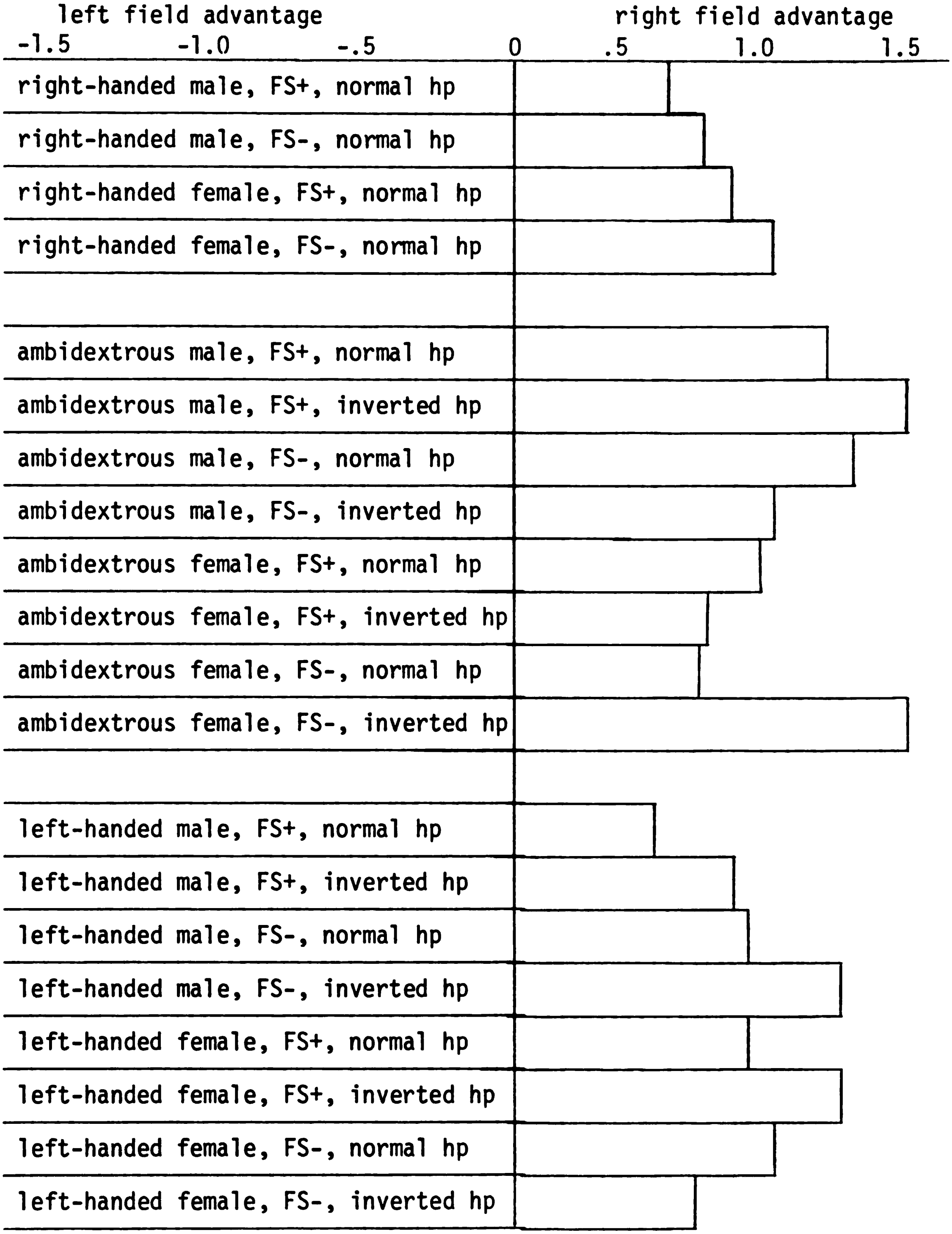


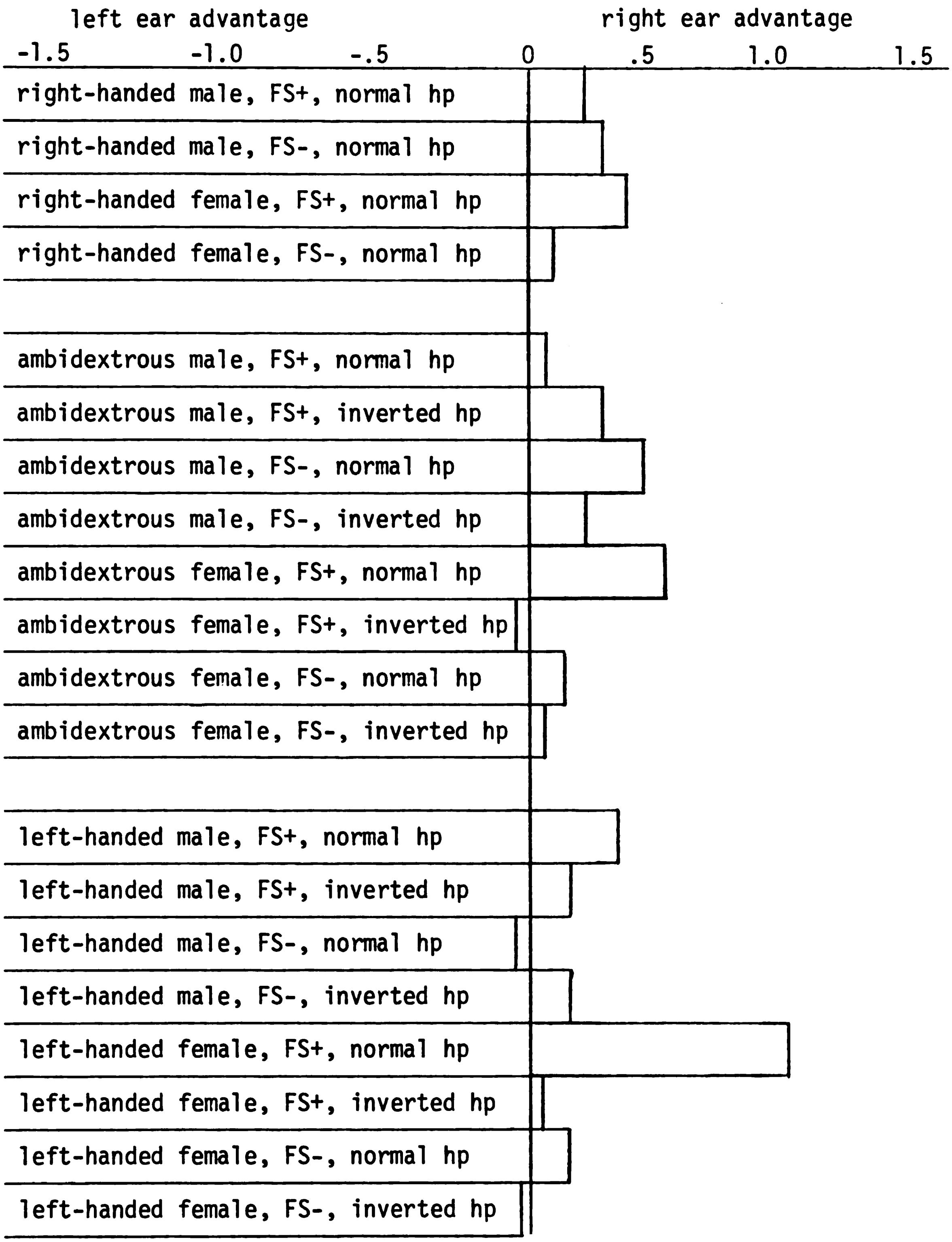
TABLE 3

Dichotic Listening Task Data

Handedness	Sex	FS	Handwriting Posture	N with Significant Field Advantage (p.<.3) left	none	right	(λ)
right	male	+	xxxxxxx	0	5	2	.182
right	male	-	xxxxxxx	0	10	9	.189
right	female	+	xxxxxxx	0	4	5	.362
right	female	-	xxxxxxx	1	9	4	.080
ambidextrous	male	+	normal	0	0	1	.027
ambidextrous	male	+	inverted	0	1	3	.319
ambidextrous	male	-	normal	0	1	1	.376
ambidextrous	male	-	inverted	0	3	4	.170
ambidextrous	female	+	normal	0	5	5	.456
ambidextrous	female	+	inverted	1	1	1	-.079
ambidextrous	female	-	normal	0	1	3	.126
ambidextrous	female	-	inverted	0	3	0	.044
left	male	+	normal	1	3	4	.212
left	male	+	inverted	1	18	12	.075
left	male	-	normal	4	7	2	-.065
left	male	-	inverted	2	7	11	.092
left	female	+	normal	5	14	13	.587
left	female	+	inverted	1	3	1	.014
left	female	-	normal	3	8	14	.119
left	female	-	inverted	3	3	5	-.041

AUDITORY LANGUAGE PROCESSING

LAMBDA



no history of familial sinistrality and normal handwriting posture, and left-handed females with no history of familial sinistrality and invereted handwriting posture.

The results of the visual task may appear somewhat incongruous on first inspection because the left-handed subjects tend to exhibit larger right visual field advantages than right-handed subjects, and show virtually no left visual field advantages. Although this is not in agreement with most previous reports, which suggest that right-handers show larger right visual field advantages for processing linguistic stimuli, similar findings have occasionally been reported in other divided visual field studies comparing handedness groups (e.g., McKeever & Van Deventer, 1977). This would appear to be in conflict with the clinical data regarding the distribution of language functioning in the sinistral population, but those data are for speech lateralization and it may be misleading to extrapolate from them to language perception, and particularly to visual language perception. Normative clinical data describing the lateralization of visual language processing in sinistrals are not available. However, there are some suggestions in the literature that left-handers may in fact rely more on left hemispher functions for processing visual language than right-handers. Hecaen and Sauget (1971) and Hecaen, DeAgostini, and Monzon-Montes (1981) report greater incidence of disturbances of visual language processing following unilateral left hemisphere lesions in sinistrals than in dextrals.

The data from the dichotic listening task are in general more consistent with what one might expect for the subject groups based on the existing literature in terms of both the magnitude and direction of ear advantages. The left-handed subjects showed a much greater tendency to have a left-ear advantage. Approximately 25% of the left-handed subjects showing a significant ear advantage had a left-ear advantage. In contrast, only one right-handed subject had a left-ear advantage. These data indicate that the dichotic listening task did elicit performance which approximately parallels what one would expect to find based on the clinical estimates of speech organization as a function of handedness.

Subject Variable Effects

The effects of the subject variables in each task were investigated in more detail by analyses of variance using the individual standardized scores derived from the lambda index as the dependent variable. The data from the visual task and from the auditory task were analyzed separately using four-way ANOVAS, with handedness (3), sex (2), familial sinistrality (2), and handwriting posture (2) as grouping factors. The data from subjects classified as right-handed who wrote with their left hand, and from those classified as ambidextrous who wrote with their right hand, were excluded from these analyses. The results of these analyses are presented in Tables 4 and 5.

In the visual task, the four-way interaction of handedness, sex, familial sinistrality and handwriting posture was significant ($F = 6.562$, $p < .02$), suggesting that each of the variables assessed in the current study contributes in an important way towards an explanation of visual language processing asymmetries. It also suggests that previous studies that have failed to consider or systematically control each of these variables may have reached unwarranted conclusions regarding the relationship between individual subject variables and cerebral organization.

TABLE 4

Divided Visual Field Task

Source of Variation	Sum of Squares	DF	Mean Square	F	Significant of F
Main Effects	12.831	5	2.566	1.109	.357
Handedness	.771	2	.385	.167	.847
Sex	.246	1	.246	.106	.745
FS	8.160	1	8.160	3.528	.062*
Handwriting Posture	2.870	1	2.870	1.241	.267
2-Way Interactions	23.033	8	2.880	1.245	.275
Hand X Sex	2.163	2	1.032	.468	.627
Hand X FS	1.571	2	.786	.340	.712
Hand X HP	1.787	1	1.787	.772	.381
Sex X FS	6.852	1	6.852	2.962	.087*
Sex X HP	8.581	1	8.581	3.710	.055*
FS X HP	2.109	1	2.109	.912	.341
3-Way Interactions	4.464	5	.893	.386	.275
Hand X Sex X FS	2.025	2	1.013	.438	.645
Hand X Sex X HP	1.892	1	1.892	.818	.367
Hand X FS X HP	1.565	1	1.565	.677	.412
Sex X FS X HP	.559	1	.559	.242	.624
4-Way Interactions	15.179	1	15.179	6.562	.011**
Hand X Sex X FS X HP	15.179	1	15.179	6.562	.011**
Explained	55.512	19	2.922	1.263	.211

* p < .10
**p < .05

TABLE 5

Dichotic Listening Task

Source of Variation	Sum of Squares	DF	Mean Square	F	Significant of F
Main Effects	39.202	5	7.840	2.731	.021**
Handedness	28.394	2	14.197	4.945	.008***
Sex	2.124	1	2.124	.740	.391
FS	5.009	1	5.009	1.745	.188
Handwriting Posture	3.557	1	3.557	1.239	.267
2-Way Interactions	22.023	8	2.754	.959	.469
Hand X Sex	4.046	2	2.023	.705	.495
Hand X FS	2.758	2	1.379	.480	.619
Hand X HP	5.659	1	5.659	1.971	.162
Sex X FS	.869	1	.859	.303	.583
Sex X HP	9.207	1	9.207	3.207	.075*
FS X HP	1.529	1	1.529	.532	.465
3-Way Interactions	14.510	5	2.902	1.011	.412
Hand X Sex X FS	13.180	2	6.590	2.296	.103
Hand X Sex X HP	.738	1	.738	.257	.613
Hand X FS X HP	.055	1	.055	.019	.890
Sex X FS X HP	1.999	1	1.999	.696	.405
4-Way Interactions	17.195	1	17.195	6.990	.015**
Hand X Sex X FS X HP	17.195	1	17.195	6.990	.015**
Explained	92.935	19	4.891	1.704	.038**

* p < .10
** p < .05
***p < .01

The overall nature of subject variable effects on visual language processing asymmetries is more clearly illustrated by examining some of the simpler effects and interactions present. There was a marginally significant main effect of familial sinistrality ($F = 3.526$, $p. = .062$), reflecting the greater right visual field advantage of FS- subjects compared to FS+ subjects. The marginally significant interaction of sex and familial sinistrality ($F = 2.962$, $p. = .087$) suggests that the effects of familial sinistrality are more complex than that simple result would suggest. Males with no history of familial sinistrality had a larger right visual field advantage than those with a history of familial sinistrality, as the main effect suggested. However, among left-handed and ambidextrous females, familial sinistrality failed to produce that effect--FS+ and FS- females showed approximately equal degrees of right visual field advantage.

McKeever and Hoff (1982) have reported a similar interaction, but their data came from a completely right-handed sample in contrast to the current results describing a predominantly left-handed sample. In the current study, right-handed male and female FS- subjects had a larger right field advantage than their FS+ counterparts. McKeever and Hoff argue against an additive model of the interaction of familial sinistrality and handedness, wherein right-handers with no history of familial sinistrality show the greatest degree or highest probability of right visual field advantage, and left-handers with a history of familial sinistrality show the smallest degree or least probability of right visual field advantage. The current results support just such a model for the visual task.

The interaction of sex and handwriting posture was also significant in the visual task ($F = 3.710$, $p. = .05$). Although neither the males nor females with normal handwriting posture in the left-handed and ambidextrous groups showed a left visual field advantage, as the Levy and Reid (1978) data would predict, and although there was no interaction of handedness with handwriting posture, there was a strong tendency for left-handed and ambidextrous males who used a normal handwriting posture to show a smaller degree of right visual field advantage compared to those who used an inverted posture, whereas the opposite was true for left-handed and ambidextrous females.

The similar analysis of the dichotic listening data also yielded a significant four-way interaction of handedness, sex, familial sinistrality and handwriting posture ($F = 6.990$, $p. < .02$). This again suggests that each of the subject variables assessed in the current study is important to consider when trying to determine the relationship between any particular subject variable and auditory language processing asymmetries.

There was a significant main effect due to handedness ($F = 4.945$, $p. < .01$). Left-handers had a significantly smaller right-ear advantage compared to right-handers and ambidexters. Many left-handed subjects had left ear advantages, while almost no ambidextrous or right-handed subjects did. The heterogeneity of each advantages for left-handed subjects would be predicted from the fact that dichotic listening tests are believed to provide an approximate test of speech lateralization, which is known to vary widely in left-handers (Levy, 1974; Satz, 1979).

There was a nearly significant sex by handwriting posture interaction ($F = 3.207$, $p. = .075$). This paralleled that found in the visual task; left-handed and ambidextrous males who used a normal handwriting posture had a smaller right ear advantage than those who used an inverted posture, whereas females with normal handwriting posture had a larger right ear advantage than female inverters, although there were also more left ear advantages among females using a normal posture.

There was also a trend towards an interaction of sex, familial sinistrality, and handedness ($F = 2.296$, $p. = .103$), that paralleled the results obtained by McKeever and Hoff (1982). Among right-handers, FS- males had a larger right ear advantage than FS+ males, whereas FS+ females had a larger right ear advantage than FS- females. Among ambidexters, a positive history of familial sinistrality was related to larger right ear advantages for both males and females. Among left-handed subjects, sex and familial sinistrality combined to produce an effect opposite to that found among right-handers; FS+ males had a larger right ear advantage than those with no left-handed relatives, whereas FS- females had a larger right ear advantage than FS+ females.

Thus, when the standardized individual scores derived from the lambda index were used in an analysis of variance, the four-way interaction of handedness, sex, familial sinistrality, and handwriting posture was significant for both the auditory and visual task. In addition, sex and handwriting posture interacted similarly in both modalities, while familial sinistrality effects varied with modality and interacted with sex and handedness differently as a function of modality.

A second set analyses was performed using the absolute values of the individual standardized scores derived from the lambda index. Because lateralization measures vary both in degree and direction, it may be revealing to examine the results of considering each separately. By examining the relationship between subject variables and the magnitude of the effect irrespective of the direction, different characterizations of the various subgroups may be obtained. This also eliminates the cancellation effect that significant left and right ear advantages within the same subgroup have on each other. Because the lambda index assigns a negative value to left side advantages and a positive value to right side advantages, using the absolute value scores has the effect of removing the influence of direction of ear and visual field advantage.

The four-way analysis of variance of the absolute values of the visual task data yielded a significant four-way interaction ($F = 7.826$, $p. < .01$), but the effect of familial sinistrality, and the interactions of sex and familial sinistrality, and sex and handwriting posture, obtained previously were eliminated. This suggests that those effects were due partly to the direction of lateralization as well as the degree.

A similar analysis of the dichotic listening task data also yielded a significant four-way interaction of handedness, sex, familial sinistrality, and handwriting posture ($F = 6.126$, $p. < .02$). The main effect of handedness previously obtained was elimianted when the magnitude of the ear advantage was considered irrespective of its direction, but the interaction of sex and handwriting posture remained significant ($F = 6.592$, $p. < .05$). Familial sinistrality and handedness also interacted significantly in this analysis ($F = 3.239$, $p. < .05$); right-handed and ambidextrous FS- subjects had smaller ear advantages than FS+ individuals, but among left-handed subjects, FS- was associated with larger ear advantages.

As noted earlier, the use of any particular index of the difference between the left and right side performance in noninvasive measures of cerebral organization represents a theory of how performance and cerebral asymmetries interact. The previous analyses were based on the lambda index, which assumes that performance and cerebral asymmetries should not be related. To date, there is no evidence that provide a critical test of such a theory. Therefore, the present data were also analyzed using ear or visual field of presentation as a within-subjects factor in an analysis of variance. This, too, constitutes a theory of how performance and perceptual asymmetries interact, since it allows performance to constrain the asymmetry (see Repp, 1977, for an illustration of this issue). This manipulation also allowed for more direct comparison of the current results with those from a number of other studies that had employed this type of analysis.

The visual and auditory task data were therefore analyzed using handedness (3), sex (2), familial sinistrality (2) as grouping factors and side of presentation (2) as a within-subjects factor in analyses of variance. Handwriting posture was not included because the lack of right-handed inverters created too many empty cells in the design for the BMDP2V program used for this analysis to function. Because handwriting posture had yielded some interesting interactions in the previous analyses, the data of the left-handed and ambidextrous subjects were also analyzed separately using all four factors of handedness, sex, familial sinistrality, and handwriting posture, with side of presentation as a within-subject variable.

The visual task data analyzed in this fashion including all subjects yielded a significant effect only for visual field ($F = 295.57$, $p. < .0001$). This, of course, reflects the pervasive right visual field advantage found in this task. When the data of just ambidextrous and left-handed subjects was analyzed, and handwriting posture was included as a grouping factor, a number of significant interactions appeared. There were significant interactions between visual field, handedness, familial sinistrality, sex, and handwriting posture ($F = 4.75$, $p. < .05$), reemphasizing the importance of each subject variable's contribution to characterizing the cerebral organization of the group. The interaction of sex, familial sinistrality, handwriting posture and visual field also approached significance ($F = 3.13$, $p. = .079$). This represented a combination of the two patterns previously described; sex and handwriting posture interact such that males with inverted handwriting posture have a larger right visual field advantage than males with a normal handwriting posture, whereas the opposite is true for females who have no history of familial sinistrality, but not for those with left-handed relatives. A nearly significant interaction of familial sinistrality and visual field also emerged, ($F = 3.19$, $p. = .076$), with FS- subjects overall showing a greater degree of right visual field advantage than FS+ subjects.

The dichotic listening task data for all subjects yielded a significant main effect of ear ($F = 33.38$, $p. < .0001$), due to the prevalence of right ear advantages. The ear by handedness interaction was significant ($F = 4.88$, $p. < .01$), due to greater prevalence of right ear advantages in right handed and ambidextrous subjects compared to left-handers. No other interactions or main effect were significant for the analysis based on the data from all subjects. When the data of only the left-handed and ambidextrous subjects were analyzed, ear of presentation interacted significantly with all four factors of handedness, familial sinistrality, sex and handwriting posture ($F = 5.61$, $p. < .02$), and with sex and handwriting posture ($F = 3.39$, $p. = .067$). The patterns of these interactions were as previously described.

To summarize, the effects of each subject variable depend partly upon the type of analysis performed, and partly on the influence of other subject variables. Only handedness produced a significant main effect in the dichotic listening task, and this was due to the presence of many left ear advantages among left-handers rather than the degree of lateralization. Familial sinistrality produced a nearly significant main effect in the visual task, with FS- subjects showing a greater right visual field advantage than FS+ subjects, but only when the effects of performance overall were removed by using the lambda index. When performance effects were included, the effect of FS was not present for the analysis based on all subjects' data, although it was present for the analysis based on the data of just left-handers and ambidextrals. Neither sex nor handwriting posture produced any main effects.

A number of interactions also cropped up repeatedly. The interactions of sex and handwriting posture were significant or nearly significant in the visual and auditory tasks under a variety of conditions, with male inverters having a greater right side advantage than males with normal handwriting posture in both tasks, and female inverters having a smaller right side advantage than females with normal posture in the dichotic task, and in the visual task, although this effect interacted with familial sinistrality for females in the visual task. Familial sinistrality and sex, familial sinistrality and handedness, and familial sinistrality, sex, and handedness also interacted repeatedly, varying in form depending on the task and the type of analysis.

Modality Effects in Measures of Cerebral Asymmetry

The second major issue of interest in the current study was the degree to which asymmetries in visual and auditory language processing would correlate, and how that correlation would vary as a function of the subject variables. Pearson product-moment correlations were calculated for the entire sample, and for each of the possible combinations of handedness, sex, familial sinistrality, and handwriting posture present in the current study, using the individual standardized scores based on the lambda index as the raw data. The results of these calculations are presented in Table 6.

Examination of these results reveals that the overall correlation is moderate, although significant due to the high number of cases ($r = .187$, $p. < .002$). This correlation compares favorably with previous reports of moderate cross-modal correlations (e.g., Hines & Satz, 1974; Zurif & Bryden, 1969). However, it can also be seen that right-handers are characterized by negative correlations, as are most ambidextrals, while left-handers are characterized by strong positive correlations in general. This contradicts previous suggestions that left-handers exhibit less cross-modal correlation than right-handers (Hines & Satz, 1974).

TABLE 6

Correlations Between the Auditory and Visual Lambda Indices

Handedness	Sex	Familial Sinistrality	Handwriting Posture	N	r
All subjects	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx			230	.187**
right	male	+	normal	1	-.260
right	male	-	normal	16	-.238
right	female	+	normal	7	-.345
right	female	-	normal	11	-.013
ambidextrous	male	+	normal	1	xxxx
ambidextrous	male	+	inverted	4	-.321
ambidextrous	male	-	normal	2	.891
ambidextrous	male	-	inverted	7	.178
ambidextrous	female	+	normal	8	-.211
ambidextrous	female	+	inverted	3	-.959*
ambidextrous	female	-	normal	4	-.414
ambidextrous	female	-	inverted	3	-.827
left	male	+	normal	8	.463
left	male	+	inverted	31	.267*
left	male	-	normal	13	.077
left	male	-	inverted	22	.537***
left	female	+	normal	31	.225
left	female	+	inverted	5	-.189
left	female	-	normal	25	.148
left	female	-	inverted	11	.163

***$p < .001$
** $p < .05$
* $p < .10$

Overall, the data indicate that subjects differ in lateralization for processing linguistic stimuli as a function of the modality of presentation. They also suggest a great deal of variation in this pattern as a function of subject characteristics. This question was addressed more directly by performing an analysis of variance of the standardized scores derived from the lambda index and by using modality of presentation as a within-subjects independent variable in combination with the between subjects factors of handedness, familial sinistrality, and sex. The overall effect of modality was highly significant ($F = 81.10$, $p. < .001$), as was the interaction of modality with all three between-subjects' factors ($F = 3.32$, $p. < .05$). In the visual modality, an absence of familial sinistrality is associated with greater right visual field advantages; in the auditory modality, familial sinistrality effects are moderated by sex and handedness considerations. Among left-handers, males with familial sinistrality and females without familial sinistrality showed a greater right ear advantage than FS- males and FS+ females. In ambidexters and right-handers, the opposite pattern was found. These findings are consonant with the results reported earlier. Moreover, the previous findings indicated a main effect of handedness in the auditory task and not the visual task, and a main effect of familial sinistrality in the visual task but not the auditory task. The present analysis reflected those findings in the interactions of handedness and modality ($F = 3.42$, $p. < .05$), and modality and familial sinistrality ($F = 3.50$, $p. < .10$).

Both the differences in degree of cross-modal correlation as a function of the subject variable groups, and the confirmation of the interactions between subject variables and modality found in the above analysis indicate that visual and auditory language processing asymmetries may reflect the operation of different processes, as does the generally low cross-modal correlation.

DISCUSSION

Given the arguments in the literature about the problems associated with the noninvasive assessment of cerebral organization, it may be asked whether the current results should be given any more or less credence than the results of other studies. Part of the answer to this question depends upon how well the current study managed to fulfill its goal of obtaining measurements of cerebral asymmetries in language processing that were relatively unbiased by strategic factors. The visual task data may appear somewhat suspect in the current study because of the high proportion of right visual field advantages that they contain--this might suggest that some form of systematic right visual field bias was introduced. However, there is evidence from other sources indicating that this particular task produces pronounced right visual field advantages. Weber and Bradshaw (1981) have criticized the Levy and Reid (1978) study on the grounds that Levy and Reid found a much higher proportion of right visual field advantages among right-handers, using procedures similar to those in the current study, than is usually reported. Their criticism is somewhat illogical, since it would be easier to argue for the validity of a task which consistently classified right-handers as left hemisphere dominant for language processing than one that did not. In fact, one would want a task that yielded results similar to those reported in the Levy and Reid (1978) study.

It seems likely that this task might draw especially heavily upon left hemisphere processing in most individuals. The task is to read a briefly presented nonsense syllable. It is difficult to envision routes to pronouncing the syllable other than through phonological encoding and processing, which may be one of the skills almost exclusively performed by the left cerebral hemispher (see Bradshaw & Nettleton, 1981). Moreover, if one chooses to give credence to dynamic models of cerebral asymmetries, then the phonological analysis and the pronunciation of the syllables may increase the degree of left hemisphere activation and thereby further increase the degree of right visual field advantage.

A related and more problematic aspect of the visual task data becomes apparent when one compares them with the Levy and Reid (1978) data. Levy and Reid (1978) found many instances of left visual field advantages among their left-handed subjects, particularly among those with normal handwriting posture, and found the high proportion of right visual field advantages among right-handed subjects already noted. The present study found very few left visual field advantages, even among the left-handed subjects. Since the procedures used in the present study were adapted from those used by Levy and Reid (1978), this is somewhat puzzling. The anwser may lie in the particular differences that did exist between the procedures used in each study. Levy and Reid (1978) projected white stimuli onto a black background; the present study projected black stimuli onto a white background. In both studies, stimulus presentation was followed by a visual noise mask. Differences in the masks, and in the masks' effects on the different kinds of stimuli, may have resulted in more central masking in one study vs. more peripheral masking in the other, which in turn may have influenced the degree of asymmetrical processing the stimuli received. Smith and Moscovitch (1979) reported results similar to those of Levy and Reid (1978) using black stimuli and a white background, but they did not use a masking procedure in their study.

As has already been noted, there is no body of clinical data which supplies normative information on the lateralization of visual language processing in sinistrals and which may serve as final arbiter of a divided visual field task's validity. The studies of Hecaen and Sauget (1971) and Hecaen , DeAgostini, and Monzon-Montes (1981) suggest that left-handers may rely more on the left hemisphere functions for visual language processing than right-handers, but these data are neither systematic nor extensive enough to serve as that arbiter. Similarly, the fact that other studies have occasionally reported a similar pattern of results (e.g., McKeever & Van Deventer, 1977) also suggests that these results may be valid. The visual task data of the current study may therefore be regarded with neither more no less credence than those of other studies; their validity remains open to proof or disproof.

The dichotic listening task data fare better in this respect. There is a body of clinical data to which the present results can be compared, and the data conform to what one might expect based on the clinical norms for the subject populations involved. This suggests at least a form of ad hoc validity. It also implies that these data may serve to characterize the cerebral organization of the subject groups for auditory language processing, and be used for comparisons of those groups with each other.

The suggestion that subject groups may be compared in terms of the degree of lateralization they exhibit on noninvasive measures of cerebral asymmetries is contrary to Colburn's arguments (1978) against such comparisons. Indeed, the analysis of the data in the current study also ignored his suggestions. Colburn (1978) has argued that there is no cogent theoretical rationale for suggesting that lateralization be considered in terms of degree as well as direction. According to Colburn's arguments, one would either have left hemisphere dominance for the particular task, right hemisphere dominance for the task, or none. If one subscribes to completely structurally determined models of cerebral functional lateralization, then Colburn's arguments have merit. However, if one incorporates any form of dynamic component into a model of cerebral functional lateralization (e.g., Kinsbourne, 1975; Moscovitch, 1979), those arguments lose their force. A dynamic model of cerebral functional asymmetries suggests that cerebral lateralization as manifested in any task performance will be a matter of degree as well as direction.

The data obtained regarding cerebral organization for language processing as a function of subject variables are interesting even if one views the visual task results with caution. It was suggested that the use of valid assessment procedures and the measurement of the joint effects of subject variables might help resolve some of the conflicts in the literature, and the current data indicate that this may be true.

The current study again establishes the importance of considering the various possible interactions among subject variables. The first result of interest was finding the significant sex difference in the incidence of normal and inverted handwriting posture in left-handers, as had been reported previously (McKeever & VanDeventer, 1980); Parlow & Kinsbourne, 1981). The importance of this result is apparent when it is considered in conjunction with the later finding of sex by handwriting posture interactions in both the dichotic listening and divided visual field tasks; if the Levy and Reid (1978) model is accurate in males but not in females, and the incidence of males who use inverted handwriting posture is high while the incidence of females who use such handwriting posture is low, and vice versa in the case of normal handwriting posture, then studies that balance cells so that there are equal numbers of individuals of each type may come to potentially different conclusion than studies that balance only for sex, or only for handwriting posture, or neither: Consider the Levy and Reid (1978) study, which had an equal number of males and females in each handwriting posture category; this created a situation where one half of the inverted handwriting posture subjects and one half of the normal handwriting posture subjects were males who would, according to the above argument, conform to the pattern Levy and Reid described. Then consider the McKeever and VanDeventer (1980) study, in which the groups were not balanced by sex; the inverted handwriting posture group in this case would be largely males, who would show the predominant right ear or right visual field advantage, while the normal handwriting posture group would be largely females, who would not show the left ear or left visual field advantage that the Levy and Reid (1978) theory predicts. McKeever and VanDeventer (1980) found just this pattern of results. Although they do not mention it, thier data also suggest the same kind of interaction between sex and handwriting posture reflected in performance on a divided visual field task that the current study found. Thus, the current data suggest that failure to control for the interaction of sex and handwriting posture may explain some of the conflicts in findings regarding the handwriting posture variable. It should, however, also be reemphasized that the current results indicate only smaller degrees of right visual field advantages and right ear advantages for male subjects with normal handwriting posture, rather than the reversed asymmetry Levy and Reid described for all of their left-handed subjects with normal handwriting posture.

The same considerations may apply to the sex by familial sinistrality interaction found in the visual task; although there was a weak effect of familial sinistrality overall, it was also much more marked in males than in females. The dichotic listening task data further suggest that this interaction may be moderated by handedness. Finally, the data also indicate that familial sinsitrality effects may be task specific or modality specific; familial sinistrality overall exerts an opposite influence in each task in the present study, with a positive history of familial sinistrality being related to greater right ear advantages and smaller right visual field advantages. The variety of interactions here leads one to speculate that such factors may have contributed extensively to the especially marked confusion that exists regarding familial sinistrality effects.

The significance of the four-way interaction of handedness, sex, familial sinistrality, and handwriting posture in both the divided visual field task and the dichotic listening task suggests that each of the subject variables measured in the current study was related to cerebral organization in an important way, and that a failure to consider any of them might result in some misleading conjectures. This in effect supports one of the rationales underlying the current study: Assessments of subject variable effects on cerebral asymmetries will be most revealing when as many of the relevant variables as possible are measured concurrently.

However, it is clear that this alone is inadequate as a means of resolving the numerous conflicts in this literature. Searleman (1980) also measured each of these variables, as well as additional ones, and found that only footedness related to the ear advantages he obtained using a dichotic listening task. McKeever and VanDeventer (1977) measured the effects of handedness, strength of hand preference, sex, and familial sinistrality using a divided visual field task and a dichotic listening task. They reported that FS+ was associated with greater right visual field advantages in left-handed subjects, and that right-handed females showed greater right visual field advantages than males. Only the main effect of handedness was significant in the dichotic listening task. The current study found the same main effect of handedness in a dichotic listening task, greater right visual field advantages for females than males, and the opposite effect of familial sinistrality--FS+ subjects in the current study showed smaller degrees of right visual field advantage than FS- subjects, and familial sinistrality interacted with sex in the current results to modify this effect. Thus, concurrence in the subject variable literature will not result from merely including all of the relevant variables in each study.

One could argue that the route to concurrence between studies of this type demands the use of tasks that are known to be reliable and valid instruments for measuring cerebral asymmetries in language processing. Apart from the theoretical muddle this points to, whereby the nature of cerebral functional lateralization is unclear, it might also be inadequate in another sense. The data from the dichotic listening task in the current study, for example, suggest that it might be such an instrument, although this is not a certainty. Geffen and Traub (1980), using a dichotic monitoring task that has previously been shown to correlate very well with invasive measure of cerebral organization for speech, found that nearly 25% of left-handers and almost no right-handers showed significant left ear advantages. They also reported that mixed handers were even more likely to show a left ear advantage and that FS+ increased the incidence of REAs in the left-handed male group. The current study found that mixed handers were more like right-handers, showing mostly right ear advantages, and that FS+ male sinistrals were no more likely to show a significant right ear advantage than FS- male sinistrals (41% to 39%), although more of the latter showed significant left ear advantages. Thus, the current study is only in approximate agreement with Geffen and Traub (1980), even though both employed what appear to be acceptable procedures.

The results reported in the current study suggest yet another source of variance in the literature. Most of the analyses reported were based on the use of the standardized scores derived from the lambda index. When the data were analyzed using ear or visual field of presentation as a within-subjects variable, the results changed;

only visual field itself produced an effect in the visual task, and only ear and the interaction of ear and handedness produced significant effects in the dichotic listening task. Similarly, a set of analyses based on the Percentage of Correct index, which is one alternative to lambda, produced yet another set of results (unreported here). Even a cursory reading of the literature indicates that a wide range of such indices has been used as the basis of analysis on occasion, as well as the repeated measures approach mentioned above. It would seem that at least part of the disarray in this literature is due to the various statistical manipulations researchers have applied to their data. A number of authors have already decried this situation, noting that one may obtain opposite results from some of the indices that have been used (Marshall, Caplan, & Holmes, 1975; Richardson, 1978).

Thus, it would appear that methodological considerations might do much to resolve the conflicts in the literature on individual differences in cerebral organization for language processing. The current findings support the idea that interactions among relevant variables may have biased previous reports. The close, although not complete, agreement between Geffen and Traub's (1980) dichotic monitoring task results and those from the dichotic listening task used in the current study supports the idea that more rigorously chosen procedures will also reduce the conflicts in findings. Some care in the selection of statistical procedures, or at least awareness of the potential biases introduced by the choice of any procedure, may also work towards that goal. The remaining question is, of course, whether these considerations alone would be sufficient to produce a consistency in the literature.

The cross-modal correlation data from the current study and portions of the subject variables data already described indicate that they probably would not. Both the general variance in cross-modal correlation as a function of subject variables and the reversals in the effects of some subject variables on cerebral organization for language processing as a function of modality suggest that theoretical reconsiderations may also be needed.

The overall cross-modal correlation is sufficiently moderate ($r = .187$) to suggest that language processing in the two modalities is not strongly related, even though the correlation reached significance due to the large number of cases used. Some cautions about the cross-modal correlations reported here are necessary, however. The dichotic listening task and the divided visual field task used had different requirements apart from those imposed by being in different modalities. In the visual task, subjects were asked to identify a briefly exposed fixation digit and nonsense syllable, and in the dichotic listening task they were asked to identify a single word that they had heard. If equivalent tasks to these were both performed in the same modality, it is not clear to what extent one would expect to find strong correlations in the degree of asymmetrical processing shown on each task. Obviously, the ideal answer to questions about cross-modal correlation for noninvasive measures of cerebral asymmetries would be to use analous procedures in each modality; however, the need to use procedures that also reliably yield asymmetries has made this goal a difficult one to achieve. In attempting to determine the importance of reliable procedures, the current study strayed far from it.

Although the cross-modal correlation data are not completely satisfactory for the reasons noted above, they do provide some interesting grounds for speculation. First, it is interesting to note that the degree of cross-modal correlation obtained between the two tasks increased in left-handed subjects, who generally showed strong positive correlations, rather than decreased as Hines and Satz (1974) found. The cross-modal correlations reported by Smith and Moscovitch (1979) conform to the present pattern in a relative sense; although all of the correlations they found were negative, the left-handed subjects in their study showed a smaller degree of negative correlation. Thus, the argument that left-handers are more likely than right-handers to show dissociation of language processes (Levy, 1982) does not appear to be supported by the present data.

Instead, the present data suggest a variation of that argument. It is tempting to speculate that left-handers' performance on various noninvasive measures of cerebral asymmetry reflects the greater contribution of a dynamic component than one finds in right-handers' performance. Left-handers' performance on measures of cerebral functional asymmetry is noted for its high variability. Besides showing a great deal of within group and between study variation on such measures, left-handers also have been reported to show greater within-subject variation on test-retest measures (Hines, Fennel, Bowers, & Satz, 1981). Whereas the variance in left-handers' performance on tasks measuring asymmetrical language organization is usually attributed to greater within-group structurally-mediated variations, the data of Hines et al. (1981) instead suggest that left-handers have more freedom in the degree of asymmetrical processing they engage in. Given the many suggestions that left-handers in general tend to have language functioning more bilaterally distributed (e.g., Hecaen & Sauget, 1971), one can suggest that an interaction between this and a flexible dynamic component of cerebral functional asymmetry would account for left-handers' greater variability of performance. If such a factor ought to influence performance more on highly demanding tasks, since attentional contributions would presumably be greater in such situations. In the current study, the visual task was quite demanding and the auditory task was relatively undemanding. Left-handers showed a very large right visual field advantage in general, suggesting that perhaps hemispheric priming of the type discussed by Kinsbourne (1975) was a factor. This is highly speculative, but it makes sense to suggest that if the presence of certain characteristics implies that an individual is less likely to be rigidly canalized to have language processing performed predominantly in the left hemisphere, then perhaps the deployment of attention that interacts with structural specialization may also be less constrained in such individuals.

The argument advanced here suggests that one locus of subject variable effects may be in a dynamic attentional component that interacts with structurally mediated asymmetries in language processing to produce greater or lesser degrees of perceptual asymmetries. An alternative and equally acceptable view would be that the current data reflects a different locus of effects for each subject variable in the underlying component processes that are required for the performance of each task. Thus, familial sinistrality might affect the overall asymmetry in task performance by influencing the asymmetry due to one component, while handedness might influence that asymmetry via a different component. The extent to which a particular task requires that component's operation will determine whether the subject variable effect is manifested. Thus, in the current study, handedness would be related systematically to a lateralized component of the dichotic listening task that was not strongly present in the divided visual field task.

The current data do not provide a means for distinguishing between these two models of the mechanisms by which subject variable effects are mediated. They do, however, suggest that each of these views is more likely to be valid than a simpler view that suggests that cerebral functional asymmetry can be dichotomously characterized in terms of left hemisphere dominance for globally defined language processing. The negative cross-modal correlations in dextral males, who have been previously considered most likely to show the greatest uniformity in language processing, argues against such a theory, as do all the variations between the current results and previous results, and as do variations within the previous results.

Thus, the current data suggest that methodological considerations are indeed important, as was illustrated earlier, but that a theoretical revision regarding the nature of cerebral functional lateralization is also appropriate. Even given methodological rigor, it is likely that asymmetrical performance as a function of subject variables will prove to be highly task-specific. In that sense, the answer to the question of which data should be given credence, given the variance in the literature, becomes "All of it". It is clear that many researchers have begun to speculate about alternative formulations to the notion of cerebral functional lateralization as being a language/visuospatial dichotomy, and from one of these formulations may come a different perspective which might return some unity to that data.

What seems to be needed are further investigations using systematic manipulations of task parameters within subjects to determine the mechanisms by which perceptual asymmetries are manifested, and to determine precisely how they are influenced by cerebral asymmetries in processing capabilities. Until this is done, the understanding of individual differences in such organization cannot be advanced much further. Distinguishing between component processes models of cerebral functional asymmetry and attentionally mediated models, and determining where the locus of subject variable effects resides, may be the next important steps for research on cerebral functional lateralization. As suggested earlier, the interplay between research on individual differences and research aimed at constructing general models of cerebral functional asymmetry should guide both endeavors.

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