HEMISPHERIC SPECIALIZATION AND IMAGERY PROCESSING

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> We've only just begun to live.
> So much of Life's ahead.
> You start out walking and learn to run,
> And yes, we've just begun!
> (We've Only Just Begun, Paul Williams)

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CHAPTER I

LITERATURE REVIEW

Introduction

The purpose of the present experiment is to determine if different types of imagery processing are associated with cerebral lateralization as indicated by differences in RT. Given that the left hemisphere is generally specialized for the processing of verbal information while the right hemisphere is generally specialized for the processing of spatial information (Gazzaniga, 1970), then imagery that is spatial in nature could show differential hemispheric processing compared to imagery that is acoustic in nature. On the other hand, it may be that different kinds of imagery are not differentiated hemispherically and are always processed in one specific hemisphere or else in both hemispheres simultaneously. To assess the above possibilities, a "split-brain" reaction time procedure will be employed. The history and nature of this procedure will now be discussed.

The Idea of Cerebral Lateralization

Available evidence (Masland, 1967) indicates that laterality of functioning is almost completely unique to the human nervous system. Some aspects of lateralization are readily apparent, e.g., handedness and footedness. Other aspects of lateralization are less readily apparent, e.g., asymmetry of cerebral functioning. Since about 1965 (the time of Broca and Dax), the concept of cerebral dominance, based upon the relationship between handedness and speech lateralization, has become generally accepted (Penfield & Roberts, 1959; Moscovitch, 1972). Cerebral dominance is rationalized as follows. Since the vast majority of individuals are left-hemisphere dominant for speech, then the general rule of thumb is that the left hemisphere is "dominant" (for speech) and the right hemisphere is "non-dominant" (mute). Within the past few years the concept of cerebral dominance as it relates to handedness has been better defined (Annett, 1967, 1970; Bryden, 1970; Curry, 1967, 1968; Curry & Rutherford, 1967; Kimura, 1967; Satz, Achenbach & Fennel, 1967; Zurif & Bryden, 1969; Bakker, 1970; Treisman & Geffen, 1968; Benton, 1965; Gazzaniga & Sperry, 1967). In addition, within the past few years the concept of cerebral dominance has been widened to take into account hemispheric asymmetry in a wide variety of functions other than speech production (see reviews by White, 1971; Blakemore, Iverson & Zangwill, 1972).

The first source of knowledge about speech laterality was limited primarily to occassions ("experiments of nature") in which aphasic symptoms developed in concurrence with hemiplegia or hemiparesis following brain injury (Satz, Achenbach

& Fennel, 1967). More recently, neurosurgical intervention has provided a secondary source of knowledge (Milner, 1958, 1962, 1967; Sperry, 1961). Finally, the introduction of the sodium amytal test of speech by Wada has added a third source of knowledge (Rossi & Rosadin, 1965; Satz, 1967). In addition to knowledge about speech laterality, these latter two techniques have provided knowledge about the laterality of other higher order functions, e.g., music (Milner, 1967; Bogen & Gordon, 1971) and emotion (Gazzaniga, 1970).

Within the past ten years interest has arisen as to whether or not the model of hemispheric lateral specialization based on the evidence provided by "experiments of nature," neurosurgery, and amytal injection adequately described lateralization for a normal population (Moscovitch, 1972; Gazzaniga, 1970). Afterall, it is not unreasonable to assume that the functional organization of persons who are candidates for neurosurgery might possibly be atypical (Satz, *et al*. 1967; Moscovitch, 1972).

To evaluate laterality effects with normal subjects various procedures have been developed, almost all of which approximate in some way or another the split-brain experimental paradigms developed by Sperry. The intent of the present paper is to briefly discuss Sperry's split-brain paradigm and then to review recent findings of the lateralization of higher order functions. The emphasis will be on the research techniques used with normal subjects.

The History of the Split-Brain Paradigm

Human beings exhibit vast amounts of complex and highly practiced learned behavior. Observing this behavior, the researcher often overlooked the linkages of the separate components because of the smoothness of the over-all pattern. One such linkage which was overlooked for years was the corpus callosum. Gazzaniga (1971) reports that up until the mid 1950's, "the majority view in psychobiology was that the corpus callosum played little or no important role in integrating sensory or motor information across the cerebral hemispheres" (p. 222). It was in the mid 1950's that Sperry and Myers began their now classic work on "split-brains" (for a brief history of the ideas and events that led up to this work see Sperry, 1961). Splitting the brain generally involves surgically cutting the corpus callosum, the anterior comissure, and the optic chiasm although procedures vary according to surgeon and the desired results (Gazzaniga, 1970). Sperry demonstrated that surgical destruction of these interhemispheric connections in the human being results in an inability of patients to verbally report printed material that is visually presented to the right cerebral hemisphere even though these same patients retain the ability to report the material if it is presented to the left cerebral hemisphere. In addition, Sperry demonstrated that the right hemisphere can receive and comprehend stimuli since patients can tactually identify the object-referents of words if they are presented to the left visual field with the tactual identification performed by the left hand (Sperry, 1968).

Sperry has interpreted these findings as indicating that the left and right hemispheres differ in their modes of information processing: specifically, the left hemisphere appears to have an analytic language function while the right hemisphere appears to have a spatial function; that is, it processes information in terms of its whole configuration (Levy-Agresti & Sperry, 1968). Levy-Agresti and Sperry (1968) have also concluded that the reason for this cerebral lateralization in man is that there is a basic incompatibility of language function associated with the dominant hemisphere and a gestalt apprehension function associated with the minor hemisphere. Thus, competition and/or interference results in lateral specialization.

Laterality Effects and Transmission of Information via the Corpus Callosum

Sperry's subjects were unable to verbally report information channelled to the hemisphere that was non-dominant for language specifically because interhemispheric transfer via the corpus callosum had been surgically terminated (Gazzaniga, 1970). The "non-speaking" hemisphere could no longer transfer either the information or an analysis of the information to the "speaking" hemisphere. With normal subjects, there is no such comparable inability to transfer data. However, an inferiority of analysis and/or response by one hemisphere in comparison to the other on language tasks with normal subjects can be demonstrated. Since the transfer of information across the corpus callosum consumes time (Bremer, 1958; Grafstein, 1959; Teitelbaum, Sharpless & Byck, 1968; Bradshaw & Perriment, 1970; Geffen, Bradshaw & Wallace, 1971; Filbey & Gazzaniga, 1969; Gibson, Filbey & Gazzaniga, 1970; Klatzky & Atkinson, 1971; Moscovitch & Catlin, 1970; Moscovitch, 1972; Rizzolatti, Umilta & Berlucchi, 1971; Poffenberger, 1912; Efron, 1963a, 1963b; Jeeves, 1969) and degrades the information signals (Dimond, Gibson & Gazzaniga, 1972; McKeever & Huling, 1971; Lordahl, Kleinman, Levy, Massoth, Pessin, Storandt, Tucker & Vanderplas, 1965), then information channelled to the non-dominant language hemisphere should be responded to slower and/or with less accuracy than when the same information is channelled to the dominant language hemisphere. Many of the same investigators mentioned above also believe that an inferiority of response by one hemisphere can be demonstrated with normal subjects for tasks other than language production.

Other investigators have a different point of view. They do not believe that differences in response times or accuracies between the two hemispheres indicate transfer of information via the corpus callosum (Kinsbourne, 1970; Geffen, *et al*. 1971; Zurif & Bryden, 1969). Kinsbourne (1970) contends that the differences in RT to stimuli presented to opposite hemispheres reflect the fact that subjects' attention is focused on the task more rapidly when information is channelled toward the hemisphere dominant for that task than when the information is channelled toward the opposite hemisphere. Consequently, the subject responds more rapidly to the information presented to the attentive field. Geffen, <u>et</u> <u>al</u>. (1971), and Zurif and Bryden (1969) offer a second point of view. They contend that with some stimuli, both hemispheres have the processing capability to analyze the stimulus information. However, they believe that one hemisphere can analyze the stimulus information faster and/or more accurately than the other. Therefore, differences between the two hemispheres in response times and response accuracies result.

A third alternative (or supplement) to transcallosal transfer of information hypothesis is the possibility that subcallosal transfer of information occurs (Jeeves, 1969; Gazzaniga, 1970). Gazzaniga (1970) notes that one of the common aspects of brain lesion work is that lost function returns with time. Gazzaniga feels that this raises questions about the possibility of multiple subcallosal pathways being involved in hemispheric synthesis of information. These pathways do not appear to be as efficient as the corpus callosum pathways (Jeeves, 1969). However, Jeeves' comparison matched normal subjects against an acallosal subject. It is possible that subcallosal pathways function differently in normals as compared to acallosals.

A final alternative (or supplement) is that cross-cueing, as opposed to callosal transfer, is used to produce information transfer from one hemisphere to the other (Gazzaniga, 1970). Cross-cueing means that the cross-over of information is not through the central neural channels but instead is by one hemisphere taking note of cues made available by the overt bodily-systemic changes executed by the other hemisphere. Thus, in a visual detection experiment using a verbal report, the left hemisphere could note eye fixation in the left visual field (which projects information to the right hemisphere) and vocalize a "positive" for detection even before the right hemisphere could transfer that same information.

In summary, investigators tend to agree that laterality of functioning for higher order information processing can be demonstrated. However, there is disagreement concerning whether or not one explanation can account for all observable laterality effects given the wide range of possible stimuli and tasks. In addition, if one explanation suffices, there is disagreement over what that one explanation should be.

Discrete Versus Graded Laterality

Before continuing, the issue of discrete versus graded lateral dominance should be considered. The classification of the cerebral hemispheres as dominant or non-dominant implies a discrete dichotomy. Much of Sperry's work and terminology, and much of the following work and terminology, perpetuate the idea of discrete dichotomies, e.g., major versus minor, speaking versus mute, verbal versus non-verbal, verbal versus spatial (Levy-Agresti & Sperry, 1968; Klatzky, 1970). In contrast, several hypotheses of graded laterality have been proposed (Bradshaw, Nettleton & Geffen, 1972; Palmer, 1964; Zangwill, 1960; Goodglass & Quadfasel, 1954; Hécaen & Pierey, 1956). Bradshaw et al. (1972) feel that laterality can be viewed as a continuum of stimulus and/or task characteristics which stretch from one hemisphere to the other. For example, one continuum might consist of language (encompassing extreme left lateralization), a prose passage (encompassing more neutral ground because of its left lateralization for language characteristics, and its right lateralization for its rhythmic nature), and pure tonal factors (encompassing extreme right lateralization). Palmer (1964) on the other hand, sees laterality as a continuum because of subject variability. Each individual varies in the nature, scope, and completeness with which he responds to each stimulus and task. Therefore, some individuals will be more lateralized for language, etc. than others, and gradation of laterality effects should be observed.

Although important to subject selection and statistical analysis, the issue of discrete versus graded lateralization does not seem to be settled. One problem is that present knowledge of laterality effects is too meager to accurately assess whether or not graded lateralization indeed exists, and if it exists, to what extent.

Modes of Presentation: Visual

Data from patients who have undergone section of the corpus callosum indicate that visual field asymmetry relates to cerebral dominance for verbal and non-verbal information. That is, a patient who is left-hemisphere dominant for speech can report stimuli presented to the right visual field but is unable to report the same stimuli when they are presented to the left visual field (Gazzaniga, 1970). Further, Gazzaniga (1970, p. 92) reports that "the visual midline represents nothing but the abutment of the two visual fields. The visual fields were found to stop exactly in the midline, with no overlap...evident".

With normal subjects, evidence of greater efficiency of the right visual field for processing verbal and/or the left visual field for processing non-verbal information has been variously reported (Kimura, 1966, 1969; Moscovitch & Catlin, 1970; Hines, Satz, Schell & Schmidlin, 1969; McKeever & Huling, 1970, 1971a, 1971b; Geffen, et al. 1971; Rizzolatti, et al. 1971; Durnford & Kimura, 1971; Bryden, 1970; Geffen, Bradshaw & Nettleton, 1972; Klatzky, 1970; Pavio & Ernest, 1971; Gibson, Dimond & Gazzaniga, 1972). Nevertheless, there are factors other than asymmetry of cerebral function, which can produce laterality effects. These factors have led to inconsistency in the asymmetry data (White, 1969). Thus, the role of hemispheric components in the control of visually guided behavior by the normal brain has remained highly controversial (White, 1969; Rizzolatti, et al. 1971). The next few sections will consider the issues in this controversy. Note that Figures 1-3 show the information pathways from the visual fields to the cerebral hemispheres. Any information in the right visual field (for one or both eyes) will go directly to the left cerebral hemisphere and vice versa for the left visual field.

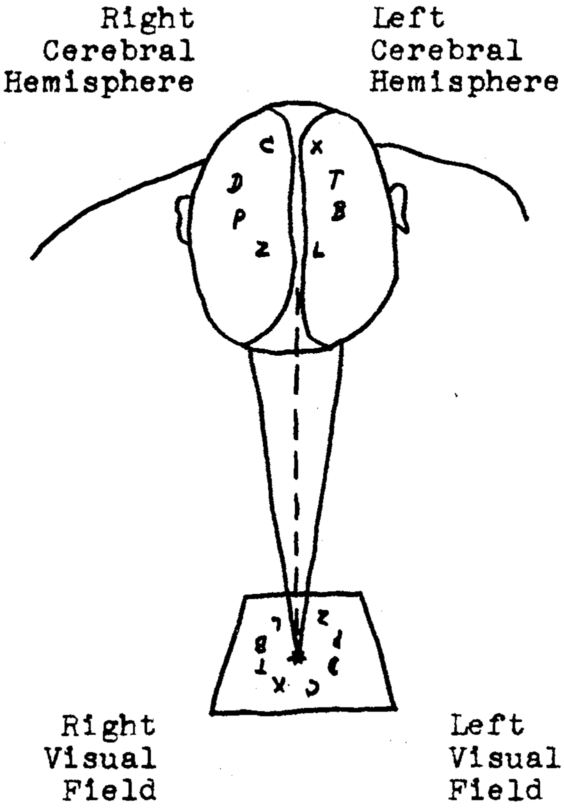

Figure 1. The Transfer of Letter Information to the Cerebral Hemispheres

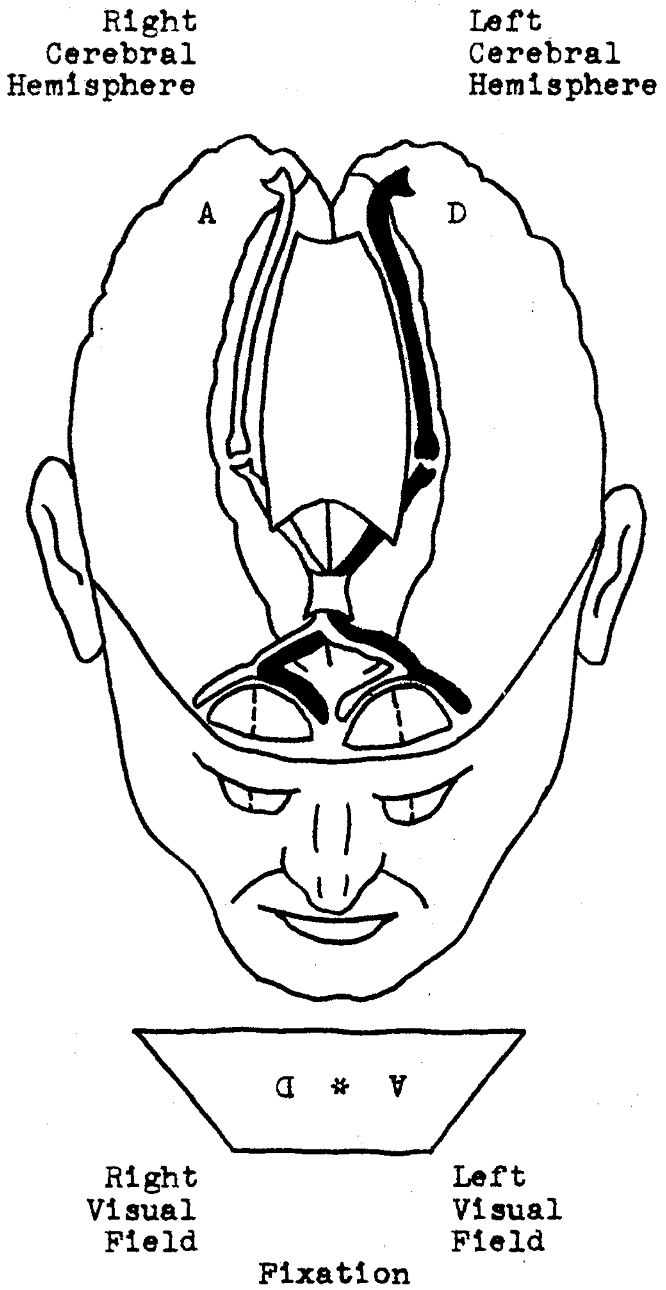

Figure 2. The Information Pathways from the Visual Fields to the Cerebral Hemispheres

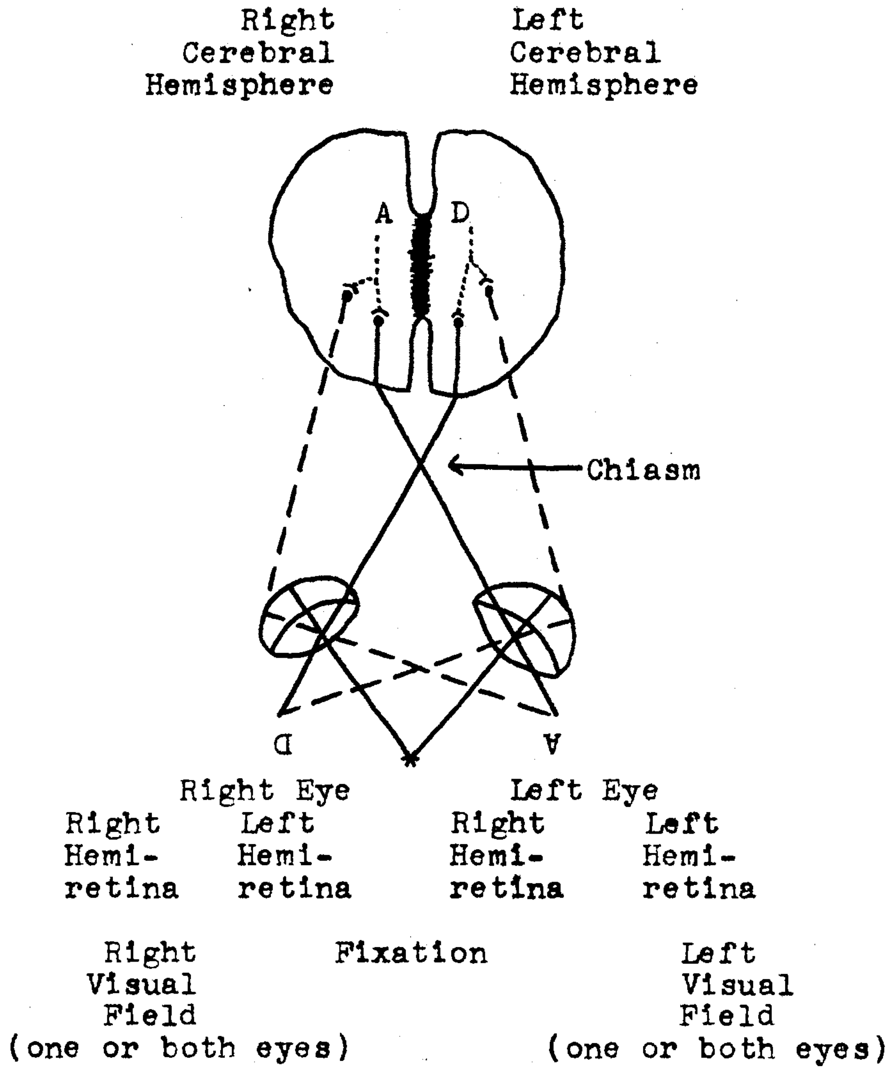

Figure 3. The Information Pathways from the Hemiretinal Visual Fields to the Cerebral Hemispheres

Simultaneous Versus Successive Presentation

White (1969) has noted that laterality effects resulting from simultaneous presentation of stimuli (material is presented to both visual fields in unison) are often discrepent with the laterality effects resulting from successive presentation (material is presented first in one visual field and then in the other). Specifically, for all types of material (both verbal and non-verbal), it is often the case that stimuli, when presented simultaneously, are more accurately reported from the left visual field (LVF) than from the right visual field (RVF). This is true under both binocular and monocular viewing conditions (Bryden & Rainey, 1963; White, 1969; Hines, *et al*. 1969). On the other hand, successive presentation yields either LVF or RVF superiority depending on the type of material presented (Kimura, 1966; Rizzolatti, *et al*. 1971). Kimura (1966) has suggested that these results indicate that successive presentation is more resistant to masking or counteracting effects and thus taps hemispheric asymmetry of function more cleanly than does simultaneous presentation. Simultaneous presentation appears to be easily contaminated by masking or counteracting effects and therefore hemispheric asymmetry often cannot be assessed.

An acquired left to right visual training bias due to learned reading habits (Kimura, 1966; Bryden & Rainey, 1963; Mishkin & Forgays, 1952; Heron, 1957; Hines, *et al*. 1969;

Harcum & Finkel, 1963; Orbach, 1953; Barton, Goodglass & Shai, 1965) is mentioned most often by investigators as complicating the interpretation of results when simultaneous presentation is used.

The visual training bias operates in the following fashion. Presented visual arrays are scanned in a left-to-right fashion. This means that there is more chance of the stimulus trace of the right side items fading below response threshold. In addition, order of report follows the left-to-right habit (Hines, et al. 1969) so that delay of report interacts with the fading stimulus trace to produce an even greater decrement.

Investigators acknowledge that left to right scanning usually biases the results of a simultaneous presentation experiment, but they also note that scanning does not necessarily have to bias these experiments. Hines, et al. (1969) have controlled scanning by using fixed recall techniques. Barton, et al. (1965) have controlled scanning by the vertical presentation of verbal materials. McKeever & Huling (1971a, 1971b) have controlled scanning by scrupulously controlling fixation. Finally, many investigators have controlled scanning by minimizing exposure durations and/or stimulus intensities. It is to be expected that as exposure durations and stimulus information tend toward the minimum that these factors should dominate a scanning process which demands both maximal information and the time to process it. The result of all of the above mentioned controls is that dual functional asymmetry (the left hemisphere being specialized for "verbal" tasks and the right hemisphere being specialized for "spatial" tasks) is demonstrated in spite of the scanning bias.

There are at least three reasons why the scanning effect does not tend to influence successive presentation. First, since there is not always information in the left visual field, subjects will not automatically shift their gaze to the left. Second, to give optimum performance with successive presentation, the best strategy is to remain fixated dead center between the two visual fields. Third, since there is no LVF versus RVF information present at the same time, there is no possibility of scanning one visual field before the other; therefore, the reading habit bias has little influence.

Other Problems with Visual Presentation

In man, the two hemiretinas of an eye do not project to the same cerebral hemisphere. The temporal hemiretina in each eye projects directly to the ipsilateral visual cortex, whereas the projections of the nasal hemiretinas cross at the optic chiasma and stimulate the contralateral visual field in such a way that stimuli from the left of fixation (LVF) are received by the right hemisphere via both the nasal hemiretina of the left eye and the temporal hemiretina of the right eye. The converse is true for stimuli from the right of fixation (RVF).

This means that possible accuity, efficiency, and dominance differences between the two eyes (McKinney, 1967; Wyke & Chorover, 1965; Overton & Weiner, 1966), as well as differences between the temporal and nasal halves of each monocular field (Overton & Weiner, 1966; Markowitz & Weitzman, 1969; Barton, et al. 1965), could influence laterality effects. Under monocular viewing conditions, the following temporal/nasal effects have been found. McKinney (1967) has demonstrated the superiority of the temporal hemiretina over the nasal hemiretina in maintaining a stable percept at low levels of stimulation. He also found that the temporal hemiretina of the left eye (RVF) was superior to the temporal hemiretina of the right eye (LVF) in maintaining a stable percept, and that the temporal hemiretina of the non-dominant eye was superior to the temporal hemiretina of the dominant eye on the stability task. Markowitz & Weitzman (1969) demonstrated the superiority of the temporal hemiretina over the nasal hemiretina on a visual accuity task using Landholt C's; the effect was greater for the right eye than for the left. Their data also suggest that this superiority may diminish with increasing luminance. Wyke and Chorover (1965) found that the temporal fields of both eyes were superior in identifying stimuli presented to the peripheral side of a standard stimulus in comparison to identifications to the central side of the same stimulus; the right eye showed a stronger effect than the left eye. No over-all difference in the performance of the temporal field compared to the nasal field was found, but this may be due to the relatively long exposure times (one second) used in the experiment. In discussing work by Hubel and Wiesel (1959), Wyke and Etlinger (1961) pointed out that lateralized differences in accuity might be related to differential activation of cortical units by temporal versus nasal projections since stimulation of nasal retinal sectors produces more widespread cortical activation than does temporal stimulation. Berlucci, Heron, Hyman, Rizzolatti and Umilta (1971), in an RT study, indicate that differences in temporal accuity in relation to density of receptors might only be effective at wide visual angles.

These differences in accuity and hemiretinal efficiencies appear to produce the following general laterality finding. With successive presentation under monocular viewing conditions, RVF superiority for the perception of words has been found to be greater for the left eye than for the right eye (Overton & Weiner, 1966; Markowitz & Weitzman, 1969; McKinney, 1967). McKinney (1967) has offered a two-factor hypothesis to explain the aforementioned finding. He notes that the dominance of the left hemisphere for verbal tasks, when combined with the dominance of the temporal hemiretina, could account for the fact that a significant difference between visual fields occurs only with the left eye. In the left eye, these two dominance effects combine to provide an advantage for materials presented to the RVF; in the right eye, these two effects cancel each other out and neither field is dominant. Refer to Figure 3 for a graphic representation.

There may be problems with this explanation however. Fudin (1969, 1970) has found that for horizontal targets, e.g., words, arrays presented in the RVF and LVF are not identically encoded. Specifically, since the beginning of a word in the RVF is closer to the fixation point, it falls on an area of greater visual accuity than does the same word when it is presented to the LVF. Thus, words should be more easily perceived and encoded when exposed in the RVF because the beginning of a word contains more information than the latter parts of a word. This means that for horizontal presentations, not only the left eye should show RVF superiority, but the right eye should also. Barton, et al. (1965) have shown a RVF superiority for both eyes; however, they used a vertical presentation. This finding complicates matters further. If with the right eye the RVF superiority for both the horizontal presentation of words and the direct access to the left (speaking) hemisphere is conpensated for by superior temporal hemiretina performance (McKinney, 1967), why is it that when the horizontal presentation is replaced by a vertical presentation (in effect decreasing the RVF advantage) the RVF advantage becomes significant? This effect is the reverse of what is predicted.

In addition, there have been other findings that further complicate the aforementioned issues. These findings are as follows. Wyke and Chorover (1965) have shown that accuracy of monocular spatial discrimination is better for the left eye than for the right eye. McKinney (1967) has found that

RVF superiority is more pronounced in subjects who are right-eye dominant. Miskin (1962) has speculated that the transcallosal pathway from the LVF to the right hemisphere is stronger than the transcallosal pathway from the RVF to the left hemisphere. This effect would lead to a right-hemisphere dominance for visual functions. Wyke and Etlinger (1961) have shown that differences between the RVF and LVF are increased as exposure time is decreased. Crovitz and Daves (1962) have shown that when rows of digits are exposed across a monocular field of vision, the direction of the immediate post-exposure eye movement was left when viewing with the left eye and right when viewing with the right eye. Finally, Harcum and Dyer (1962) have found that perception of the peripheral regions of a pattern is more accurate than perception of its central area. In other words, for both eyes elements at either extremity of a horizontally presented pattern are more accurately perceived than those in its center.

Most of the aforementioned effects are not understood, especially in relation to laterality. Fortunately, however, in general these effects seem to be easily overshadowed by the functional asymmetry of the cerebral hemispheres if one is careful with procedure and materials (Kimura, 1966). With successive binocular presentations, any acuity differences which may exist between temporal and nasal fields of one eye or between eyes would be expected to balance out over left and right fields (Kimura, 1966). Kimura (1966) also found that eye dominance had a negligible effect on field differences in her experiment (binocular and successive presentation). Moscovitch and Catlin (1970) found that the functional interpretation of the laterality effects found in their experiment (binocular and successive presentation) could not be reexplained as a function of eye dominance. Geffen, et al. (1971) used successive binocular presentation with digits and found significant RVF superiority consistent with the dual asymmetry of function hypothesis. The authors showed that the effect could not be explained by eye dominance or a difference in temporal and nasal hemiretina sensitivity. In addition, even with successive monocular presentation, if directional scanning is controlled, and if the tasks are very strongly related to asymmetrical hemispheric functioning, and if "verbal loop" effects are minimized (see the section on "response modes and responses"), then differences in visual acuity between nasal and temporal parts of the retina appear to have a negligible effect on the results (Rizzolatti, et al. 1971; McKeever & Huling, 1971b). Finally, McKinney (1967) in a correlational study between monocular and binocular data, found that the temporal hemiretina for both eyes combined only accounted for 16% of the variance of the binocular data, the nasal hemiretinas accounted for less than 9% of the variance, the non-dominant eye accounted for less than 9% of the variance, and the dominant eye accounted for less than 2% of the variance.

In summary, laterality effects with visual presentations appear to be a composite of many factors. RVF versus LVF superiority findings depend upon (a) the type of stimulus presentation (successive or simultaneous), (b) the amount of stimulus elements (one or a horizontal string), (c) the intensity and exposure duration at which the stimulus is shown, (d) the order in which the information is reported, (e) the viewing condition employed (monocular or binocular), (f) the ocular dominance of the subjects, and (g) the spatial arrangement of the stimuli. Finally, it is not known how these factors interact. One possibility suggested by White (1969) is that structural effects and functional characteristics are probably on an interacting continuum. For example, as occular dominance, etc. become less important as a determining factor, directional characteristic and sequential processes could become more important.

Modes of Presentation: Auditory

As was seen with visual input, there now appears to be a substantial body of evidence which indicates that the two cerebral hemispheres are functionally asymmetrical with respect to auditory input (King & Kimura, 1972; White, 1969; Treisman & Geffen, 1968). In fact, White (1969) claims that the evidence of functional asymmetry is much more clear-cut with auditory input that it is with visual input. As was mentioned earlier, studies of patients with temporal lobectomy indicate that, in general, the left hemisphere is dominant for perception of speech (Kimura, 1961; Milner,

1958) while the right hemisphere is dominant for identification of non-verbal characteristics such as tonal pattern and quality (Milner, 1962; Shankweiler, 1966).

Techniques that employ simultaneous auditory stimulation to the two ears have provided an alternative (though possibly less precise) method of determining cerebral asymmetry. The advantage of the behavioral techniques is that they are applicable to the normal population; the disadvantage of the behavioral techniques has been the difficulty in producing reliable laterality effects. The main problem is that stimuli arriving at either ear are relayed to both hemispheres. Thus, in comparing the lateralization effects between the two ears, two factors must be considered: first, the degree of functional lateralization of the stimuli under study; and second, the degree of asymmetry in the representation of the two ears at the ipsilateral and contralateral hemispheres.

The Function of Ipsilateral and Contralateral Auditory Pathways

The ear asymmetry effect is generally observed with normal subjects only under conditions of dichotic stimulation (Dirks, 1964; Blakemore, et al. 1972; Kimura, 1961b, 1963, 1964, 1967; Kimura & Folb, 1968; King & Kimura, 1972; Treisman & Geffen, 1968; Satz, et al. 1967; Satz, 1968; Bradshaw, Nettleton & Geffen, 1971, 1972). This finding has been related to the following physiological evidence: first, there is a greater amplitude of evoked response to contralateral than to ipsilateral stimulation; and second, under binaural stimulation, the ipsilateral connections are partially occluded by the contralateral connections (Rosenzweig, 1951). Kimura (1961b, 1963, 1964, 1967) has been the foremost proponent of the position that competition in the form of dichotic stimulation of the two ears is necessary to demonstrate asymmetry of cerebral functioning. In her 1967 paper, Kimura summarizes her arguments. Palmer (1964) previously, and Bradshaw, et al. (1971) subsequently have presented additional data and arguments.

Briefly, the reason why competition in the form of dichotic stimulation of the two ears should be necessary for asymmetry of cerebral function to be demonstrated is as follows. Part of the answer seems to be that the auditory receiving area receives stronger signals from the contralateral auditory pathways than from the ipsilateral pathways (Rosenzweig, 1951; Tunturi, 1946; Bocca, Calearo, Cassinari & Migliavacca, 1955). Also, neurophysiological evidence indicates faster contralateral impulse passage in cats (Gross, Small & Thompson, 1967) and in man (Majkowski, Bochenek, Bochenek, Knapik-Fijalkowska & Kopec, 1971). In addition, there is a point of overlap between the contralateral and ipsilateral pathways at which the contralateral pathways are capable of occluding impulses arriving along the ipsilateral pathways (Rosenzweig, 1951; Hall & Goldstein, 1968; Kimura, 1961a, 1967; Milner, Taylor & Sperry, 1968; Sparks &

Geschwind, 1968). When different stimuli are presented to the two ears (as is the case with dichotic listening), the information arriving along the ipsilateral pathway is partially occluded; thus the already present advantage of the contralateral over the ipsilateral pathway is enhanced (Figure 4 diagrams the occlusion of the ipsilateral pathways). Finally, while the experimental evidence gathered so far all indicates that this "occlusion" occurs prior to the signals reaching the cortex (Bradshaw, _et_ _al_. 1971), Kimura (1967) has suggested that this occlusion at this level may not be the only place occlusion occurs. Kimura suggests that central occlusion occurs as well. For example, when two speech sounds must compete for overlapping pathways in one of the hemispheres, contralateral input may have an added advantage over ipsilateral input due to central competition occlusion. Further research is needed to see if this suggestion is supported by physiological evidence.

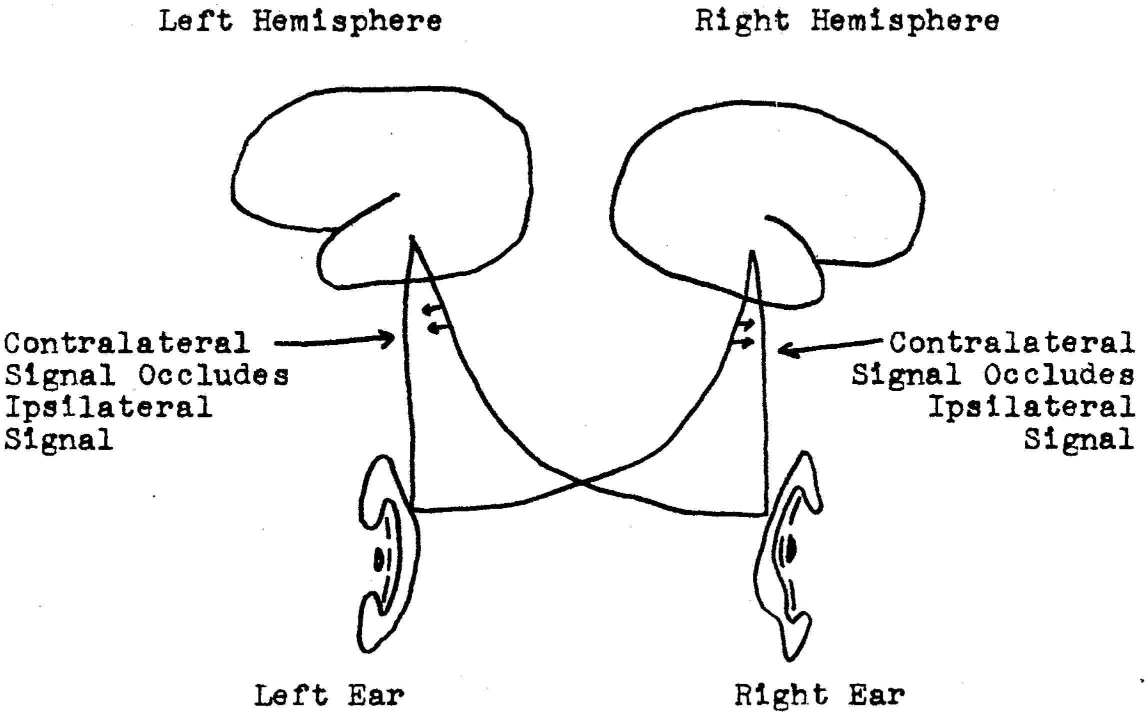

Figure 4. The Information Pathways from the Ears to the Cerebral Hemispheres

Simultaneous Versus Successive Presentation

The only way to achieve successive auditory presentation is produced by means of monaural stimulation. However as mentioned earlier, with monaural stimulation each ear projects information to both hemispheres. Therefore, laterality differences are very difficult to demonstrate since the hemisphere dominant for the task has approximately the same amount of information in approximately the same amount of time no matter which ear was stimulated. The only hope for demonstrating laterality differences monaurally lies in the fact that the contralateral pathways appear to project information from ear to hemisphere faster than the ipsilateral pathways (Rosenzweig, 1951). Given this difference in transmission times, information from the right ear arrives in the left hemisphere slightly ahead of the arrival of information in the right hemisphere (and vice versa for the left ear). Therefore, the hemisphere dominant for handling the presented information would have a slight temporal processing advantage over the opposite hemisphere and could therefore be identified by means of RT data. The foregoing discussion assumes that the difference in contralateral versus ipsilateral projection time is large enough to be picked up by an RT task.

Only a few experiments with monaural presentation have resulted in significant laterality effects (Simon, 1967; Bakker, 1967, 1968, 1970); however, Simon's results appear to be attributable to an ear preference bias rather than to an asymmetry of function effect. Kimura (1967) failed to find significant laterality effects as did Murphy and Venables (1970) and Satz (1968). Also, Palmer (1964) cites several studies with monaural presentations which failed to produce reliable asymmetry results. Thus, it seems that Bakker (1967, 1968, 1970) may stand alone in finding positive asymmetry effects with monaural stimulation. The reason for Bakker's unusual success may be his procedure. Bakker requires ordered recall, and it appears that ordered recall is extremely important in over-coming some of the biases present in auditory tasks (Satz, 1968). Also, it will be remembered that Hines, _et al_. (1969) were able to eliminate the scanning bias present in simultaneous visual presentations by using a fixed recall technique. Bakker has also found that rate of presentation, amount of stimulus material, and difficulty of stimulus material all help in the demonstration of asymmetry effects with monaural presentation. Thus it appears that, given successive (monaural) auditory presentation, many of the same factors involved in allowing demonstration of asymmetry effects given simultaneous visual presentation are necessary to demonstrate asymmetry.

On the other hand, simultaneous (dichotic) presentation in audition is about as successful and problem-free in producing asymmetry effects as is successive presentation in vision. It again appears that the asymmetry of function effect is sufficiently strong to overcome whatever various attentional and response influences there may be.

Before leaving this topic, challenges to the hypothesis that a functional asymmetry effect can be produced by dichotic listening tasks will be discussed. Oxbury, Oxbury and Gardiner (1967) have speculated that right ear superiority may be the result of an attentional bias toward the right ear when free recall methods are used. Treisman and Geffen (1968) have reached a similar conclusion. An attentional bias occurs when a subject focuses on the stimulation arriving at one ear to the exclusion or detriment of stimuli arriving at the other ear. This focusing can occur if the subject knows at which ear the stimuli will arrive or if the subject knows what type of stimuli are being presented (verbal versus non-verbal). In this latter case, attention will be directed toward the ear contralateral to the hemisphere dominant for that class of stimuli (Kinsbourne, 1970, 1972). Attention bias effects are generally studied by eliminating conditions that are seen as necessary for an attention bias, i.e., randomizing stimulus input and materials to the ears, to see if laterality effects are still present (Geffen, et al. 1972). Murphy and Venables (1970) found that while an attention bias can occur, its effects can be minimized; when this happens perceptual asymmetry is revealed. Satz (1968) concurs with this finding. He reports that while there is a tendency towards an attentional bias under free recall (subjects report stimuli from one ear before the other), in experiments where order of report has been controlled right ear superiority still prevails

(Bartz, Satz, Fennel & Lally, 1967; Bartz, Satz & Fennel, 1967; Broadbent & Gregory, 1964; Cooper, Achenbach, Satz & Levy, 1967; Satz, Achenbach, Pattishall & Fennel, 1965; Bryden, 1963). Satz (1968) argues that Oxbury, et al's results are due to improper design (too slow rate of presentation, low recall, and discrepent rate x recall interaction results). Treisman and Geffen's (1968) results appear to be a function of improper analysis of inter-ear competition (competition being necessary for ipsilateral occlusion).

Additional influences which impinge upon dichotic demonstration of functional asymmetry of the cerebral hemispheres are as follows. Different competing sounds produce differing ear effects, e.g., as the competing sounds in the right ear become more and more distorted from speech, the performance of the left ear progressively improves (Bradshaw, et al. 1971, 1972). Accuity differences between the two ears (due to either enhanced accuity for one ear or to an accuity deficit for one ear) produce larger laterality effects (Palmer, 1964). Actual or perceived intensity differences produce larger laterality effects (Gregory, Harriman & Roberts, 1972). Increased memory load produces increased laterality effects (Yeni-Komshian & Gordon, 1973; Bakker, 1970). The ability to form and retain an auditory image may have an effect on the production of laterality (Massaro, 1971). Finally, an experiment by Kinsbourne and Cook (1971) suggests to some extent that processing by the visual and/or tactile systems may unpredictably influence hemispheric lateralization for speech during dichotic presentation.

In summary, the relationship between cerebral asymmetry of function and the locus of auditory stimulation seems to be fairly well demonstrated (White, 1969; Blakemore, _et al_. 1972). In comparison to visual presentation, auditory presentation requires simultaneous competitive input to produce reliable laterality effects; this often complicates both design and interpretations (Bradshaw, _et al_. 1971). However, both visual and auditory presentation appear to be equally feasible in well designed studies.

Subject Variables

Age

Most studies of age have been concerned with finding the age at which hemispheric functions become specialized. In one of the first studies, Kimura (1963) tested children from age four on up in a dichotic listening task. She found that a significant right ear superiority for spoken digits appeared as early as four years of age. Knox and Kimura (1970) studied a group of children using both verbal and nonverbal stimuli. They found that with dichotic presentation, nonverbal stimuli were more accurately identified from the left ear while verbal stimuli were more accurately identified from the right ear. Knox and Kimura concluded that for their sample of children, the left and right hemispheres begin to show functional differentiation by age five; no obvious further development of the ear asymmetry was observed past this age. Knox and Kimura's (1970) findings seem to be at odds with the findings of Bakker (1967b) and Bryden (1970). Bakker (1967b) found that children of age six achieve better results with the left ear for nonverbal material, but show no difference in ear performance for verbal material. However, at and after age ten children show right ear superiority for both verbal and nonverbal material. Bakker interpreted his results as meaning that age ten might be regarded as a critical stage at which ear asymmetry becomes constant. It should be noted that Bakker (1967b) used monaural presentation while Kimura (1963) and Knox and Kimura (1970) used dichotic presentation. As noted earlier, the results of monaural presentations can easily be distorted by a right ear attention bias; this distortion may be a factor in Bakker's findings. Bryden (1970) used dichotic presentation. The difference between his study and those of Kimura (1963) and Knox and Kimura (1970) was that Bryden analyzed separately for handedness. Bryden (1970) found that in general, the percentage of subjects showing right ear advantage for verbal stimuli increases with age for right-handers and decreases with age for left-handers. This effect did not stabilize until about age 12 or 13. It is not known what Kimura's (1963) results or Knox and Kimura's (1970) results would have shown if they were analyzed separately for handedness.

However, there is support for Kimura's (1963) and Knox and Kimura's (1970) contention that functional asymmetry of the cerebral hemispheres is developed and stabilized by the age of four or five. Using the technique of sodium amytal injection, Wada and Rasmussen (1960) have found some data that suggest that if damage occurs to the language center hemisphere before the age of five, lateralization of the speech function tends to transfer and reorganize in the other hemisphere. However, if the damage occurs after the age of five, speech representation tends to remain in the damaged hemisphere rather than transfering to the unaffected hemisphere. In addition, Gazzaniga (1970) reports that interhemispheric communication is slight at birth and increases with age, with good communication seen around the ages of two to three.

McKeever and Huling (1970) performed an experiment in which they defined age differently; they defined age on the basis of reading ability. They tested seventh grade children who differed in reading ability. Half of the children had normal reading ability while the other half read at third grade level. The stimuli used were words and presentation was visual. The results indicated that words directed at the left hemisphere were recognized significantly more often in the RVF than in the LVF by both reading groups; however, no significant difference between the two reading groups was found. Thus, while previous studies have shown that chronological age is important in laterality effects, McKeever and Huling's (1970) results indicate that mental age (as defined by reading ability) is not a factor in laterality effects in their experiment.

One final study on age factors is worth reporting. Simon (1967) studied two age groups: (1) 18-25 (average age 20.6), and (2) 65-86 (average age 71.6). Simon found that although both age groups showed significant right ear advantage for verbal stimuli, the effect was not as great for the younger age group. However, the younger age group had faster RTs than the older group.

Sex

Lansdell (1964, 1967) has speculated that there are some left-right differences in the brain which become clear when the sex of the person is considered. For example, Lansdell has reinterpreted data on myelination of the brain, of venous drainage of the brain, and on length of the hemispheres in the brain. In all cases, Lansdell claims that the observations indicate that a person's sex is a factor in cerebral asymmetry of function; however, he admits that the statistics supporting the differences are not highly significant.

Darley (1967) points out that if one reviews the literature on language development and looks at the material concerning sex differences, one finds that the sex differences are generally not significant. If the differences are significant, the significance is usually due to case or group selection rather than to sex differences. But Lansdell (1961, 1962) has performed two studies that show statistically significant sex difference effects. The 1962 study indicated that based on pre- versus post-operative data from the Graves Design Judgment Test, underlying artistic judgment and verbal ability appear to overlap in the female brain but are lateralized in opposite hemispheres in the male. The 1961 study indicated that based on pre- versus post-operative proverb scores, verbal ability decreased after left temporal removal in males, but remained the same in females. Eisenson (1967) supports this latter finding. He reports that women do not show the same amount of linguistic and intellectual impairment following right brain damage as do men of comparable age. Eisenson's conclusion is that it takes more than a cerebral lesion in the right hemisphere to cause a woman to have any significantly measurable difficulty in speech production or comprehension. The same is not true for men. It is not reported by either Lansdell (1961, 1962) or Eisenson (1967) whether or not the male and female populations had equal numbers of same-sided speech dominance. Kimura (1969) reports that at least for Lansdell's (1962) study, some of the cases showed "atypical" cerebral dominance patterns.

In general, the study of male/female differences in lateralization for normal subjects has seemingly been ignored. Most studies reporting male/female comparisons report either no differences or inconsistent results. King and Kimura (1972) found no significant effects due to sex. Kimura (1969) found no sex differences for over-all accuracy of performance in detecting visually presented dots; however, males were significantly different from females in the lateralization of response to the location of these same dots. Also, Kimura (1969) found that several unpublished observations from her laboratory indicate that males and females sometimes (though not always) approach simple perceptual tasks differently; this difference tends to be related to a differential use of verbal and nonverbal systems. Finally, Simon (1967) reports some third order interactions involving sex differences that he does not know how to interpret. This last statement seems to typify the lateralization studies which involve the sex variable; even if significant differences are found, the differences are often impossible to interpret.

Age by Sex Interactions

A few studies have looked at the interaction of sex with age. These studies have assumed that the sex variable effect is so weak that it only shows its lateralization influence at an early age before the predominant adult lateralization pattern is firmly established. Ghent (1961), Bryden (1970), Kimura (1967), and Knox and Kimura (1970) have all found significant sex by age effects. Ghent (1961) demonstrated a lag in the development of somesthetic asymmetry in boys as compared to girls. Girls showed the adult pattern of asymmetry at six years of age while boys did not show the adult pattern until 11 years of age. Bryden (1970) found that for a dichotic listening task, the adult pattern of laterality was not achieved until the sixth grade for boys, but was achieved by the fourth grade for girls. Kimura (1967) found that girls showed a significant right ear superiority on a dichotic listening task from age five on up, while boys did not start showing a significant right ear effect until age six. Finally, Knox and Kimura (1970) have found that boys of age five are superior to girls of age five in identifying nonverbal environmental sounds in a dichotic listening task. It appears that the sex variable may be a consideration at early ages, but when the adult lateralization pattern appears it is questionable whether or not the sex variable has any significant influence.

Handedness

The origins of handedness and its relation to speech lateralization are still uncertain. Annett (1964, 1967, 1970a, 1970b) has been the foremost proponent of a genetic interpretation of handedness and speech laterality. Annett (1970b) discusses three main possibilities as to the genetic basis of lateral preference. First, inherited determinents of preference could be so weak in comparison to environmental factors that they can be discounted. Second, preference could depend on some relatively simple genetic mechamism which involves only a few alleles (paired genes giving rise to contrasting characteristics) whose expression is systematically distorted by environmental factors. That is, handedness is basically discrete but is blurred during growth. Third, handedness may involve many genetic factors, e.g., handedness would be analogous to height or intelligence rather than to a simple character such as eye color. Annett (1970b) thinks the third possibility is the most likely. This is a departure from her earlier position where she regarded both handedness and speech lateralization as being determined by two alleles, one usually dominant and the other imperfectly recessive (Annett, 1967). This earlier position was taken relative to the data that when handedness is classified in terms of right, left, and mixed, the percentages of these groups are in a binomial distribution relative to preference and skill. Her current position is based on newer findings (Annett, 1970a, 1970b) that give evidence that handedness demonstrates a continuum of preference which can be coordinated with a continuum of skill. Annett (1970a, 1970b) has supported her genetic model through studies that show that (1) handedness is related to parental and filial handedness, (2) in spite of the fact that today's environment has generally been geared to the benefit of right-handers, there is no evidence that the frequency of left-handers has decreased since historical times, and (3) both the distribution of hand preferences and relative manual speed between the ages of three and one half and 15 years of age remain surprisingly constant.

On the other hand, several authors emphasize learning over genetic factors. Gazzaniga (1970) presents one fairly speculative point of view which supports the learning position. Gazzaniga points out that the neonate starts out with a split or partially split-brain. As the child begins to explore his environment and manipulate objects, this will be done with a slightly greater frequency with the right than with the left hand. Gazzaniga gives no reason for this right-hand preference other than to state that experimental studies with monkeys suggest that this is true. When a child explores with the right hand, visual, auditory, or tactual engrams are established in the left hemisphere; with a left-hand set the engrams would be laid down in the right hemisphere. This occurs because the nerve pathways run contralaterally from hand to brain. Since more explorations are made with the right hand, the left hemisphere quickly develops a functional lead. Consequently, since the left hemisphere knows more, it asks more questions of its environment which in turn results in more right-hand exploration. Thus, hand use reinforces hemisphere use and vice versa. The net result is that the left hemisphere-right hand connection becomes more and more dominant in relation to interacting with the environment. Provins (1967) offers some support for this position. He notes that only when more complex movements are beginning to be acquired does consistent use of one hand begin to show itself. At this time 65% of infants favor the right hand (one year of age). At four to five years of age, 90% of the infants favor the right hand. Provins suggests that there is differential development of skill on the two sides depending on previous experience.

The foregoing discussion has provided some idea as to the complications encountered in defining the origin of handedness. One difficulty mentioned was that instead of being laterally discrete, handedness appears to be a graded phenomenon. However, Annett (1970b) points out that despite recognition that manual preferences are not discrete, discussions of handedness continue to imply that left and right handedness are clearly distinct phenomena. In addition, lateral hand preferences, by and large, continue to be ascertained through particular actions which are themselves discrete and occur in discrete combinations, e.g., writing and hammering; thus it is inevitable that hand preference is seen as discrete. Satz, _et_ _al_. (1967) points out that another complicating factor is self report which is usually both discrete and unreliable.

Benton (1962) has used a test of manual dexterity to ascertain the relative handedness of a group of self-reported strongly right-handed subjects and a group of self-reported strongly left-handed subjects. Benton's findings indicate that while self-report did have some relationship to manual dexterity, there was considerable individual variation. While a majority of the self-professed right-handers did show marked superiority of the right hand, 16% showed only slight superiority and 12% showed either equal dexterity or left-hand superiority. The results are even more variable for the self-professed left-handers. The majority showed equal dexterity or only slight left superiority, while about 25% showed better performance with the right hand. Satz, _et_ _al_. (1967) performed a somewhat similar analysis and found comparable results. It seems reasonable to conclude that right-handers are more strongly right-handed than left-handers are left-handed.

Some authors feel that the difficulty in relating handedness to speech dominances is a result of over-looking the graded function of handedness (Annett, 1970a, 1970b; Satz, _et al_. 1967; Benton, 1962). However, many authors simply ignore the issue or else use exclusively right-handers on the basis of Branch, Milner, and Rasmussen's (1964) findings (using amytal injection) that approximately 90% of self-professed right-handers had speech lateralized in the left hemisphere, while only 60% of self-professed left-handers had speech lateralized in the left hemisphere.

Satz, _et al_. (1967) tried to systematically grade handedness by means of tests, and then to relate this test-determined handedness to lateral dominance for speech as determined by a dichotic listening test. Satz, _et al_. (1967) found that the variables of self-report of hand preference and the dichotic test are not independent. However, their relationship was found to be small and consistent with previous findings based on amytal injection. Test-classified hand preference had a strong relationship to speech laterality (speech represented contralaterally to the dominant hand) as defined by the dichotic test. There were exceptions to the relationship although the frequency of these cases was not high. The exceptions consisted of test-classified right- and left-handers who had speech representation on the same side as the dominant hand. Further analysis indicated that 56% of the right-handed exceptions and 57% of the left-handed exceptions had a family history of left-handedness. Satz, et al. (1967) suggested that this finding may indicate a hereditary independence of speech and hand lateralization. Although the methods of this study are far superior to other work in this area, further improvement might be made by grading speech lateralization by means of differences in dichotic scoring. Thus results could be correlated based on the graded hand and speech scores rather than on a discrete version of hand and speech laterality.

Dimond and Beaumont (1972) approached the problem of the relationship between handedness and cerebral dominance from a different point of view. They felt that if the hand is representative of the functions of the hemisphere by which it is controlled, then an influx of information to the hemisphere should overload the information processing ability of that hemisphere and thereby interfere with simultaneous performance by the hand. The results indicated that influx of information to the visual hemisphere does not interfere with simultaneous hand performance. Since Dimond and Beaumont (1971) had previously found that the exercise of bimanual skill interferes with the influx of visual information to the cerebral hemispheres, Dimond and Beaumont (1972) concluded that control of unimanual hand function can be switched from one hemisphere to the other as need arises. That is, the hemispheres are not locked into an unchanging dominantsubordinant relationship with hand function.

Kinsbourne and Cook (1971) experimented along somewhat similar lines. After practicing, they had subjects balance a dowel rod on the left and then on the right index fingers, first while silent and then while carrying on a unilateral conversation. Compared to the silent condition, the speaking condition yielded shorter balancing times for the right hand but longer times for the left hand. Kinsbourne and Cook interpreted these findings as indicating the occurance of a mutual interference between the main and secondary tasks in the left hemisphere, thereby setting up an over-all decrement of performance of the right side. The superior performance of the left side was felt to be related to the fact that speaking produced just enough distraction to avoid full attention to the balancing. Kinsbourne and Cook noted that full attention to the mechanics of a practiced task is often detrimental to performance.

The previous discussions have indicated some of the difficult issues involved in investigating the relationship between handedness and cerebral lateralization of function. Thus, it does not seem too surprising that the results of studies which have attempted to demonstrate a relationship between handedness and cerebral laterality show that about as many studies fail to find a relationship as do find a relationship. Some of the studies that did not find a relationship are as follows. Rizzolatti, _et al_. (1971), using visual presentation for letter and face discriminations, found no relationship between lateralization and handedness. Treisman and Geffen (1968), using auditory presentation for speech messages, found no relationship between the degree of hand and ear asymmetry. McKinney (1967), using visual presentation for a perceptual stability task, found that the lateral difference which occurred was not related to handedness. Kimura (1967), using auditory presentation for a digit recognition task, found no relationship between ear pattern and handedness. Finally Curry (1967), using auditory presentation for verbal and nonverbal identification tasks, found no relationship between laterality effects and handedness for groups that showed either normal cross-lateral effects or homo-lateral effects.

On the other hand, studies that have found a significant relationship are as follows. Bakker (1970), using auditory presentation for verbal and nonverbal material, found that ear asymmetry effects increase with age for right-handers. Bryden (1970), using auditory presentation for verbal material, found a significant relationship between laterality effects and handedness for older children. Finally, as reported earlier, Satz, et al. (1967) found a significant relationship between handedness and speech laterality.

It appears that the definitive study relating handedness and cerebral lateralization of function cannot be performed until the nature of handedness itself is better understood. The present data indicate that the best way to avoid handedness complications in laterality effect experiments is to follow the lead of Satz, et al. (1967). First, collect a group of self-reported right-handers; eliminate any with a familial history of left-handedness; finally, give the remaining group the Satz, et al. (1967) handedness test battery and eliminate all but the highly right-handed scorers.

Stimuli and Laterality Effects

So far in the present paper the two cerebral hemispheres have been labelled dominant-nondominant, speaking-mute, verbal-nonverbal. Also, it was mentioned that these labels have a history extending from the time of Broca and Dax, through the "experiments of nature" studies, the amytal injection studies, and the surgical studies--particularly "split-brain" surgery. Through all this history though, exact definitions of what is verbal and what is nonverbal have not been agreed upon. To say that verbal stimuli exist, and that verbal precesses are secured in the left hemisphere of the brain begs the question of definition; it is still not clear of what verbal activity consists. For example, Bryden (1966) suggests geometric forms are nonverbal; but certainly verbal labels can be affixed to these forms. At the point where the labels are affixed do the geometric forms suddenly become verbal stimuli, or do they remain nonverbal stimuli? Along the same lines, the nonsense syllable, although containing elements used in "meaningful speech", may not evoke any degree of conceptualization. What makes the lateralization studies on normal subjects important is that they are able to gather meaningful data on issues such as those mentioned above. The findings of lateralization studies relative to verbal-nonverbal stimuli and right/left hemispheric processing will now be reviewed.

Verbal Stimuli

Kimura and Folb (1968) found that when two reversed playback sounds of recorded speech are presented dichotically to the left and right ears of subjects and when these same subjects were exposed to four more backward sounds from which they were to select the two sounds they originally heard, the sounds arriving at the right ear were more accurately identified than those arriving at the left ear. Based on this finding Kimura and Folb suggest that the neural mechanisms underlying perception of linguistic sounds are not differentiated along the lines of meaningfulness, familiarity, or conceptual content. Bryden (1970) in a similar study, used words and word approximations (fourth order approximations to English) and found RVF (left hemisphere) superiority for both types of stimuli. This finding appears to support Kimura and Folb's (1968) finding and analysis as just presented. Barton, et al. (1965) found that Hebrew and English words were better recognized from a list of four alternatives in the RVF (left hemisphere) than in the LVF by both Israeli and American subjects. Since Hebrew is read from right to left, and since Hebrew words tend to be very unfamiliar to Americans, this finding not only supports the hypothesis that words are indeed "verbal" stimuli, but it also supports the two previous studies in finding that alphabetic and/or linguistic sound stimuli are also "verbal" stimuli.

Disagreeing slightly with the previous conclusion, Gibson, et al. (1972) have offered three alternative hypotheses as to the nature of word processing. Gibson, et al. (1972) admit that word processing relies heavily on language related factors. However, they note that much spatial analysis must take place during the early stages of word recognition, and spatial processing has traditionally been viewed as a right hemisphere function. Thus, three hypotheses should be considered: (1) the LVF should be superior for word recognition under some conditions; (2) perhaps there is no such thing as general spatial ability; therefore the left hemisphere has a special ability to handle spatial configurations related to verbal material while the right hemisphere is better at handling spatial configurations related to faces, shapes and the like; (3) possibly both hemispheres work together in handling complex stimuli; thus, procedural variables dictate unequal contributions from the two hemispheres at various times resulting in asymmetry effects. Gibson, et al. (1972) tested these hypotheses using a perceptual word-matching technique. They found a LVF (right hemisphere) superiority for this task and interpreted this result as meaning that word recognition is a multistage process involving both physical-spatial and linguistic properties. Treating a word as a verbal stimuli appears to be justified only when the task stresses language related properties.

Moscovitch and Catlin (1970) and Fudin (1969, 1970) found a RVF (left hemisphere) superiority for responding to letter stimuli suggesting that letters are verbal stimuli. Also, in all three experiments, deflated scores occurred for letters that had structural similarities. Fudin (1970) suggested that in addition to verbal properties, letter structure may be an important variable in letter recognition and hemispheric asymmetry. This suggestion is a multistage process. It may be that letter recognition is also a multistage process. Moscovitch (1972) has shed some light on this issue. He had subjects scan a memory set of one or six letters for the presence of a visually presented test letter. Moscovitch found that the RT was shorter for LVF (right hemisphere) test letters when the memory set contained only one letter and was shorter for RVF (left hemisphere) test letters when the memory set contained six letters. Moscovitch suggested that subjects perceptually match the set and test letters when the set contains only one letter and verbally match the set and test letter when the set contains six letters. Moscovitch's finding adds a new dimension to Gibson, *et al*'s finding; namely, it is not always clear what determines the verbal and/or nonverbal nature of a task.

Digits would seem less likely than words or letters to stress language related properties; yet asymmetry of function studies find that digits are processed faster in the RVF than in the LVF (Hines, *et al*. 1969; Satz, *et al*. 1967; Geffen, et al. 1971) or by the right ear (Kimura, 1964, 1967). Both Kimura (1967) and Geffen, et al. (1971) have speculated that the process of naming the digits might be the basis for the asymmetry effect favoring the left hemisphere. Each performed an experiment to test this assumption, and they both found that naming was a factor. Kimura (1967) has suggested that digits have their own unique articulatory experience, and it is this articulatory experience which produces the left hemisphere laterality effects. Geffen, et al. (1971) used visual presentation to require their subjects to use a nonsense verbal response to identify digits. This meant that the subjects probably responded to the digits as flashing lights rather than as the unique articulatory experience of the digit names. No laterality effect was found. This result was taken to be supportive of the idea that the phenomenon of "naming" is necessary to produce a left hemisphere laterality effect.

Given that digits are processed in the left hemisphere due to their unique articulatory properties, the question now arises as to whether or not all phonetic elements or all features of phonetic elements are processed in the same way. Abbs and Smith (1970) have suggested that left hemisphere dominance for any stimulus is related most decisively to unique components of speech, specifically those components that demand the greatest precision of motor control, e.g., the articulatory components. Haggard (1971) studied the lateralization of speech signals that varied in their acoustic and phonetic properties, i.e., stop consonants, semivowels, and vowels. The results indicate that a complicated "encoded" relationship between the acoustical stimulus and the response phoneme is a necessary condition for producing a right ear advantage; simple acoustical properties are not involved while encoding seems to be a necessary stimulus property. Adding an element of encoding to vowels produces a right ear advantage. This right ear advantage is not present with vowels that do not possess this element of encoding. The nature of encoding is as follows. In acoustical terms, the more highly encoded sounds undergo more restructuring as a function of neighboring phonemes. In psychological terms, these sounds require special processing in order to be perceived. Stop consonents appear to be the most highly encoded speech sounds and vowels the least; liquids ("r" or "l") fall somewhere in the middle. Day and Vigorito (1973), Cutting (1973), Shankweiler and Studdert-Kennedy (1967), and Studdert-Kennedy and Shankweiler (1970) have presented data that bears upon the above findings and conclusions of Haggard. Day and Vigorito (1973) have found that some speech sounds are more highly encoded (more lateralized) than others. Day and Vigorito used stops, liquids, and vowels in a dichotic listening test. They found that stops showed a large right ear advantage, liquids showed a lesser right ear advantage, and vowels showed a left ear advantage. Cutting (1973) also tested stops, liquids, and vowels on a dichotic listening task. He found a large right ear advantage for stops, a lesser left ear advantage for liquids and no ear advantage for vowels. The results of these two studies suggest the operation of a "special speech processing mechanism". This "mechanism" could be the same as Haggard's "trigger feature".

Shankweiler and Studdert-Kennedy (1967) studied a set of six stop consonant syllables which differed according to features of voicing and place of articulation. For a dichotic listening task they found a significant right ear advantage for synthetic consonant syllables but not for synthetic steady state vowels. The effect was greater for consonant-vowel pairs differing on two articulatory features than for pairs differing on just one. This last finding suggests that the perception of such consonant syllables may involve feature analysis.

Finally, Studdert-Kennedy and Shankweiler (1970) studied spoken consonant-vowel-consonant syllables presented in dichotic pairs. These pairs differed in only one phoneme (initial stop consonant, final stop consonant, or vowel). Significant right ear advantage was found for initial and final stops and for the articulatory features of voicing and place of production. No ear advantage was found for vowels. Based on these findings, Studdert-Kennedy and Shankweiler suggested that specialization of the dominant hemisphere for speech perception is due to possession of a "special linguistic device" and not to specialized capacities for auditory analysis. Also based on these findings, they have concluded that while a general auditory system common to both hemispheres equipped to extract auditory parameters of a speech signal exists, only the dominant hemisphere appears to be specialized for the extraction of linguistic features from those parameters.

The above statements by Studdert-Kennedy and Shankweiler suggest a lack of linguistic processing ability for the nondominent hemisphere. Gazzaniga (1970) has done an in-depth analysis of the linguistic processing ability of the right hemisphere. His results appear to be at variance with Studdert-Kennedy and Shankweiler's conclusion. A brief summary of Gazzaniga's analysis will now be presented. Information perceived and/or generated exclusively in the minor (right) hemisphere cannot be communicated either in speech or in writing; the right hemisphere is mute. Thus, linguistic expression is organized exclusively in the left hemisphere. The comprehension of language (spoken and written) is found in both the minor and major hemispheres with the minor hemisphere being less proficient in this respect.

The minor hemisphere was tested for language comprehension. Comprehension was demonstrated by having the subjects point to the correct answer presented as one item among an array of incorrect items. The results are as follows. Noun-object words were best comprehended, adjectives were second-best comprehended, and there was no evidence that comprehension of verbs occurred at all. Comprehension of words was as good for visual presentation as for auditory presentation. Also, the minor hemisphere was capable of making spelling responses for words. Thus, the minor hemisphere has some capability for competing with the major hemisphere for the processing of verbal stimuli and yet asymmetry studies consistently show a major hemisphere dominance for processing these stimuli. This possible complication has been ignored for the most part.

Nonverbal Stimuli

Most nonverbal stimuli have been examined as part of comparison experiments. That is, the experiments compared two or more stimuli that were felt to vary as a function of verbalness. Three experiments that investigated nonverbal stimuli disjunctively will be discussed first, then the comparison studies will be examined. Kimura (1969) performed an experiment in which a series of dots was presented tachistoscopically to either the right or left visual field. Subjects were to detect the dots and then to localize them on spatial maps depicting all of the dot locations presented. The results indicated that a dot can be more accurately located when presented to the LVF (right hemisphere), and simple dot detection was not more accurate for one visual field than for another. Thus, the difference between fields in the locating of dots does not appear to depend on the detectability of a dot. Kimura concluded that the LVF superiority for dot localization is probably due to better visuospatial processing ability for the right hemisphere than the left. If this conclusion is accurate, then visuospatial ability appears to be a "nonverbal" ability (or vice versa).

Gregory, et al. (1972) have found a cerebral dominance effect for the perception of rhythm. Subjects listened to pure tone stimuli presented alternately to each ear. On one ear the stimuli were presented precisely every 1000 msecs. On the other ear the timing could be adjusted over a range from 430 to 570 msecs. The subjects adjusted the timing of the stimulus second tone so that the perceived rhythm was completely regular for both ears. The results indicated that the tones to the right ear were delayed relative to the tones to the left ear; this suggested that the right hemisphere is involved in the perception of rhythm. It appears that rhythm perception is a "nonverbal" ability.

Dimond and Beaumont (1972) asked subjects to perform calculations with two-digit numbers persented to either the RVF or the LVF. The results indicated that there was no difference in response latencies between the hemispheres. However, fewer errors were associated with presentations to the LVF indicating a right hemispheric dominance for calculation tasks. Dimond and Beaumont concluded that the failure to find a significant difference in response latency was quite likely due to the long interstimulus interval used to permit the calculations to be completed before an answer (true half the time/false half the time) was required. Results somewhat contradictory to Dimond and Beaumont's are related by Gazzaniga (1970). He indicated that the right hemisphere has computational ability, but this ability appears to be limited in comparison to the left hemisphere.

However, Gazzaniga's results are based on tactual presentation of relatively simple calculations. It may be that tactual presentations bias the results, or that simple calculations are not sufficient to produce the full effect, or both. The question of cerebral dominance for calculation appears to be open for the time being.

Experiments concerned with comparing supposed verbal and nonverbal stimuli will now be considered. White (1971) compared capital English letters (verbal) with lines presented in different orientations (nonverbal). The stimuli were presented to the LVF and RVF. The results indicated that, for both types of stimuli, a significant RVF superiority was found (this was in spite of simultaneous presentation which usually biases the results in favor of the LVF). White felt that the results indicated a commonality between the perception of line orientation and the perception of letters. For example, the distinction between an A and an H is the orientation of the two side elements. Thus, the left hemisphere may have dominance over selective contour-tuning apparati such as those described by Hubel and Wiesel (1965) in addition to its dominance over linguistic processing elements.

Klatzky (1970) performed a memory-matching experiment similar to Moscovitch's (1972) experiment. Instead of just letter stimuli however, Klatzky used both letter (nonverbal) and picture (verbal) stimuli. The reason the letter stimuli were considered nonverbal is that the task required that the presented letter be matched with the presence of absence of the same letter in a memory set. The reason the picture stimuli were considered verbal is that the task required that the picture be named and then matched to the presence or absence of a letter in the memory set. The letter in the memory set had to be identical to the first letter in the picture name to be considered a match. The results indicated the following. Unlike the Moscovitch (1972) experiment, hemispheric asymmetry did not change as a function of memory set for the letter stimuli. For all memory set sizes (2-5 letters) the LVF (right hemisphere) presentation was superior to RVF presentation. For pictures, with the smaller memory set (two letters) RVF (left hemisphere) superiority was found; with the larger memory sets (3-5 letters) LVF superiority was found. These results indicate that the subjects changed from verbal processing (smaller memory set) to nonverbal processing (larger memory set). Klatzky was unable to offer a strong explanation for this processing shift. One possible explanation is that imagery is used in some way for the larger memory set; Seamon and Gazzaniga (1973) have found superior right hemisphere processing for imagery during memory tasks.

Rizzolatti, et al. (1971) compared letters (verbal) with faces of unknown persons (nonverbal). The results indicated a RVF (left hemisphere) superiority for letters and a LVF superiority for faces. The results were interpreted as supporting the idea of dual functional cerebral asymmetry.

King and Kimura (1972) compared hummed melodies (nonverbal) with human non-speech sounds, e.g., laughing and crying (unpredicted). The results indicated that both melodies and non-speech sounds had left ear (right hemisphere) superiority. King and Kimura concluded that since the same articulatory musculature is used in humming non-speech sounds as is used in producing speech, the right hemisphere can and does process auditory stimuli. This processing would be very similar (though not identical) to the auditory processing in the left hemisphere associated with speech stimuli. King and Kimura were not certain whether this hemispheric differentiation is based on acoustic or on articulatory patterns, or even if those two processes can be separated.

Curry (1967) compared three dichotically presented stimuli: (a) words (verbal), (b) nonsense words (nonverbal), and (c) environmental sounds (nonverbal). The results indicated that there was a right ear (left hemisphere) superiority for words and nonsense words and a left ear superiority for environmental sounds. This finding was felt to support the dual asymmetry of cerebral function hypothesis. Curry concluded that since words and nonwords have an obvious similarity, namely phonemic properties, that the left hemisphere may have a specialized phoneme sensitive analyzer.

Kimura (1967) reported two comparison studies. In the first study, digits (verbal) and melodies (nonverbal) were compared. The results indicated a left ear (right hemisphere) superiority for melodies and a right ear superiority for digits as expected. The second study compared familiar but unnamable melodies with unfamiliar melodies and with digits. The results indicated a left ear superiority for both familiar and unfamiliar melodies, and a right ear superiority for digits. Kimura concluded from these two studies that familiarity, of itself, does not appear to be a crucial factor in hemispheric specialization of functioning.

The foregoing studies indicate that stimuli can be classified, with a relatively strong degree of reliability, as being either verbal (processed by the dominant hemisphere) or nonverbal (processed by the nondominant hemisphere). However, two very important complicating factors have been noted: (1) task requirements, and (2) the ability to name the stimulus. Gibson, _et al_. (1972) demonstrated how task requirements could overcome typical asymmetry of processing. Moscovitch (1972) demonstrated that the task requirements that function in an experiment are not always readily apparent to either the experimenter or the subjects. Two other experiments have investigated the relationship between task requirements and stimulus processing asymmetry. The first experiment was performed by Geffen, _et al_. (1972). The stimuli stayed the same for two different kinds of tasks. The stimuli were letters and the two tasks were physical versus name matches along the lines studied by Posner and Mitchell (1967). The results indicated that letters which were "name matched" were responded to most quickly when presented to the RVF (left hemisphere) whereas the stimuli which were "physically matched" were responded to most quickly when presented to the

LVF. Geffen, et al. (1972) concluded that task requirements are more important than the type of stimuli in determining hemispheric asymmetry. The second experiment was performed by Haggard and Parkinson (1971). The experiment was composed of two studies. In the first study, stimuli that differed in processing asymmetry (left hemisphere versus right hemisphere) were varied while the task requirement (one favoring a right ear advantage) remained the same. The experimental question was: will the task influence the stimuli thereby producing an over-all right ear advantage, or will the properties of the stimuli overcome the task influences thereby retaining a left ear advantage? The results indicated that a right ear advantage was obtained for both stimuli. The second study investigated the opposite side of the coin: what happens when the task requirements are varied so as to produce differing asymmetry of hemispheric processing while the only stimuli used are ones with characteristics favoring right ear advantage? The results indicated both left and right ear advantages for the stimuli thereby supporting the idea that the task requirements are of prime importance in determining ear advantages. If task requirements were not of prime importance, then the left ear advantage would not have appeared. Haggard and Parkinson offered the over-all conclusion that in experiments capable of giving either a right ear advantage or a left ear advantage, the nature of the task requirements appear to exert a greater influence than stimulus attributes. The importance of carefully ascertaining both the nature of the task requirements and the stimulus attributes before proceding with any kind of asymmetry of function experiment cannot be overemphasized.

On a related issue, it has been pointed out by Kimura (1966, 1967) and by Geffen, et al. (1971) that the ability to give a nonverbal stimulus a name may alter the supposed nature of the stimulus, e.g., make a nonverbal stimulus a verbal stimulus. Bryden and Rainey (1963) performed an experiment relevant to this issue. They compared three types of stimuli for asymmetry of processing: (a) letters (verbal), (b) geometric forms (nonverbal), and (c) outline drawings (nonverbal). The results showed a RVF (left hemisphere) superiority for all three types of stimuli; however, the effect was graded. RVF superiority was greatest for the letters and least for the geometric forms. Bryden and Rainey interpreted these findings as indicating that the subjects tended to name the drawings and forms rather than process them for their spatial properties. They concluded that the naming of the objects and forms was what produced the RVF superiority. The fact that letters, objects, and forms have differing tendencies to be named accounts for the graded RVF superiority effect. Thus, the tendency of a stimulus to have a name applied to it appears to be an important consideration when selecting stimulus materials for experiments in which the investigation of the asymmetry of cerebral functioning is concerned.

In summary, it appears that, in general, stimuli can be classified as either verbal or nonverbal. It also appears that verbal and nonverbal stimuli are sent to different processors, each of which performs its analysis independent of the other (Day & Bartlett, 1971). Unknown as yet is the nature of these processors. Also unknown is the exact nature of the selection of the stimulus attribute mechanisms of these processors that allow stimuli to be processed as "verbal" or "nonverbal".

Response Tasks and Modes

The dependent variable (response task) employed in the asymmetry of function experiments with normal subjects has traditionally been of two general types: (1) correctness of memory responses, or (2) reaction time (RT). The sensory modes (response modes) utilized in obtaining the memory responses or RTs also have traditionally been of two kings: (1) vocal, or (2) manual.

Memory Responses

Three basic types of memory responses have been discussed in the lateralization literature: (a) recall, (b) memory matching, and (c) choice recognition. Recall consists of reporting the identity of an item or group of items previously presented either visually or auditorily. The identity of an item is usually its name. Many authors report achieving significant and meaningful results using this type of response task (Markowitz & Weitzman, 1969; Fudin, 1969, 1970; McKeever

& Huling, 1971; Curry, 1967; Haggard & Parkinson, 1971; White, 1971; Bryden & Rainey, 1963; Palmer, 1964; Barton, et al. 1965; Hines, et al. 1969). However, there are problems with this type of response task (these problems have been discussed thoroughly in other contexts). Report order biases (Hines, et al. 1969), scanning/accuity biases (Fudin, 1969, 1970), and naming biases (Bryden, 1963) have all been found. In spite of possible complications of these biases, memory report is still a very reliable and useful response task.

Memory matching consists of presenting one or more protocols to be held in memory; a test item is than presented and the subject makes a judgment as to whether or not the test item matched any of the memory protocols for a given characteristic. This method of responding has been reported by some authors as producing large and reliable laterality results (Dimond, et al. 1972; Gibson, et al. 1972). As was reported earlier in other contexts, there are problems with this type of response task. Gibson, et al. (1972) pointed out that these task requirements often have a stronger influence on the laterality effects than do the stimulus attributes under study, and Moscovitch (1972) and Klatzky (1970) have demonstrated that protocol size has large and sometimes unpredictable effects on laterality. This method of responding has been used in other contexts for some time (Sternberg, 1966) but is relatively new in the laterality effects literature; however, it appears to be a promising tool for studying laterality effects.

Choice recognition consists of presenting one or more test stimuli to one hemisphere or the other and then presenting a multiple choice recognition task to see if a subject can correctly choose the test stimuli from among the choices given. Superior recognition is taken to mean superior processing by that hemisphere. Kimura seems to be the main proponent of this type of response task, and she reports obtaining significant laterality effects using it (Kimura & Folb, 1968; King & Kimura, 1972; Kimura, 1967). The advantage of this type of response task is that report order biases and naming biases can be controlled to some extent (though not always completely) by either ordering or randomizing the presentation of the multiple choices.

One final consideration that may or may not be a problem when using memory responses is that in many cases (though not always) memory responses require that the response is verbal. Verbal responses must always be made through the left hemisphere since the right hemisphere is mute. This necessity for channelling the response through the left hemisphere may interfere with and/or cancel out some laterality effects (Geffen, et al. 1971). However, as mentioned, most authors are not finding that verbal responding produces any abnormal or interfering effects. It should be noted that memory responses are almost a necessity for laterality experiments using auditory presentation; the other response alternative, RT, is not viable for most of the experiments because of the dichotic presentation. The difficulty is having the subjects respond to a processed signal rather than the onset of its sound, and in addition having the subjects respond to the test stimulus rather than the distractor stimulus or a fusion of the two.

RT Responses

As just mentioned, RT responses are used almost exclusively in laterality experiments having visual presentation. RT seems to be a consistently reliable response measure. Almost all of the authors who report using RT, report strong and meaningful laterality effects (Rizzolatti, *et al*. 1971; Geffen, *et al*. 1972; Klatzky, 1970; Moxcovitch & Catlin, 1970; Moscovitch, 1972; Simon, 1967; Murphy & Venables, 1969, 1970; Filbey & Gazzaniga, 1969; Efron, 1963a, 1963b; Jeeves, 1969; Dimond & Beaumont, 1972).

The rationale behind the use of RT is fairly simple. Since each visual field projects directly to the contralateral hemisphere, the RT to the stimuli presented to the half-field projecting to the hemisphere processing the stimuli and/or emitting the response should be faster than for stimuli presented to the opposite field. The difference in RT should be equivalent to the time it takes a stimulus to cross the corpus callosum. The same principle appears to work with certain kinds of auditory presentation tasks, e.g., disjunctive RT tasks (Murphy & Venables, 1970) where a white noise is presented dichotically along with the target stimulus. The white noise tends to occlude the ipsilateral pathways;

therefore, each ear effectively stimulates only the opposite hemisphere, and RT is equivalent to the transcallosal crossing time. There are problems with RT responses and auditory presentation however. Bradshaw, *et al*. (1971, 1972) have demonstrated a dramatic decrease in the ear asymmetry effect as the competing stimulus is changed in characteristic from the target stimulus, e.g., word-word to word-music to word-white noise). In fact, Bradshaw, *et al*. (1971) failed to achieve significant effects with white noise as the competing stimulus. Thus, it would appear that the optimum condition for achieving accurate laterality effects with auditory presentation is when two stimuli with similar characteristics, e.g., two words, compete. The problem with using the RT measure under these conditions is that an instructional set of some kind, e.g., look for property "X", would be necessary in order for subjects to be able to properly select the target word from the competing word when responding; a set of this kind may bias the asymmetry effects by priming the subject's response (for a discussion of priming biases see Kinsbourne, 1970).

Vocal and Manual Responses

With the memory response measures, a vocal response is used almost exclusively. A vocal response is needed so that the experimenter can determine the correctness or incorrectness of the responses. One exception to this generality is the study by Haggard and Parkinson (1971). They used a written response.

With the RT measure, a vocal response is seldom used. Moscovitch and Catlin (1970) and Filbey and Gassaniga (1969) are about the only investigators to use both RT and vocal responding. The other investigators use some kind of manual response, e.g., key pressing (Geffen, _et_ _al_. 1972; Rizzolatti, _et_ _al_. 1971; Murphy & Venables, 1970; Klatzky, 1970; Simon, 1967; Dimond & Beaumont, 1972), or finger touching (Moscovitch, 1972). The key pressing has been tried in a variety of ways--one finger and one hand only, alternating hands, alternating fingers and hands, and using two fingers and two hands at the same time. All these methods seem no better or no worse than one another for obtaining laterality effects. However, there is some controversy concerning the use of these responses versus vocal responses. Bradshaw and Perriment (1970) have found differences in RT for both hands and fingers. The hand ipsilateral to the visual field in which a target stimulus was presented yielded a faster RT than the contralateral hand. In addition, subjects responded faster with their index fingers than they did with their middle fingers. Either of these differences could bias asymmetry effects. However, the finger difference result may have been an artifact of Bradshaw and Perriment's procedure since Geffen, _et_ _al_. (1972), using a similar procedure, found the index finger to be slower than the middle finger--though not significantly so. Gazzaniga (1971) warns that manual responses can unnecessarily complicate laterality interpretations or even neutralize the laterality effects. However, Moscovitch and Catlin (1970) point out that Gazzaniga's criticism would probably apply only to gross hand movements and not to finger responses. Moreover, the plethera of studies achieving significant results using manual responses should allay any fears about manual responses.

Geffen, _et_ _al_. (1971) presented a series of studies comparing vocal and manual responses. The results indicated that manual responses may be superior to vocal responses at least when RT measures are used. Geffen, _et_ _al_. found that faces showed the expected LVF superiority when a manual response was used, but no laterality effects when a vocal response was used. In addition, digits showed the RVF superiority for both manual and vocal responses. Finally, when subjects were required to make an undifferentiated verbal response ("bonk") to the digits, no laterality effects were produced. It appears that vocal responses, since they must be initiated by the left hemisphere (the right hemisphere being mute), might bias the RTs. LVF RT superiority for nonverbal stimuli such as faces or unnamed digits can be eliminated by the necessity of transferring the information to the left hemisphere to be reported. That is, even though stimuli are processed in the right hemisphere, they cannot be reported until the information is transferred to the left hemisphere thus eliminating the advantage of faster processing. On the other hand, with verbal stimuli the RVF RT superiority for the processing of the stimulus combines with the left hemisphere reporting ability and the end result is a strong positive RVF laterality effect. No such similar criticisms can be made about the manual responses; they produced the expected laterality results under the same conditions that the vocal response produced the atypical results.

The question now arises as to why similar biases have not been observed with vocal memory responses. The answer seems to reside in the nature of the response task. Typically in an RT task, a nonverbal stimulus arriving in the left hemisphere primes the vocal responding mechanism. At the same time, it signals the right hemisphere to transfer just enough information about the present stimulus so that it can complete the already primed vocal response. On the other hand, a nonverbal stimulus arriving at the right hemisphere must first undergo a fairly thorough processing before being transferred to the left hemisphere. When this information finally is transferred to the left hemisphere, the vocal responding mechanism can then be primed to emmit the proper response. Therefore, the only place the left hemisphere looses processing time in relation to the right hemisphere is in signaling the right hemisphere for information. However, this loss of time is compensated for by the greater processing time consumed by the right hemisphere when it initially receives the stimulus (as opposed to when it is only asked for specific information about that stimulus). The end result is no difference in laterality for nonverbal stimuli when using a vocal RT response. However, when a vocal memory response is required, the speed of the response decreases in importance. Therefore, the greater processing the right hemisphere performs increases in importance. The greater processing means more information upon which memory decisions can be made. This results in superior memory responses for the right hemisphere for nonverbal stimuli and the laterality effects are observed as expected. The RT process works similarly for verbal stimuli, but since verbal stimuli are processed in the left hemisphere, no competition between processing and responding occurs for either RT responses or memory responses.

In summary, the choice of response task and response mode seems to depend heavily on the type of stimuli geing investigated and the type of presentation being used.

Summary

The present paper has not attempted to settle the various controversial issues surrounding the use of the split-brain paradigm with normal subjects. Instead, the present paper has attempted to outline and clarify methods and techniques that have been used to investigate laterality effects in the past so that the pitfalls that plagued earlier investigators can be avoided. The present paper has also tried to point up some of the problems and controversies associated with applying the split-brain paradigm to normal subjects in the hopes that bringing these issues together in one forum will lead to new insights in and methods of dealing with them.

CHAPTER II

STATEMENT OF THE PROBLEM AND PREDICTIONS

Introduction

While the first part of this paper has dealt with perceptual and/or memory processes, the remainder of the present paper will deal with imagery processes. If perception is conceived of as a temporary change in the nervous system generated by receiving, organizing, and interpreting data via the sense organs, and if memory is conceived of as a more or less permanent change in the nervous system generated in response to at least some of the temporary changes produced by perception, then imagery can be conceived of as a self-generated temporary change in the nervous system resulting in a subjective sense-like experience.

Just as perception can be associated with any of the senses, so can imagery be associated with any of the sense experiences. However, for the present paper only two of the sense experiences will be studied in relation to imagery; they are (1) subjective and/or representational visual experiences--visual imagery (VI), and (2) subjective and/or representational auditory experiences--auditory imagery (AI). Thus, visual imagery will be defined as a subjectively fabricated sense-like depiction of a visual experience. Auditory imagery will be defined as a subjectively fabricated sense-like depiction of an auditory experience. It is not intended that the present definitions of imagery be confined to subjective "awareness"--subject reportability. Subjects may or may not be able to report their imagery experiences in detail. All that is required is that some objective measure of imagery occurrence, such as rate of processing, be available to some outside observer. The question of whether or not the subjects are "aware" of (can report) their imagery experience is not crucial to the present definitions. (Note: Not all investigators would agree with this interpretation of imagery.)

In summary, in studying imagery, the investigator first needs to be assured that his respondents are in fact having an "imagery" experience, and second he needs to be able to describe the "imagery" experience in terms of some objective parameters, such as rate of occurrence.

The present study attempts to deal with both of these issues. Following Weber and Kelly's (1972) procedures, it was possible to employ objective criteria for the imaging of letters. For visual imagery, subjects can be required to classify lowercase letters of the alphabet on the basis of their vertical size. Some letters are vertically small (a, c, e, i, ..., z) and other letters are vertically large (b, d, f, g, ..., y). By requiring differential responses to imagined vertically large and small letters, we are somewhat assured that the subject is having imagined visual experiences. In addition, there is the objective parameter of "response accuracy" (whether or not the subjects correctly classified the letters) by which this imagined visual experience can be described. For auditory imagery, subjects can be required to classify letters of the alphabet on the basis of whether or not a letter name has a long "e" sound. Thus, some letters have a long "e" sound (b, c, d, e, ..., z) and other letters do not (a, f, h, ..., y). Again, by requiring differential responses to imagined long "e" and not long "e" letters, we are somewhat assured that the subject is having imagined auditory experiences. Concurrently there is the objective parameter of response accuracy.

Laterality and Visual Imagery

Not much previous work has been done in the way of assessing the laterality effects of visual imagery. Only two studies of this nature could be found to report at the present time. Pavio and Ernest (1971) studied two groups of subjects who differed in "visual imagery" ability--high and low visual imagery. The two "imagery" groups were selected by means of a test battery consisting of two spatial manipulation tasks, and by an 87-item true-false questionnaire concerning imaginal techniques in thinking and problem solving (Pavio & Ernest, 1971). Pavio and Ernest found that high imagers did not differ from low imagers in the ability to process visually presented alphabetic letters (a perceptual task). The question asked in this study was whether or not differing imagery ability differentially affected perceptual responding. Evidently it does not. Both groups processed the letters faster from the RVF than from the LVF, a finding that is consistent with the results of previous work on the perceptual lateralization of letters. Thus, the perceptual manipulation was effective, the imagery manipulation was not.

Seamon and Gazzaniga (1973) studied asymmetry of functioning for a visual imagery task. Subjects were given relational imagery and verbal coding strategies for a same/different recognition task using paired-associate stimuli. First, the subjects were told which coding strategy to use. For example, if the paired-associates were "bear-book", using the rehearsal (verbal coding) strategy the subjects simply repeated the words to themselves. Using the imagery strategy, the subjects tried to picture a book with a bear on the cover or something along those lines. Next, a pair of words were visually presented to either the LVF or RVF and the subjects were asked to say "yes" if it was a pair they had seen before and "no" if they had not seen the pair before. The dependent variable was RT. Response errors were monitored and were found to be infrequent. The results indicated that the response times were faster for the left versus the right hemisphere when using the verbal code (as expected), and faster for the right versus the left hemisphere when using the imagery code. Seamon and Gazzaniga concluded that cerebral laterality effects are functionally related to coding strategies, and that generated visual information may be viewed as a coding alternative to verbal mediation.

Laterality and Auditory Imagery

Only a small amount of work has been done with auditory imagery, and no known studies directly relate auditory imagery to functional laterality effects. Some investigators (e.g., Crowder, 1971; Liberman, Mattingly & Turvey, 1972) talk about an "echoic" image that outlasts the sensory input. As such, they appear to be studying something that may bear about the same relationship to a self-generated AI (as defined in the present paper) as does Sperling's VI to a self-generated VI--that is, not very much. However, it may be that this "outlasting of the sensory input" may be a self-generated process and therefore of interest to the present study. No data seem to bear directly on this point. The present paper is concerned with the self-generated type of AI as opposed to the echoic type. With this in mind, the work of Crowder (1971) and Liberman, *et al*. (1972) will be considered.

Crowder (1971) has described an "auditory image" that is unique to vowels and that outlasts sensory input by several seconds. In addition, this "auditory image" appears to occur after auditory presentation but not after visual presentation (Crowder, 1971). However, Crowder's use of auditory and visual presentations is somewhat unique. The subjects were asked to read (either silently or aloud) visually presented seven-syllable nonsense words constructed from either the syllables "Bah, Dah, Gah" or the syllables "Bee, Boo, Bih". The silent reading condition was considered the visual presentation while the aloud condition was considered the auditory presentation. The subjects read 15 of the words one at a time and after each presentation they were asked to recall in order as many of the seven syllables as possible. The results indicated that for the vowel condition (syllables "Bee, Boo, Bih") the auditory presentation (reading aloud) produced a greater number of correct responses than the visual presentation (reading silently). For the stop consonant condition (syllables "Bah, Dah, Gah") there was no difference between the "visual" and "auditory" presentations. Crowder's data also shows that the "visual presentation" for vowels produced recall that was superior to that for the stop consonant conditions; Crowder did not take note of this. Considering this last bit of data, it might be concluded that a "visually" derived auditory image exists and is functional (although it may not produce quite as many correct responses as an "auditorily" derived auditory image). This last point is important since the present paper is concerned with AIs derived from visual presentation of letters.

Liberman, Mattingly, and Turvey (1972) describe the characteristics of the speech code as follows. Stop consonants are always highly encoded; that is, in the interconversion between acoustic signal and phonetic message the information is radically restructured. In linguistic terms this means that for stops there is no auditory image of the signal available but only the output of a specialized processor. This specialized processor strips the auditory signal of all normal sensory information in order to store the representation as a single neural event. Vowels, on the other hand, are not always encoded as defined above. Very often they are enciphered (stored in a one-to-one relationship to the acoustic signal) so that they might be perceived in a different and simpler way. As a result, some of the auditory characteristics are preserved for a while. If this preservation is the result of a subjectively fabricated auditory experience as opposed to a perceptual "echoic" experience, then this "auditory image" can be said to conform to the definition of auditory imagery as defined in the present paper.

Much work has been done investigating the lateralization of vowels compared to stops. However, every one of the studies of this nature that could be found used auditory presentation. Auditory presentation produces perceptual processing as opposed to imagery processing as defined by the criteria used in the present paper. Thus, the results of these studies may not be appropriate for generalization to imagery processing; however, the typical results are as follows. Day and Vigorito (1973) found a right hemisphere advantage for vowels; Cutting (1973) found no hemispheric lateralization of function for vowels; and Haggard (1971) found a left hemisphere advantage for vowels. Shankweiler and Studdert-Kennedy (1967) found a very slight but inconsistent laterality effect favoring the left hemisphere for vowels. It is not known at this time why these results are so inconsistant. It is hoped that the present study will shed some light on this issue.

Nature of the Present Study

The present study is a further investigation of the cerebral laterality effect for visual imagery (VI) and auditory imagery (AI). An attempt is made to clear up some of the problems in previous experiments, and in addition, to add new knowledge to the area of imagery processing.

The present study attempts to get around the problem of not knowing whether subjects are indeed using VI by having the subjects extract a spatial property from their VI and report its vertical height along the lines of Weber and Kelly (1972) as reported earlier. The present study attempts to get around the problem of "echoic" versus subjective/representational AIs by having the subjects extract the AI from visually presented letters and then respond to this extracted AI along the lines of Weber and Kelly (1972).

Next, an issue that has not been considered before is the relative speed of extracting and responding to VIs compared to AIs. Seamon and Gazzaniga's (1973) results indicate that the imagery condition may have been faster than the verbal condition although a statistical analysis was not reported. In a different context, Weber and Kelly (1972) reported that the rate of processing VI for visual properties was slightly faster than the rate of processing AI for auditory properties though not significantly so. The present study will directly compare the rates of processing of VI and AI.

Finally, in addition to imagery effects, the present study is concerned with investigating the role of practice on the imagery and laterality performance. Practice effects do not seem to have been extensively investigated for either split-brain or imagery tasks. However with the present task, practice effects seem important to consider: it may be relatively simple for subjects to avoid the effort of using an imagery mediator by pairing a particular response to a particular letter. It is not known what the nature of the laterality effect might be if through practice imagery is dropped as mediator. It is expected that RT will decrease with practice, but the particular form of the interaction of imagery with practice is not predicted.

Predictions

1. VI will be processed spatially and therefore show a LVF-right hemisphere superiority of processing.
2. AI will be processed verbally and therefore show a RVF-left hemisphere superiority of processing.
3. Three possibilities exist concerning the relative rates of VI and AI:

a) if the mechanisms underlying imagery for auditory information are not different than those underlying imagery for spatial information then the processing rates of VI and AI should be equal, since the stimulus letters are identical in both cases;

b) if these mechanisms differ then the small amount of experimental evidence gathered so far would indicate the likelihood that VI would be processed faster than AI;

c) there is the possibility that because of the on-off nature of the presentation, the VI could be temporarily masked (Wegman, 1973). Therefore, information extraction would be delayed and AI would be processed faster than VI.

4. Practice effects will occur and reaction time will decrease significantly from block I to block II. The nature of the resultant laterality effects is not predicted.

Rationale for Experimental Procedures

Sex Differences

Since previous investigators have not found any consistend systematic differences between male and female laterality performances, the present study will not investigate sex as an independent variable.

Handedness

Previous investigations have indicated that handedness is related to cerebral dominance and lateralization of functioning. Therefore, it was decided to use only right-handed subjects in the present experiment. However, as reported earlier only about 90% of self-classified right-handers are left dominant for speech. In an attempt to eliminate the 10% cross dominant subjects that might be included in the experiment, all subjects were screened with a handedness questionnaire (see Appendix). Any subjects reporting any familial history of left-handedness and/or any subjects reporting more than two instances of left-hand use (the "either" category was considered left-hand use) was eliminated from the experiment.

Presentation Mode

It was decided to use visual presentation so that the same set of stimulus items (capital letters) could be used for both AI and VI. For VI, the subjects are required to translate the capital letters to lowercase letters (by means of VI) so that spatial height properties can be extracted. Note that if the spatial properties were extracted directly from the capital letters, this would be a perceptual task. Similarly, for AI, the subjects are required to translate the letters into an auditory image so that the long "e" sound can be extracted. With auditory presentation, the extraction of the long "e" sound would be a perceptual task.

It was decided to use successive presentation in order to control for left to right reading bias and in addition to assure fixation was maintained. In reviewing the literature on successive visual presentation, there did not appear to be any reports of deviation of gaze from the fixation point when successive presentation was used provided exposure time was 150 msecs. or less.

Stimuli

Since letters were found to be processed by either the right or the left hemisphere depending on the task (Geffen, *et al*. 1972), letters seemed to be the ideal stimuli for investigating the lateralization of imagery tasks. As mentioned previously, letters have already been used successfully in studies of VI and AI (Weber & Kelly, 1972), and in addition, the same stimulus population and same presentation mode could be used for both the VI and the AI tasks.

Response Mode

To avoid the complication involved in interpreting vocal responses, it was decided to use a bimanual response. A bimanual response was chosen since it makes it more likely that both hemispheres are in control and response asymmetry is therefore minimized. It was decided that the bimanual response would be button depression using both index fingers to simultaneously depress two centrally located buttons, and both middle fingers to simultaneously depress two peripherally located buttons. Geffen, et al. (1971) have shown that this method words very well if subjects can maintain equal leverage on all the buttons, and if subjects are instructed that a simultaneous response is required although in reality the first button depressed stops the timer. The idea of using throw-switches was eliminated since this might involve too much hand movement. Gazzaniga (1971) reports that manual response involving too much gross hand movement can complicate laterality interpretations or even neutralize the laterality effects.

Response Task

Reaction time from the letter presentation to the classification of the image will serve as the dependent variable. Correctness of response was monitored so that it could be considered in relation to the analysis if appropriate. However, exposure time was set so that all letters would be easily identifiable. Any trials that produced errors of response were repeated at the end of the experiment so that 100% correct responses could be used in the analysis.

Methods

Subjects

Twenty-eight Oklahoma State University lower division undergraduate volunteer subjects were used, 14 in each of two between-subjects conditions: (1) AI, and (2) VI. Both males and females were used. Subjects received extra course credit for their participation. All were right-handed according to questionnaire answers and they had no familial history of left-handedness. Also, because glasses could not be fitted into the viewing apparatus, none of the subjects word glasses (although contacts were permitted).

Stimuli

The stimuli consisted of 16 uppercase letters of the alphabet. Eight of the letter names had a long "e" sound /i/ (b, c, e, g, p, t, v, z), and eight of the letter names did not have a long "e" sound (f, j, l, n, r, s, x, y). It was the presence or absense of this long "e" sound that was to be classified in the AI task. In addition, eight of the letters were vertically small (c, e, m, r, s, v, x, z), and eight of the letters were vertically large (b, f, g, j, l, p, t, y) when seen in lowercase form. It was this spatial property of small or large vertical height that was to be classified in the VI task. Thus, imagery was needed to convert the letters to their auditory or spatial forms. The stimulus pool was constructed so that half of the letters with the long "e" sound were vertically large and the other half were vertically small. Similarly, half of the letters without the long "e" sound were vertically large and the other half were vertically small. This same situation holds for vertically large and small letter groups in relation to long "e" and not long "e" sounds. All 16 letters were presented to the subjects in uppercase form, 3 mm. in height and 2 mm. in width on 3½" x 5" cards projected from a tachistoscope. The linear separation between the fixation point and the center point of the letters in the right or left visual field was 2.5 cm. Each letter subtended a visual angle of .89° at a viewing distance of 83 cm.

Apparatus

A two-channel Scientific Prototype tachistoscope Model 800E was used. Luminance was constant between preexposure and exposure fields. Onset of a stimulus triggered a Hunter KlocKounter. The clock stopped when the subject made his bilateral finger response, thus producing the RT. An electronic signal indicated to the experimenter which buttons had been pressed. Specifically, the two central forefinger buttons indicated one response, and the two peripheral middle finger buttons indicated the opposite response.

Procedure

Subjects were randomly assigned to either the VI or the AI condition before they entered the experiment.

VI Condition. All subjects were told that they would be visually imagining letters of the alphabet; "imagining something visually is like picturing it in your mind". The subjects were told that they would be visually presented with capital letters. Therefore they would need to use their visual imagery in order to translate these capital letters into their lowercase form. As each letter was imagined in its lowercase form, the subjects were to classify the letter as being vertically large or small. The subjects were then to respond to this classification of the letters by pressing buttons on the response panel in from of them. Both hands were required for this response since a bilateral response made it more likely that both hemispheres were in control. The subject's forefingers were placed on two central buttons and his third fingers were placed on the peripheral buttons. Half of the subjects responded with their forefingers if the letters were vertically large and with their third fingers if the letters were vertically small. The other half of the subjects responded with their forefingers if the letters were vertically small and their third fingers if the letters were vertically large.

The subjects were given a series of eight practice trials with the experimental task before the start of the experiment proper. Four uppercase alphabetic letters (non-members of the experimental pool--A, D, H, M) were presented to the subject's left or right visual field via the tachistoscope. The subject controlled the onset of the stimuli by depressing a switch with his foot. The letter was displayed for 150 msecs. The onset of letters triggered an electronic timer which was stopped when the subject depressed a response button. The subject's task was to report (manually) whether the presented letter was vertically large or small when visually imagined in its lowercase form. Experimental letters were presented in the same manner as the practice letters and the same responses were required. The letters were presented successively and randomly to the left and right visual fields until all 16 letters had appeared once in each field. After a very short pause, this procedure was then repeated to get data for practice block II. Each time the subject responded correctly to the stimulus, the experimenter recorded the RT. Each time a subject responded incorrectly, the experimenter noted this but did not record the RT. Incorrect trials were repeated at the end of a block. The subject's fixation was maintained in the center of the presentation field by having a fixation point in the center of the preexposure field present at all times except during presentation of a stimulus. In addition, the subject was told that his best strategy for optimum performance was to maintain fixation at the fixation point since the stimulus would appear randomly to either side of it. The subjects were instructed to respond as rapidly as possible while striving for 100% correct responses.

AI Condition. This condition was similar in all respects to the VI condition except that subjects were tested for the ability to auditorily imagine the letters of the alphabet. "Imagining something auditorily is like hearing it in your mind". Subjects were to classify and respond to the alphabetic stimuli according to the presence or absense of the long "e" sound. Again, half of the subjects responded with forefingers to the presence of the long "e" sound and half responded with their forefingers to the absence of the long "e" sound.

Design

A split-plot 2x2x2 AOV (Kirk, 1968) served as the design. The independent variables were as follows. There was one between-subjects variable: AI/VI. There were two within-subjects variables: practice blocks and left/right visual fields. The dependent variable was RT.

CHAPTER III

RESULTS

Due to the variability of the data, medians were used to average the individual subject data. Each subject's median RT for a given condition was computed and the mean of the medians was then obtained. This data is depicted in Figure 5. Each point represents 224 events (16 letters x 14 subjects). The letter classifications (large/small and long "e"/not long "e") were collapsed because previous experiments have found no differences between these classifications.

The results of the analysis of variance were as follows: for imagery conditions (tested by a between-subjects error term), $\underline{F}$ (1,26) = 4.11, $\underline{p} > .05$; for practice blocks, $\underline{F}$ (1,26) = 87.84, $\underline{p} < .05$; for the Imagery x Practice interaction, $\underline{F}$ (1,26) = 2.85, $\underline{p} > .05$; for visual fields, $\underline{F}$ (1,26) = 22.07, $\underline{p} < .05$; for the Imagery x Visual Fields interaction, $\underline{F}$ (1,26) = 1.65, $\underline{p} > .05$; for the Practice x Visual Fields interaction, $\underline{F}$ (1,26) = 10.43, $\underline{p} < .05$; and for the Imagery x Practice x Visual Fields interaction, $\underline{F}$ (1,26) = 1.88, $\underline{p} > .05$. Thus, the information processing rates of VI compared to AI were not to be different; practice with the task improved performance; and imagery information tended to be processed faster from the LVF than from the RVF although this relation-

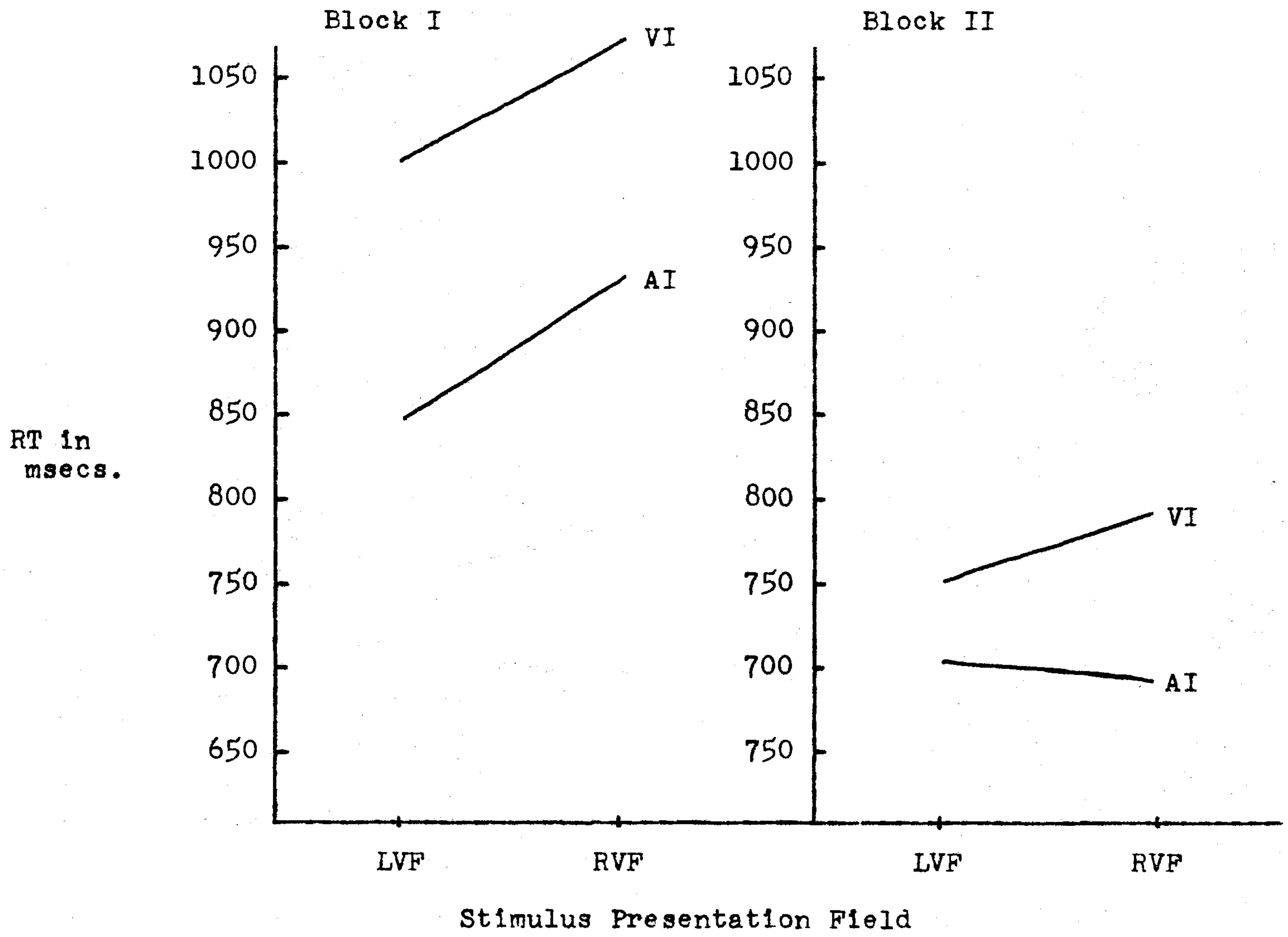

Figure 5. Imagery Mode, Practice, and Visual Field Effects

ship tended to change as the task was practiced.

To examine the practice by visual field interaction more closely, post hoc Neuman-Keuls tests were performed. The results of these analyses are presented in Table I. As can be seen, there was a significant decrease in RT between practice block I and practice block II for both visual fields in both imagery conditions. Thus, both AI and VI appear to benefit from practice and this improvement is not unique to either visual field.

In addition, the imagery processing from the LVF is faster than imagery processing from the RVF initially (practice block I), but with practice there appears to be a tendency for this RT superiority to diminish. In fact, with AI after practice, there is no difference in the rate of processing between the two fields.

It should be noted that this "no difference" finding is statistical. It could be the result of the subjects showing equal processing ability for both visual fields. That is, the stimuli would be processed as fast from the LVF as from the RVF. Alternatively, it could be the result of approximately half of the subjects showing slower processing times from the RVF while the other half of the subjects show slower processing times from the LVF. An examination of Table II (in which each individual subject's performance is shown) indicates that whereas initially 13 of the 14 subjects showed slower RTs from the RVF, after practice only eight of the 14 subjects showed slower RTs from the RVF while six of

TABLE I

NEUMAN-KEULS PRACTICE BLOCKS AND VISUAL FIELD COMPARISONS

Practice Block Effects

	Imagery Condition	Practice Block	Visual Field	Mean Difference
	VI	I	LVF	
1.		versus		248.86*
	VI	II	LVF	
	VI	I	RVF	
2.		versus		284.14*
	VI	II	RVF	
	AI	I	LVF	
3.		versus		141.43*
	AI	II	LVF	
	AI	I	RVF	
4.		versus		228.78*
	AI	II	RVF	

W = 72.49   * = $p < .05$

Visual Field Effects

	Imagery Condition	Practice Block	Visual Field	Mean Difference
	VI	I	LVF	
1.		versus		81.14*
	VI	I	RVF	
	VI	II	LVF	
2.		versus		45.86*
	VI	II	RVF	
	AI	I	LVF	
3.		versus		79.92*
	AI	I	RVF	
	AI	II	LVF	
4.		versus		7.43
	AI	II	RVF	

W = 39.87   * = $p < .05$

TABLE II

TABLE OF INDIVIDUAL SUBJECT'S MEDIAN RT PERFORMANCE

Visual Imagery

	Practice Block I			Practice Block II		
	LVF		RVF	LVF		RVF
1.	1066	<	1124	715	>	667
2.	915	<	994	724	<	669
3.	1116	<	1271	801	<	989
4.	985	<	1112	737	<	750
5.	1020	<	1044	644	<	661
6.	863	<	880	674	<	687
7.	716	<	734	597	<	618
8.	1333	<	1579	930	<	945
9.	840	<	867	767	<	778
10.	703	<	749	534	<	573
11.	1005	<	1070	896	<	1020
12.	998	<	1052	792	<	837
13.	1370	<	1421	895	<	1125
14.	1064	<	1233	804	<	833
	LVF<RVF:		14/14	LVF<RVF:		12/14

Auditory Imagery

	Practice Block I			Practice Block II		
	LVF		RVF	LVF		RVF
15.	591	<	674	551	<	582
16.	958	<	1034	570	<	644
17.	1128	<	1492	844	<	867
18.	1022	<	1145	787	<	816
19.	801	<	972	710	>	673
20.	844	<	850	724	>	664
21.	796	<	805	704	>	620
22.	795	<	900	733	>	690
23.	693	<	765	677	>	616
24.	760	<	783	630	>	609
25.	855	<	893	744	<	749
26.	936	<	979	673	<	675
27.	909	<	952	840	<	846
28.	781	>	744	702	<	734
	LVF<RVF:		13/14	LVF<RVF:		8/14

the 14 show slower RTs from the LVF. Thus, the data seems to indicate that subjects do not tend toward equal hemispheric processing ability after practice. Instead, the subjects appear to be switching from right hemisphere processing to left hemisphere processing.

In a final note, subjects made very few errors in either the AI or the VI tasks. For both tasks, the subjects made an average of 2.0 errors out of 64 trials. These errors, when they did occur, were almost exclusively at the beginning of testing when the subjects were getting used to coordinating the finger responses with the imagery classification. Due to the low number of errors, no analysis of the error data was felt to be necessary.

CHAPTER IV

DISCUSSION

The VI lateralization results of the present experiment are consistent with the findings of Seamon and Gazzaniga (1973). In both, VI was found to be processed faster by the right cerebral hemisphere than by the left. However, the prediction that the AI would be processed in the left hemisphere was not supported. The finding of right hemisphere processing for AI was not expected and seems to indicate that imagery processing is not modality specific as is perception. That is, imagery processing seems to ignore modality related characteristics (verbal/spatial) that tend to lateralize differentially in perception. In addition, the finding that AI and VI show statistically equivalent RTs is consistent with the position that different "forms" of imagery are processed in the same manner.

If AI is not modality specific, then a consistent argument would be that VI is not modality specific either. If this is the case, then it may be inappropriate to conclude that VI is processed by the right hemisphere because of VI's assumed "spatial" nature. The data seems to compel an explanation of the nature of VI right hemisphere processing that is compatible with the finding of right hemisphere processing of AI imagery. One explanation that is consistent with the finding of right hemisphere processing for both AI and VI is that both AI and VI are abstractions of subjective sound and picture representations rather than subjective sound and picture representations themselves. Pylyshyn (1973) talks to this issue. In discussing imagery, Pylyshyn (1973, p. 5) states:

> the need to postulate a more abstract representation...is unavoidable. As long as we recognize that people can go from mental pictures to mental words or vice versa, we are forced to conclude that there must be a representation...which encompasses both. There must, in other words, be some common format or interlingua.

In summary, the lateralization data from the present experiment leads to the conclusion that there exists specialization of hemispheric processing for imagery. This specialized processing occurs in the right hemisphere with the result that imagery tasks channelled to the right hemisphere are processed faster than those channelled to the left hemisphere. Finally, the lateralization of imagery processing appears to be the result of some sort of abstract representation that is not fundamentally modality specific as is perception.

The results of the data on practice effects as presented in Table II seem to indicate that after practice some subjects no longer process the stimuli in the right hemisphere but instead process them in the left hemisphere. The nature of this change in processing is unknown, but some reasonable guesses about its occurrence can be made. It seems logical that the subjects become more familiar with the relationship between the stimulus characteristics over time. It is possible that increase in familiarity leads to a switch from the abstract (right hemisphere) processing to some form of concrete verbally mediated and/or verbally coded (left hemisphere) processing. The most likely form for this "verbal" processing to take is phonetic. Conrad (1972) reports that when alphabetic shapes are presented visually to subjects, the tendency is for the subjects to convert this visual information into a phonetic form. This conversion takes place in spite of the fact that the subjects are capable of retaining these alphabetic shapes as visual information (images). Conrad says that the reason that this conversion to phonetic form occurs is that information can be stored and dealt with more efficiently in this phonetic form.

Given that the switch in processing from the right hemisphere to the left hemisphere is the result of subjects switching from abstract representational processing to verbal (phonetic) processing, then two major questions concerning the present data need to be answered: (1) why does the present data show that the AI condition has more shifts from imagery to verbal processing than does the VI condition (see Table II), and (2) why does VI processing tend to shift to verbal processing at all? In response to the first question, a long "e" sound is used for the discriminative response in the AI condition while a spatial configuration is used for the discriminative response in the VI condition. It may take longer to learn a relational "concept" between a spatial configuration (the letter shape) and a verbal representation (the letter name) than it does to learn a relational "concept" between a long "e" sound and a phonetic representation. That is, a verbal representation is likely to be more compatible with the letter name than with a letter shape.

In response to the second question (why would VI processing switch to verbal [phonetic] processing?), as mentioned previously, Conrad's (1972) data show that there is a tendency for subjects to convert visually presented information to a phonetic form even though this information can be held and used in visual imagery form. In addition, since images are difficult to generate (Weber & Harnish, 1973) and are easily masked or interfered with (Segal & Gordon, 1969; Brooks, 1967, 1968), it seems reasonable that, given a task calling for high accuracy of response, imagery processing might be abandoned in favor of verbal (phonetic) processing. The present task does call for high accuracy of response. Given the above speculations, it would seem worthwhile to repeat the present experiment using increased practice trials to see if the VI and AI conditions eventually switch completely to left hemispheric processing.

Since in the present experiment there was an attempt to combine the best parts of the methodology from previous experiments, an evaluation of the success of some of the present procedure seems warranted. An attempt was made to get a consistent group of strongly left hemispheric language dominant subjects. Only right-handed subjects were used, and these subjects had to be not only self-professed right-handers, but also right-handed on the bases of questionnaire data. In addition, they could not have any family history of left-handedness. This screening procedure was fairly successful. Only one subject out of 28 appeared to have reversed lateral dominance (see Table II, number 14 under the AI condition block I). In comparison, Geffen, et al. (1971) used only self-report of right-handedness as a screening criterion for their subjects. They found that seven out of 36 of their subjects showed reversed lateral dominance. Since subjects with reversed lateral dominance complicate the statistics, the present study appears to offer a very promising approach to eliminating this problem.

The presentation mode (visual) and the response mode (manual) seemed to work very well. No unusual problems were encountered, and as can be seen, the lateralization data looks very consistent.

Concerning the question of whether or not the subjects used imagery, it seems apparent that they did. Very few errors were made by the subjects (two errors out of 64 trials was average). The mean RTs for the VI task are comparable to RTs for similar VI tasks (Weber & Harnish, 1973). Processing was done in the right hemisphere as expected (at least for the VI task). Finally, right hemisphere processing appears to be a function of the fact that imagery processing occurred rather than a function of some methodological bias since with practice some of the subjects switched to left hemisphere processing.

As concerns future work in this area, one suggestion has already been presented. It appears that it would by highly informative to repeat the present task using many more practice trials. It could be seen whether or not the processing shifted completely from the right hemisphere to the left. Possibly some learning timetables could be established for the tasks. Finally, possibly the subjects would be able to give some clue as to the nature of the hemispheric processing change (when asked in the present experiment, the subjects said they were unaware of any changes in their processing).

Another reasonable study would be to repeat the VI condition of the present experiment using auditory instead of visual presentation. Two things would be looked for: (1) does auditory presentation differentially affect imagery lateralization processing, and (2) does auditory presentation differentially affect the switching hemispheric processing with practice?

Finally, the present experiment might be replicated using deaf subjects. Deaf subjects are supposed to have very good VI and little or no AI. This supposition could be directly tested. In addition, it seems as though it would be extremely interesting to find out how real subjects would respond to the practice trials.

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APPENDIX

APPENDIX APPENDIX

HANDEDNESS QUESTIONNAIRE

115 115

With which hand do you perform each of the following activities? (check the appropriate answer)

	Right Hand	Left Hand	Either Hand
1. Write			
2. Throw a ball			
3. Hammer			
4. Pull back a bow string and arrow			
5. Use a racket (e.g., tennis, ping pong, etc.)			
6. Hold a match while striking it			
7. Use a toothbrush			
8. Hold the thread when threading a needle			
9. Use a table knife			
10. Use a spoon			
11. Use to drink a glass of water			

Were any of the following relatives left-handed? (check the appropriate answer)

	Yes	No	Don't Know or Not Applicable
1. Mother			
2. Father			
3. Sisters			
4. Brothers			
5. Grandmothers			
6. Grandfathers			

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