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ABSTRACT

The purpose of this report is to distill curricular and testing implications of brain research. The report will focus on three topics. One topic is the possibility that brain lateralization--that is, the degree to which the two brain hemispheres specialize in different types of information processing--is an individual differences variable that should be measured, just as we measure individual differences in verbal and mathematical aptitudes. Second, since one of the better-established findings is that verbal and spatial abilities tend to reside in different hemispheres, the possibility of incorporating spatial ability into admissions testing is explored. Third, the calls for curricular reform based on brain research are examined. (Author)

RESEARCH REPORT

BRAIN LATERALIZATION RESEARCH: EDUCATIONAL AND PSYCHOMETRIC IMPLICATIONS

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Abstract

The purpose of this report is to distill curricular and testing implications of brain research. The report will focus on three topics. One topic is the possibility that brain lateralization--that is, the degree to which the two brain hemispheres specialize in different types of information processing--is an individual differences variable that should be measured, just as we measure individual differences in verbal and mathematical aptitudes. Second, since one of the better-established findings is that verbal and spatial abilities tend to reside in different hemispheres, the possibility of incorporating spatial ability into admissions testing is explored. Third, the calls for curricular reform based on brain research are examined.

Brain Lateralization Research: Educational and Psychometric Implications

Isaac I. Bejar

This paper reviews recent developments in the study of brain lateralization, an area of research concerned with identifying functions associated with the two cerebral hemispheres. Our purpose is not to settle the many controversies in a literature involving many specialized disciplines but rather to distill from that literature the better-established claims and then to investigate their educational and testing implications. The plan is first to review some of the clinical research that led to the postulation of different cognitive functions for the two cerebral hemispheres. Although much of the clinical evidence appears very compelling it is not always easy to generalize to normal populations. For example, lesions to certain parts of the brain seem to affect only certain cognitive functions. Can we therefore infer from this evidence that different parts of the brain control different mental functions in normal brains? Our review suggests that there are in fact important differences between what each brain hemisphere is best at and that there may be important educational and measurement implications of lateralization research.

The Evidence

The idea of locating cognitive functions in the brain has a long history in psychology. Phrenology, for example, attempted to correlate anatomical characteristics of the head with psychological characteristics. This theoretical perspective led to perhaps one of the first instances of designing a "psychometric" instrument based on a psychological theory. The instrument was simply a means of measuring the length and width of the skull. Phrenology has, of course, since fallen into disrepute and along with it the idea of measuring human skulls, but this episode in the history of "psychometrics" illustrates what can happen to a measurement instrument directly linked to a psychological movement: Should the movement falter or fail, chances are the measurement instrument will, too.

Phrenology fell into disrepute because its claims could not be verified experimentally. However, a few decades later, in the 1860's, evidence that specific psychological functions reside in different parts of the brain was produced by the anthropologist, Paul Broca. He presented two patients whose speech had been lost after injuries to the left part of the brain, a language disorder known as aphasia. There is now ample evidence to support the claim that injuries to the left brain result in language disorders. For example, in a survey of the effect of surgery on the left or right hemisphere (Penfield and Roberts, 1959), it was found that the incidence of aphasia following left-brain surgery was 73%, whereas it was less than 1% for the right brain. Evidence such as this suggests that language skills are located in the left hemisphere. If language skills are disrupted when damage to the left hemisphere occurs, what is the effect of damage to the right hemisphere? This turned out to be a difficult question (see Renzi, 1982) because of the difficulty of inferring the skills involved. It was, however, gradually realized that spatial abilities were affected by right-brain damage. Hecaen (1962) is credited with providing clear-cut clinical evidence that the right brain's forte is spatial ability.

Thus, the picture that emerges from the clinical literature is that the left brain is primarily involved in verbal ability, while the right brain is primarily involved in spatial ability. Of course, this is an oversimplification. For example, verbal ability is usually located in the left hemisphere, but not always. It seems to be so with right-handed individuals but not always with left-handed individuals. Moreover, in normal persons the hemispheres collaborate in executing complex behavior:

> Despite the clear involvement of the left hemisphere in language functions, the right side is necessary for normal communication in the broader sense. The usual standarized tests of linguistic ability focus on pronunciation and grammar. In these, the left hemisphere is clearly dominant. But the behavioral function of language is more complex than that, and for normal activity multiple cerebral functions are necessary. These studies on right hemisphere patients demonstrate the interdependence of the two hemispheres in normal functioning, as well as

> the inadequacy of the notion that one hemisphere can be completely dominant over the other in normal (complex) behavior. (Segalowitz, 1983, p. 41)

Implications

What are the implications of the clinical research for normal persons? In other words, what do we make of the fact that the two hemispheres have distinct functions? The rest of this report will focus on three possibilities.

1. Spatial skills are to the right brain what language skills are to the left brain. Therefore, it may not be unreasonable to argue that in order to have a fuller assessment of a student's strengths and weaknesses we should assess his or her spatial ability as well as verbal and quantitative skills.

2. Lateralization, that is, the degree to which different cognitive functions are located exclusively in one of the two hemispheres, may be an important variable for predicting academic success; therefore, it may be reasonable to include a measure of lateralization as part of an admission test.

3. If lateralization is an individual-differences variable then perhaps school curricula should be modified to take that variable into consideration.

Enlarging the Predictor Space

One inescapable conclusion that may be drawn from the lateralization literature is the existence of two fundamentally different abilities. One ability is linguistic, the other is spatial. Differential psychologists have long postulated the existence of spatial abilities. An impressive array of studies have demonstrated, time and time again, the presence of one or more spatial ability factors (e. g., Michael, 1949; Flaugher and Rock, 1972; DeFries et al., 1974). Curiously, despite all this research in the last two or three decades there has been a decline in the frequency with which spatial abilities are measured. For example, the College Board admissions program at one time included a spatial test, but it was discontinued. Unfortunately, there seems to be no written record of the reasons for that decision. There is, however, some anecdotal evidence. According to Dr. Harold Gulliksen, dropping the spatial test from the SAT was not justified. In his recollection, the test was useful in predicting grades in certain engineering courses at some schools, but not at others. Apparently, this was so because of the different types of final exams used in different universities.

More recently, the armed forces reached a decision to drop the spatial subtest from the ASVAB battery. We could not locate the official document outlining the reasons for this decision, but the psychometricians involved in developing the test said the decision is not a final one but was implemented because the spatial subtest lacked predictive power. Because the criteria most often used for validating the ASVAB scores are end-of-course grades, low predictive power of the spatial test may be a function of the nature of the criteria. Whether or not the verbal and spatial abilities are in different parts of the brain, it stands to reason on psychometric considerations alone that a spatial test would add little to the prediction of final grades if exams tend to deemphasize the spatial content of the course.

In fact, there is ample evidence to suggest that spatial tests can be good predictors under certain circumstances (e.g., Holzinger and Swineford, 1946; Hills, 1957; Karlins et al. (1969). For example, Myers (1953) studied six spatial tests on a sample of 254 male first-year college students and found correlations as high as .40 and .68 with mathematics and drawing grades, respectively. Unfortunately, he did not report, nor does the evidence apparently exist elsewhere, on what spatial tests add to predicting college grades beyond what verbal and quantitative tests already predict. There is, however, a growing body of evidence suggesting that spatial ability is highly correlated with mathematics and science achievement (see, for example, Fennema and Sherman, 1977). Some of the evidence linking spatial ability and performance in science and mathematics appears in the field-dependence literature (e.g., Witkin et al., 1977), but it is nevertheless relevant to the present discussion since field dependence is often measured with instruments that are essentially measures of spatial ability. A valuable finding that emerges from the field-dependence literature is that students whose initial choice of major is not congruent with their cognitive style (i. e., level of spatial ability) tend to shift to areas that are more compatible with their cognitive style. This suggests that spatial ability may prove useful in counseling in addition to demonstrating its value in predicting academic performance (P. Oltman, personal communication).

Nevertheless, much of the literature that addresses the predictive value of spatial tests is outdated. Society has changed radically since those studies were conducted, and we cannot say with any certainty that the studies are relevant today. For example, computers are changing the way drafting is done. Indeed, CAD (Computer-Assisted Design) is one of the fastest growing computer fields. Because CAD systems are expensive, there may be reason to improve the prediction of who will be most capable of using the equipment. On the other hand, it is conceivable that CAD, because of its ability to perform the tasks that formerly required the operator's spatial ability (e.g., in rotation of the object being drawn) may make spatial ability less necessary. These comments are, of course, speculative. However, a team of researchers at the Bell Labs (Egan & Gomez, in press) have found evidence that spatial memory was one of the best predictors of learning to use a text editor. The point is that much of the available literature is dated, and new research initiatives may be required to properly evaluate the role of spatial ability in today's highly technological society.

Interestingly enough, while psychometricians were losing interest in spatial ability and spatial tests were becoming less frequent, experimental psychologists were becoming keenly interested in this ability. Their interest has contributed greatly to our current understanding of spatial ability. Before discussing that literature we will review briefly the classical literature.

There are two major sources of spatial theorizing, the first being the factor analytical or correlational literature, which dates back to Spearman at the beginning of this century. The second source is far more recent and has a cognitive or information-processing orientation. In what follows, we briefly review both sources.

Factor analytic research. The factor analytic approach to spatial ability research utilizes the classical psychometric paradigm, namely, accounting for test variance. The central issue in much of this research has been establishing the "existence" of a spatial ability factor. A large number of studies have been conducted over the years (e.g., Guilford, 1972; Guilford et al., 1952; Michael et al., 1950; Thurstone, 1950; Zimmerman, 1954). These have been reviewed recently by Lohman (1979). He concluded that three factors had been established. These factors are spatial relations, spatial orientation, and visualization. The spatial relation factor is defined by tests that require rapid mental manipulation of the stimulus. Spatial orientation refers to ability to imagine how a stimulus would appear from a different perspective. Lohman notes that spatial orientation is difficult to measure since items in tests designed to measure that factor can often be a mental rotation strategy. The third factor, visualization, is defined by unspeeded tests that are spatial or figural in content, but the solution of the item is more complex than for items from the other two factors. Lohman noted that visualization seems to be close to Spearman's g as measured by the Raven Progressive Matrices.

Information-processing research. Independent of the factor analytic research, experimental psychologists began in the late 60's to lay a research foundation that would ultimately lead to a new approach to spatial ability theorizing. According to Cooper and Shepard (1973),

> The most dramatic progress in the study of mental operations on spatial subjects, and hence the bulk of the work that we shall be reviewing here, has taken place relatively recently. This work has focused more directly on the internal cognitive processes that presumably underly both the behavior observed in laboratory experiments and the performance recorded on mental tests (p. 109).

A central issue in this research is whether the transformation applied by the subject to the stimulus is a continuous one or a discrete one. A second issue of theoretical importance is the mechanism used by subjects for coding the stimulus. For example, it is theoretically relevant to determine whether subjects encode the stimulus by means of a verbal mechanism or a pictorial one.

The most striking finding from research designed to elucidate those issues is that response time is a linear function of the stimulus characteristics. For example, Shepard and Metzler (1971) asked subjects to determine whether a pair of computer-generated perspective line drawings were the same or were different rotations of the same stimulus. They found that the mean reaction time across subjects was a linear function of the angular disparity between the two stimuli. Moreover, this linear relationship held for individual subjects as well. On the basis of this and subsequent research, Cooper and Shepard have concluded that the means or process used in solving the problem is analogous rather than discrete.

The mental rotation task is an instance of research design to analyze the processes underlying performance on a single spatial task. The remarkably ordered results that have been obtained are largely due to the fact that a single underlying process is responsible for performance of the task. However, some research has been initiated to study correlates of individual differences in the mental rotation tasks. (Snyder, 1972; Wilson, DeFries, McLern, Vanderberg, Johnson, and Rashad, 1975).

Seemingly simple tasks can often be subject to different information processing strategies. Cooper (1980) has exploited this fact to explore individual differences in these strategies. Cooper noted that in a series of experiments, differing patterns of performance were obtained for the fastest and slowest subjects in the solution of correctly solved problems. For example, for the slow subjects, error rate and reaction time were positively correlated, whereas for fast subjects they were not. Cooper suggests that this difference in pattern of performance could reflect differences in the nature of the spatial comparison process, with the fast subjects appearing to use a holistic strategy and slow subjects appearing to use an analytical strategy. A similar point is made by Carpenter and Just (in press).

To summarize, in this section we have traced the scientific history of the concept of spatial ability. Psychometricians deserve credit for first identifying it, but experimental cognitive psychologists are responsible for our current understanding of the ability. We have also noted that with the rapid technological changes occurring in society much of the literature on the predictive value of spatial tests is dated. Specifically, in light of developments in the computer hardware and software industries, further research is needed to determine the usefulness of spatial tests.

Lateralization As an Individual Difference Variable

One implication that follows from lateralization research is that the hemispheres may not be organized in the same way in all individuals. For example, the role of the hemispheres may be reversed in certain individuals, or the collaboration between the hemispheres may be greater or lesser. That is, lateralization may be an individual-difference variable. We should perhaps then consider assessing individual differences in this dimension just as we measure individual differences in verbal ability as a predictor of academic performance. However, before we do so, we need to demonstrate that differential organization is in fact related to academic performance. Would it matter for purposes of predicting academic performance whether, in a given individual, verbal ability is located in the right or in the left hemisphere or in both? It could be that lateralization is one factor in determining verbal ability, as measured by psychometric instruments. For example, although the evidence is not terribly consistent, there are indications that reduced lateralization is associated with language deficits (e.g., Bryden, 1982, Ch. 15). If this is so we may already be indirectly measuring lateralization with existing verbal tests.

Nevertheless, it is important to be aware first of how lateralization may be measured so that we may be in a better position eventually to evaluate claims that may or may not be made with respect to the relationship of lateralization and measures of academic performance or admissions tests.

First of all, what do we mean by lateralization? Lateralization refers most often to the degree to which, in a given individual, the two brain hemispheres specialize in different functions. Thus maximum lateralization occurs when one of the hemispheres is unable to process linguistic information while the opposite is equally incapable of processing visual-spatial information. These extremes are probably only observed with brain-injured patients. With normal subjects it is more likely that both hemispheres are capable to some extent of processing both types of information. The measurement tools that have been developed to assess laterality presumably give us an indication of the extent to which a given individual's right or left hemisphere is relatively better than the other at processing different types of information. As can be expected, these measurement devices are different from the conventional paper-and-pencil tests, but psychometric know-how is relevant to the evaluation of their properties and the relationships they may or may not have with other variables.

From the point of view of test development, the most difficult aspect of constructing a test to measure laterality is insuring that only the targeted hemisphere sees the "item." If this were possible then we could, with the help of existing psychometric theory, develop parallel forms of a test and present them to both hemispheres. The difference in performance on the two tests could be taken to index degree of lateralization.

This targeting, of course, is not possible. With healthy individuals the two hemispheres are connected through the corpus collosum. That is, the hemispheres in intact brains can exchange information freely. There is nothing to prevent the subject from effecting that transfer, and as a result the score we might derive from such a test will not necessarily reflect the construct we intended to measure.

With certain patients the corpus collosum has been severed, and in principle it is possible to implement such a measurement scheme. In practice, there are many reasons why results from those subjects could not be interpreted unambiguously (Segalowitz, 1983, pp. 63-64) since such operations are seldom tidy, and the possibility of damaging parts of the brain is very real. Moreover, there is usually no information on how the subjects performed before the operation.

Fortunately, the inputs from various senses are lateralized in such a way that it is largely possible to present "items" to one hemisphere or the other. In order to illustrate the findings using this approach we will focus on the results obtained with the auditory modality.

Dichotic listening. The essence of this technique is to present to the left and right ear different input messages. The basis for this test is that each ear is connected more strongly to the contralateral hemisphere, so that information presented to the right ear is transmitted to the left hemisphere while information presented to the left ear is transmitted to the right hemisphere. The rationale for this approach is summarized by Segalowitz:

> Let us trace what would happen to such input in a person that was left-lateralized for language skills. Say we put the word "one" in the left ear and "two" in the right ear...The "two" would arrive at the language hemisphere first and therefore would have a better chance of being understood. We would expect the ear opposite to the language hemisphere to show an advantage over the other ear for recognizing words (1983, p.66).

This technique appears to provide a sound means of assessing laterality. However, the input to each ear is actually transmitted to both auditory cortices, except that there is some evidence that the connections are denser and faster to the contralateral hemisphere (Bryden, 1982, p. 41). This evidence might lead us to believe that the reliability of results from the technique are less than perfect.

The basic finding from using the dichotic listening tests is that there is a right-ear advantage for linguistic stimuli. This finding has been replicated so many times that it is not unreasonable to conclude that the result occurs because the left brain specializes in language tasks. It is another matter to conclude that we can use the dichotic listening test to assess individual differences in laterality. Many investigators do not even bother to report reliability measures, but according to Bryden (1982, p. 41) the reliability is in the neighborhood of .60 to .70, which is rather low.

Summary. The conclusion from the research is that auditory asymmetries are related to lateralization. However, from a psychometric standpoint the existing instruments leave much to be desired. First, the existing instruments are not very reliable, a situation which presents many problems. Thus if we wanted to use lateralization as a covariate, for example, the sizable error of measurement would present serious problems. Secondly, the construct validity of laterality measures is not strong. It is known that performance on laterality measures, whether they are auditory, visual, or tactile, is affected by factors other than laterality, such as attentional bias. In fairness to researchers in the laterality field, it should be acknowledged that these measurement problems affect all psychological measurement instruments. However, precisely because of this problem, psychometricians have developed an arsenal of techniques to assess the validity and reliability of measurement instruments. It seems fair to conclude, on the basis of conventional psychometric criteria, that the current techniques of assessing laterality have not reached the point where they can be used routinely for assessing individuals.

Educational and Curricular Implications

The distribution of functions between the two hemispheres appears to be well established. There has consequently been ample speculation about the educational implications of the two specialized hemispheres. For example, according to Nebes:

> If there is any truth in the assertion that our culture stresses left-hemispheric skills, this is especially true of the school systems. Selection for higher education is based predominantly on the ability to comprehend and manipulate language--a fact which may help explain why it took so long for science to come to grips with right-hemisphere abilities. If the right hemisphere does indeed process data in a manner different from the left, we may be shortchanging ourselves when we educate only left-sided talents in basic schooling... Many problems can be solved by either analysis or synthesis; but if people are taught to examine only one approach, their ability to choose the most effective and efficient answer is diminished. (1977, p. 105)

Two types of implications will be examined in this section. One type is the educational correlates of laterality, the other is the curricular implications of brain research.

Educational Correlates of Laterality

Reading. By far the most thoroughly investigated educational problem involving laterality is the possibility that laterality may be involved in certain language deficits. Specifically, it may be argued that increased lateralization, that is, the extent to which language is housed exclusively in one hemisphere leads to more efficient processing of linguistic information, and therefore better performance in linguistic tasks. Several surveys of this literature have been presented (Bryden, 1982, Ch. 15; Naylor, 1980), although the research is plagued with all sorts of methodological problems. Bryden summed it up as follows:

> Despite unreliable instruments, a plethora of experimental effects that contaminate the results, various methodological absurdities, and frequent instances of contradictory evidence, one theme continues to recur. That is the notion that bilateral representation of function is associated with deficit. With poor readers, with the deaf, and with female spatial abilities, there are signs that poor performance is associated with weak lateralization or bilateral representation. The generality fails for verbal skills in women, where women seem to be less lateralized but show better verbal skills than men. (1982, p. 257)

Other researchers are less positive about the relationship. Thus Naylor summarized his review of the literature on reading disability and lateralization as follows:

> ...there is litle evidence either that these (reading-disabled) children are more bilateral than normally reading children in cerebral organization or that they have a specific deficit in left-hemisphere processing. (1980, p. 542)

Spatial ability and sex differences. As with almost anything else in this area of research, it is difficult to extract some solid conclusions about the possibility of sex differences in brain organization. Since females almost universally tend to excel in verbal tests and seem to perform less well than males on spatial tests (Harris, 1978; Buffery and Gray, 1972), it is tempting to implicate brain organization as an explanatory variable. After all, the one incontrovertible finding from this literature is that one hemisphere specializes in spatial tasks and the other specializes in linguistic skills. Could it be that the male and female brains are organized differently? If so, does the different organization explain the sex differences in spatial tasks?

A sizable amount of evidence implicates biological, genetic, and hormonal factors in the differential performance on spatial tasks of the two sexes (Harris, 1978; Buffery and Gray, 1972; Yen, 1975). Other research, however, (Burnett et al., 1983) suggests that gender-specific lateralization may not be the reason for the differential performance. Instead, differential experience may be the answer (e. g., Linn & Petersen, 1983). Indeed, there is ample evidence that training can improve spatial skills (Harris, 1978, pp. 426-428) In reanalyzing this vast literature, Linn and Petersen concluded that gender differences in spatial ability are limited to speed of mental rotation and the use of kinesthetic cues and that there are no significant differences in visualization. Since mental rotation has been shown to respond to practice, this conclusion suggests that gender differences in spatial tasks that involve mental rotation could be due to experience.

The importance of all of these findings to education may be that spatial ability is involved in achievement in mathematics. That is, since males tend to outperform females in mathematics achievement, and spatial ability is in turn involved in mathematics achievement, it may be reasonable to postulate that females' lower achievement in mathematics is owed to inferior spatial ability (e.g., Benbow & Stanley, 1980). This, apparently, is not the case. Fennema and Sherman (1977) found that the premise of females' having lower mathematics achievement was false. That is, when account is taken of the fact that males and females have different educational experiences, differences in mathematics achievement disappear.

In short what we can say with confidence is that spatial ability is a mportant variable in mathematics achievement. And although a strong case can be made for the biological basis of the skill, it is less certain that the reason for the differential performance between the sexes is exclusively biological.

Laterality and the SAT. As part of this review an extensive search was conducted in several bibliographic databases to identify reports that might relate laterality to performance on the SAT. Admittedly, the capacity of those systems to uncover relevant articles is far from ideal, yet it is remarkable that almost no articles could be found. One report (Weiten and Etaugh, 1974) used lateral eye movement as an indicator of laterality. The indicator has been suggested by Bakan (1969). As the name implies, this indicator is based on the direction in which the subject's eyes move while performing some mental task. Weiten and Etaugh (1974) asked 48 subjects a series of questions and recorded on videotape the direction of eye movements. They found that some of the students consistently move their eyes to the right, other to the left, while others did not consistently move their eyes to the right or left. Weiten and Etaugh found that the inconsistent movers tended to have lower scores, while the left and right movers had higher scores on both the verbal and quantitative SAT. They interpreted this to mean that "the hypothesis relating incomplete cerebral dominance to intellectual deficits should not be discarded" (Weiten and Etaugh, 1974, p. 206). Indeed no hypothesis, including the null one, should be discarded on the basis of their study since 25% of the 48 subjects did not have SAT scores. Apart from this methodological problem, laterality is such an elusive concept that it is not reasonable to use a single indicator.

Curricular Implications

Brain research has received considerable attention from educators, but unfortunately it appears that many of the results from the scientific literature have been overinterpreted. For example, learning styles have been attributed to different brain hemispheres. Some writers (e.g., Rubenzer, 1982, p. 10) have gone as far as to imply that one of the skills of the left brain is "giving 'correct' answers, [and] scoring well on IQ tests." There is, however, little scientific basis for attributing global styles to one hemisphere or the other. According to Segalowitz:

> Imagination, intuition, and creativity have not been linked to brain activity in any direct experimental work, and, to repeat, even if they were it is not a logical necessity that they should be pertinent to the school system because of that link (p. 211).

It appears to make more sense to evalute curricular suggestions by appeal to their educational value rather than their biological basis. In fact, many of the curricular suggestions that have been made by alluding to brain research could be justified on their educational value alone. Who could be against training for creativity and problem solving? For example, Williams (1983) has proposed a curriculum for educating the right brain. Some of the techniques she recommends are visual thinking, fantasy, evocative language, metaphor, and direct experience, to mention just a few. Many of her suggestions are eminently reasonable. For example, she justifies the use of visual thinking as follows:

> Words, sentences, and paragraphs are not always the most efficient ways to represent thinking. Many ideas are better expressed and more easily understood through pictures, maps, diagrams, charts and mind maps. These visual strategies provide images which draw together and integrate information in a form that some students find much easier to understand and remember (1983, p. 30).

This suggestion is hardly controversial, and it is one that could be made without reference to brain research.

In short, one cannot help but sympathize with proposals to improve the achievement of all students. Precisely because of these proposals it is important to examine the appropriateness of justifying curricular reforms and teaching techniques on the basis of brain research. If we examine the literature, there appears to be no basis for doing so. A sounder strategy would be to justify these proposals on the basis of their educational impact as measured, for example, by achievement tests. This strategy will insure that the truly effective techniques are retained and the ineffective ones removed.

Conclusions

We may confidently conclude that the two brain hemispheres have different strengths. The following table from Bryden (1982) is a conservative statement of what can be safely derived from the experimental literature:

Table 1
Strength of the Two Hemispheres
from Bryden, 1982, Table 6.1

	Left superiority	Right superiority
Auditory	Words Speech sounds	Environmental sounds Music (melodies) Emotional expression in speech
Tactual	Letters Sequential finger localization	Finger localization Random shapes Braille, line orientation
Visual	Words Letters Name matches	Color ? Line orientation Dot localization ? Mental rotation ? Complex polygons Face recognition

Note. The "?" indicates lack of complete replication.

However, there is no solid scientific evidence to link laterality with learning styles or creativity. This is not to say that there is no relationship but only that the relevant research has not been reported. Many of the claims by enthusiasts of brain research seem to be extrapolations of the experimental literature. Often those writers have conveniently ignored the methodological problems that plague this area of research and have not referred to readily accessible reports that disagree with their conclusions.

Nevertheless, it appears reasonable to suggest on the basis of this review that spatial ability probably deserves more attention than it now gets. The argument for such attention is not that one of the hemispheres tends to specialize in processing spatial stimuli. Rather, the argument is that spatial ability is apparently a potent determinant of mathematics achievement and is no doubt involved in other fields, such as architecture and engineering. Moreover, the field-dependence research suggests that spatial measures may be useful for counseling purposes and as predictors of changes in field of study.

The role of spatial ability in the brain literature leads to the following suggestions for further research:

What is the nature of the relationship between spatial ability and the SAT-Q? We have seen that spatial ability is involved in mathematics and science achievement. There are some indications, however, that whatever spatial ability may contribute to academic achievement may already be tapped by the SAT (Witkin et al., 1977). If so, perhaps spatial ability would not then contribute much to prediction. Other literature, however, suggests that spatial ability is a potent contributor to the prediction of academic success in certain fields. As part of this study it would thus be desirable to investigate the possibility that spatial ability measures may provide valuable counseling information that could be used also for forecasting retention.

The second possibility worth investigating is the role of spatial ability in performance on the SAT-Q. If, for example, in some of the items a visual strategy is more efficient, females, as a group may be at a disadvantage if, for whatever reasons, they use a nonvisual strategy. To the extent that this choice occurs only for certain items, the strategy may lead to bias in those items.

A third possibility is to sponsor research on the development of laterality measures. Many of the difficulties encountered in studying the educational implications of laterality research can be traced to inadequate measures of laterality. It may be possible, with advances in technology and psychometric theory, to devise a more reliable and valid indicator of laterality.

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