

Reprinted from COGNITIVE GROWTH AND DEVELOPMENT: ESSAYS IN MEMORY OF HERBERT G. BIRCH, Edited by Morton Bortner, Brunner/Mazel, Inc., New York, 1978.

1

The Origins of Sensory Bias in the Development of Gender Differences in Perception and Cognition

DIANE MCGUINNESS and KARL H. PRIBRAM

INTRODUCTION

A chapter relating sex differences and neurophysiology may seem out of place in a volume dedicated to Herbert Birch, as he was involved in neither field of investigation. Nevertheless, as with any pioneer, his ideas and endeavors have had a significant impact on many areas apparently unrelated to his own fields of study. This impact has been critical for one of us (DM) in the formulation of certain theoretical proposals which attempt to chart the development of perceptual and cognitive differences between the sexes and to relate this to brain function.

The essence of living organisms is that they adapt to their environment. This adaptation is always regulated by biological constraints. One aspect of the process of adaptive biology has been highlighted in a pioneering study in human development by Thomas, Chess and Birch (1969). Applying ethological techniques in a longitudinal framework, these researchers were able to show that biologically endowed temperamental and behavioral characteristics endure from infancy to adulthood. The healthy psychological development of the individual was seen to be determined by the interaction of specific combinations of traits and the way parents and society responded to them. For example, a child with a slow tempo, who needed time to adapt to change in his environment, could be handled with patience and forbearance. If, however, such a

child was pressured or rushed, the ensuing stress could lead to a gross sense of inferiority and neurotic symptoms. These findings are particularly relevant to an assessment of the development of differences between the sexes. The critical problem is to establish which inherent capacities are the most or least modifiable.

Birch's research has also added insight into another important area in the study of sex differences. This deals with the question of how certain perceptual and motor skills become integrated to give rise to the qualitatively different abilities found in males and females. Modality preferences seem evident and lead to the suggestion that cross-modal integration may be different between males and females. This relates not only to the primary sensory modalities but also to the integration of the image of an act with its subsequent visual-motor feedback. Birch's initial involvement with problems of cross-modal function have been detailed in an excellent review by Freides (1974), in which he charts the development of the field from the original work of Birch and Belmont (1964). In his assessment of the literature, Freides is led to ask the following questions:

Is it possible that modality preference (verbalizers versus visualizers) interacts with informational demands to determine the pattern of differentiation or integration at higher levels of cognitive processing? Do genetic factors or early childhood experiences differentially bias or organize modality preferences? The questions do not appear to have been asked in this way, so the data are not available (pp. 302-303).

These are precisely the questions that one of us has been asking (McGuinness, 1976a). That the answers appear elusive may in large part be due to the fact that almost all the studies on cross-modal functioning have ignored sex differences, or have selected subjects in such a way that sex differences are obscured or eliminated. For example, as most females are good readers, and most remedial reading classes contain largely males, a selected population of either all good or all bad readers includes an abnormal sample of male or female subjects.

This chapter takes up the questions posed by Freides and will go on to suggest that the answers are in the affirmative. By assessing the problem in terms of sex differences it can be seen that both genetic and environmental factors do bias modality preferences and that these preferences lead in turn to differences in efficiency for certain cognitive skills. Used in this fashion, the study of sex differences in some circumstances can substitute for more time-consuming longitudinal techniques.

As the sexes differ noticeably and consistently in certain cognitive abilities, the fundamental question is whether or not they also differ in more basic sensory capacities which may contribute to the higher-order function, and if so, does this occur in a consistent manner? For instance, a high degree of discriminative ability in the auditory mode would scarcely be expected to bear much relationship to visual-spatial skill, but could conceivably be involved in the perception of speech.

If we succeed in presenting a convincing case for basic sensory differences between the sexes, we are also faced with the awkward but fascinating question of how similar brain tissue and functional anatomy can give rise to such differences. We propose in the final section a model of brain function in which specific processing facilities are based on the integration of brain *systems*. This is in contrast to current theories which attribute differences in cognitive skills to isolated regions of brain tissue.

The chapter is organized in the following manner: The next section reviews the literature relevant to establishing that basic sensory differences between the sexes do exist and that they can be detected at early ages. This section also includes information on the differences in response patterns between the sexes. In the final section these data are used to present a theory of attention which illustrates the way in which attention to sensory information can act as a bias on the developing system. This section also details the data that support a "systems" theory of brain integration, and contrasts this approach to current simple hemisphere dominance hypotheses.

SEX DIFFERENCES IN PERCEPTION AND COGNITION: A REVIEW

Sex Differences in Sensory Capacities and Response Characteristics

Sex differences in sensory capacity and response characteristics provide some of the most important evidence on the development of perceptual differences. It is difficult to argue that basic sensitivities or responsivities over which the subject has little control are the products of subtle differences in reinforcement due to environmental contingencies. If there is evidence for consistent differences in sensory capacity and responsivity between the sexes throughout life, then it is conceivable that these differences may contribute to other more complex central processes.

Sensory capacity in infancy

In the very young infant, neither the ear nor the eye is functional at any level approaching that of the child or adult (Spears & Hohle, 1967). Thus, the possibility for individual variation in the rate of development is great and sex differences are, therefore, difficult to demonstrate. Tactile sensitivity appears somewhat greater in females in some studies (Lipsitt & Levy, 1959; Bell & Costello, 1964; Wolff, 1969), but negative findings appear in others. Lipsitt and Levy (1959) report a failure to replicate, and Gullicksen and Crowell (1964) could find no sex differences. Data on the neonate for the auditory and visual modalities show little effect of sex (Engel et al., 1968; Eisenberg, 1972; Korner, 1970, 1971; Korner & Thomas, 1970), which suggests, in view of the differences found subsequently, that these modalities in the neonate are not sufficiently developed to provide much useful information. Reviews by Korner (1973) and by Maccoby and Jacklin (1974) essentially confirm this.

There is, nonetheless, a consistent trend in a number of studies investigating neonates and infants up to the age of about four months (Friedman et al., 1970; Greenberg, 1971; Greenberg & O'Donnell, 1972; Collins et al., 1972). When measuring fixation to either checkerboards, stripes, or dots of increasing complexity (diminishing size), females are generally found to fixate the larger or the simpler of the stimuli. Males tend to rapidly habituate to the larger simpler input, while females often habituate more rapidly to the most complex input. As it has been clearly demonstrated that this effect is age dependent, with older children spending more time in fixation of the more complex input, this paradigm seems to be tapping an acuity mechanism (Greenberg & Weizmann, 1971; Greenberg & O'Donnell, 1972). The results from several of these studies suggest that females may have poorer acuity than males, and that the reason they habituate quickly to a fine grained checkerboard or fine stripes is because they appear as a uniform surface. One exception to this result was found in a study by Greenberg and Weizmann (1971) where girls showed more appropriate differential responses to checkerboards of three sizes. Nevertheless, the boys produced more rapid habituation in most stimulus conditions. These findings accord with the significantly superior visual acuity found in males at later ages.

Sensory capacity in the child and adult

Taste. Apart from the finding that females tend to prefer greater concentrations of sugar or saccharin to males (see Maccoby & Jacklin,

1974), the only available information on taste differences and sensitivities between the sexes comes from a well-controlled study by Bailey and Nichols in 1888. They tested 82 males and 46 females of college age to determine thresholds for taste sensation across a number of categories. Their initial interest was the relationship among taste sensitivities to different substances, but they were surprised to find consistent sex differences in each case. The mean scores for males and females for the different thresholds are presented in Table 1. No statistics were performed on these data, but the trend is clearly present, with females most sensitive.

TABLE 1
Sex Differences in Taste
*The number of parts of water to one part of
substance for detection threshold*

	<i>Quinine</i>	<i>Sugar</i>	<i>Acid</i>	<i>Alkali</i>	<i>Salt</i>
Males	392,000	199	2,080	98	2,240
Females	456,000	204	3,280	126	1,980

N = 128 from Bailey & Nichols (1888)

Smell. Nichols and Bailey (1886) again provide evidence on sex differences in sensitivity to smell. Here the trend is reversed, with males considerably more sensitive. Their sample of subjects was 17 male and 17 female college students in the first study and 27 males and 21 females in the second. The data have been collated from the two experiments and are presented in Table 2.

Nichols and Bailey's findings were replicated on 50 adults by Ottolenghi in Italy in 1888. Ottolenghi included a control for smoking. Unfortunately, no further studies are available on either taste or smell to corroborate these very interesting results.

Touch. The trend favoring females in tactile threshold in the neonate is convincingly demonstrated in children and continues into adulthood where the evidence shows overwhelming sensitivity in the fingers and hands of females (Jastrow, 1892; Axelrod, 1959; Weinstein & Sersen, 1961; Ippolitov, 1972). Often there is no overlap between male and female scores. It seems, therefore, reasonable to suggest that greater levels of sensitivity in females will contribute to their superior ability in tests of finger dexterity, which will be discussed in the next section.

TABLE 2

Sex Differences in Smell

Combined data from two studies indicating the number of parts of water to one part substance for detection threshold

	<i>Oil of Cloves</i>	<i>Nitrate of Amyl</i>	<i>Garlic</i>	<i>Bromine</i>	<i>Cyanide</i>	<i>Prussic Acid</i>	<i>Oil of Lemon</i>	<i>Oil of Wintergreen</i>
Males	88,218	783,870	57,927	49,254	109,140	112,000	280,000	600,000
Females	50,667	511,330	43,900	16,244	9,002	18,000	116,000	311,000

Total N = 82 from Nichols & Bailey (1886).

Audition. In the auditory mode, studies on threshold for sound have consistently demonstrated superior hearing for high frequencies in females from childhood onwards. The sex difference increases with higher frequencies and with age (Corso, 1959; Eagles et al., 1963; Hull et al., 1971; McGuinness, 1972). Corso's findings are particularly relevant, as he could find no evidence that sex differences were in any way attributable to specific environmental factors. After eliminating all subject who had even remote experience with environmental noise, or any history of hearing difficulties, the sex differences remained and were, if anything, more pronounced than those found in the total sample.

The most important and consistent difference between the sexes in auditory sensitivity is found in tests involving response to intensity. Since we will be presenting a theoretical position based on such differences in sensitivity and leading to the development of speech and the reaction to inflection, the evidence will be considered in some detail. Females are intolerant of loud levels of sound both in childhood (Elliott, 1971) and adulthood (Corah & Boffa, 1970; McGuinness, 1972). The data from the experiment by McGuinness are presented in Figure 1, which illustrates the level at which adults adjust the volume of sound until it is perceived as barely "too loud." The mean scores across all frequencies were 75 db for the women and 83 db for the males. As loudness doubles

Comfortable Loudness Tolerance Level

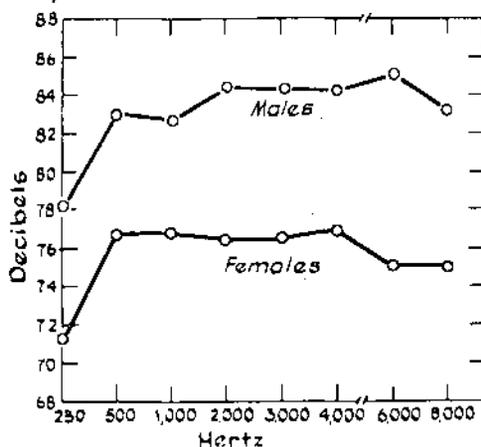


FIGURE 1: Levels of volume set by 25 males and 25 females to the criterion of just "too loud." College age sample. From McGuinness, 1972.

subjectively at about 9-10 db, the findings suggest that by about the level of 85 db, females will hear the volume of any sound as twice as loud as males.

Sensitivity to volume is also found in other tasks. Zaner et al. (1968) report that when children aged 4 to 8 years were asked to judge which aspect of an auditory stimulus was varying, girls were significantly more able to distinguish between changes in intensity. The sexes did not differ in their ability to notice changes in frequency, duration, or number of signals. Also, when Shuter (1964) factor analyzed her results on 200 male and female students of above-average musical ability, a broad general factor of musical ability was found. An appreciation of intensity changes was included in the factor for women, but was entirely absent for men. Shuter also found no sex differences in pitch discrimination between the sexes, a finding which has been replicated (McGuinness, 1972).

Women's sensitivity to sound intensity also occurs during sleep. Wilson and Zung (1966) instructed subjects to waken at the sound of two specific stimuli and to remain asleep during all other noises. EEG was monitored throughout. The sexes behaved similarly in the instructed condition: All awakened, but significantly more EEG activation occurred in females to the noises that subjects were told to ignore. A further study, in which subjects were unaware of the response they were producing, showed that women habituated more slowly on an autonomic measure of digital blood flow to a series of repeated tones (McGuinness, 1973). Slower habituation appears to be reflected by intolerance of auditory repetition in females (McGuinness, 1972).

In the study by McGuinness (1972), it was demonstrated that efficiency in hearing is not continuous across a range of tasks. No correlations could be found among tests of threshold, intensity judgment, pitch discrimination, and tolerance of repetition. This suggests that the total auditory experience is the result of "multiplexing" a number of unrelated sensitivities (Spinelli & Pribram, 1967; Lindsay, 1970). Of the tasks investigated, only pitch discrimination showed any effect of training, improving linearly with the amount of time spent in musical study. As training had no effect on any of the other tasks, it was suggested that these sensitivities are inherently stable and unchanging.

Vision. Sensory capacity in the visual modality also differs between men and women; in this instance the male is more efficient in conditions of light and females more sensitive in the dark. The ability of males in photopic visual acuity has a well documented history. Carter in 1892 calculated the sex difference ratio with respect to the population at

large and 10,000 patients seen by him for ophthalmological treatment. Greater defects in all types of acuity disorder were demonstrated in females 6% more often than should normally occur. His conclusion was that this was due to defective eye muscles. Normative surveys carried out in Sweden (Key, reported in Ellis, 1896) and in America and England by West (1892) and Warner (1893) show that at all ages except at 5 years, girls had more minor visual defects, generally myopia and hyperopia. In Key's report on 14,000 children aged 10-11, over three times as many girls as boys were found to be myopic. All of these authors, however, report a greater number of serious defects in male vision and more blindness; however, with respect to the general population, these are uncommon.

More recent and better controlled studies have produced identical results indicating male superiority in both static and dynamic visual acuity (Roberts, 1964; Burg & Hulbert, 1961; Burg, 1966; McGuinness, 1976b). However, all these studies are on teenage to adult populations. The early work suggesting defects in younger females has not yet been replicated. Skoff and Pollack (1969) could find no sex differences in Vernier acuity for either colored or black and white targets in 96 boys and girls ages 7-14.

In general, comparable data to those presented on the auditory mode are lacking. Only one study is available (McGuinness, 1976b) in which a number of visual tasks were investigated and compared. The study looked at sex differences in young adults in threshold, intensity judgment, acuity, and short-term iconic store. Here, the sex difference in judgment of intensity was the reverse of the finding in audition, with males significantly more sensitive to brightness. However, females were consistently more sensitive in tests performed in the dark, adapting more rapidly and to lower threshold levels than the men (Figure 2). In the visual persistence test (iconic memory), females showed significantly longer visual holding than the males, but only in the dark. The difference disappeared entirely after light adaptation. As in the auditory study, no correlations were found between the tasks, with the one striking exception of photopic acuity and scotopic dark adaptation. This only occurred when the sexes were assessed separately, but was highly significant in both cases.

Other visual phenomena have yielded sex differences. In a continuation of the persistence experiment above, McGuinness and Lewis (1976) investigated sex differences in young adults in response to a Ganzfeld (a field of uniform saturation) and to an after-image produced by a black cross silhouetted against a white photoflood. Men had longer dura-

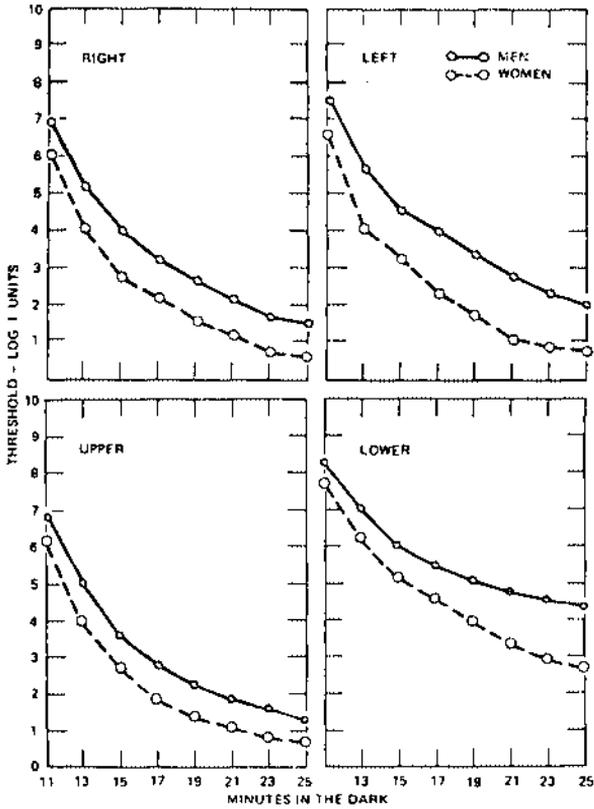


FIGURE 2: Dark adaptation curves for four field positions tested at 20 degrees of visual angle in 30 adult males and females matched for visual acuity. From McGuinness, 1976b.

tions of visual experience in both cases. This was particularly significant in the Ganzfeld experiment. Also, in this study men were consistently more liable to report large fluctuations in the disappearance and reappearance of color, often experiencing the perception of a number of colors not actually in the visual field. None of these effects was commonly observed by the women.

The finding that men have longer after-images corresponds to a similar result in a study by Brownfield (1965). McGuinness and Lewis also investigated sex differences in the phenomenon called the "flight of colors," which is a common effect in an after-image experience. Subjects were asked to report colors at fixed intervals. Table 3 illustrates the frequency distribution for the various colors reported. One hundred percent of

the women, as opposed to 50% of the men, reported colors in the pink-red or low frequency spectrum domain. This was highly significant. It is interesting that the greater sensitivity to red was also shown in the Ganzfeld study, in which women, but not men, held the perception of red significantly longer than green.

TABLE 3

Frequency Table Showing the Number of Subjects Reporting Colors in the After-Image Experiment

	<i>Violet</i>	<i>Blue</i>	<i>Blue/Green</i>	<i>Green</i>	<i>Yellow</i>	<i>Orange</i>	<i>Red/Pink</i>
M	8	11	4	9	10	1	10
F	4	13	7	4	11	1	20

From McGuinness and Lewis, 1976.

In tests where illusions are demonstrated, sex differences are also found. Boys are more susceptible to experiencing rapid reversals in a reversible figures test (see Garai & Scheinfeld, 1968). A further study (Immergluck & Mearini, 1969) on children aged 9, 11, and 13 showed that boys had higher reversal rates over all ages. The authors note that in a previous study on adults a high correlation was found for rate of reversals and performance on the Rod and Frame Test, which suggests that rapid reversals may have some connection to visual-spatial skills. This will be discussed later.

On other tests of visual illusions sex differences are not so stable. Pohl and Caldwell (1968) found that women had lower thresholds for the Phi phenomenon, the apparent movement of two alternatively lit figures. Females also tend to show less susceptibility to the autokinetic effect, where a stationary light appears to move in the dark (Voth, 1941; Chaplin, 1955; McKittrick, 1965). However, in later studies (Aranoff, 1973; Simpson & Vaught, 1973), these findings were not replicated. It is possible that many of these results could be related to the superior performance of females in the dark as shown above. When dark adaptation and room light conditions are not precisely controlled, sex differences may be exaggerated.

In summary, the evidence on sensory capacity shows that females are more sensitive to all modalities at threshold, with the possible exception of smell, and that they possess a certain advantage in some aspects of tactile and auditory processing. Men have superior visual acuity and

greater sensitivity to light. The findings are supported largely by studies on an adult population. This is particularly true of tests on vision, which is rather surprising. There are at present no normative data to support the findings on children carried out at the turn of the century, though the data available are in the predicted direction. Until more developmental studies are performed, the firm evidence on consistent sex differences across the whole age range seems to be that on tactile thresholds and sensitivity to high frequencies and loudness in the auditory modality.

Responses in infancy

In early infancy males tend to be awake for longer periods than females (Moss, 1967; Sander & Cassel, 1973). Male activity is considerably stimulated by the mother who spends more time in direct physical contact with her son (Moss, 1967; Lewis, 1972). Maternal activity has been found to correlate with increased exploratory activity in later childhood (Rubenstein, 1967), which has been demonstrated to be the province of males, particularly at ages 3-6 years (see Maccoby & Jacklin, 1974).

Studies which have investigated overall activity levels, including both gross and discreet actions, often find that no differences can be demonstrated between the sexes (Maccoby & Jacklin, 1973). However, differences do arise when types of response are investigated. As children develop, response differences begin to reflect intended action. Responses are organized to a purpose and, as will be demonstrated, this purpose is to achieve an understanding and control of the environment.

By nursery school age, males are more apt to engage in rough and tumble play and in aggressive acts (Sherman, 1971; Smith & Connolly, 1972). Findings by Goldberg and Lewis (1969) show that boys of one year are more attracted to the unusual and spend more time in play with objects other than toys, while devising novel ways of using them. Girls' activity is generally directed to play which is highly suitable to the toy.

When the total amount of vocalizations are assessed, sex differences fail to emerge, but again the *types* of vocalizations subsequently employed by each sex are noticeably different. In the rate of early babbling, males and females are similar (Moss, 1967; Lewis, 1972), but it has frequently been observed that over time a much higher rate of vocal interchange develops between mothers and daughters (Goldberg & Lewis, 1969; McCall, 1972; Messer & Lewis, 1972). Lewis' study (1972) suggests that this occurs because of a complex interaction between the vocal behavior of the infant and the behavior of the mother. First it was noted by Lewis that girls receive much less physical attention from the

mother, which supports the findings by Moss (1967) noted above, and that girls appear to be comforted by "distal" stimulation, like speech and singing. Males, by contrast, require physical comfort. However, the infants do not differ in the amount of vocalization they produce, and Lewis found that mothers actually reinforce more of the male vocalizations than those of the female. When he looked at his data in terms of how vocalizing by the infant initiated a response from the mother, he found that 50% of male vocalizations elicited a response, but that only 37% of female vocalizations were reinforced. However, 67% of female vocalizations were *in response to* maternal behavior, despite the lower level of reinforcement for these responses. Certainly mothers do not appear to speak more "effectively" to one or the other sex. In a complex series of experiments, Phillips (1973) could find no difference whatsoever in the number and complexity of words per utterance to male and female infants aged 8, 18, and 28 months.

In general, there is little support for the idea that the language facility, both in amount and quality, in females could be produced by the reinforcing behavior of the mother. Lewis' study might even suggest the opposite. The relevant issue is the function of vocalization to the female. Girls use vocalizations to *communicate*, to acquire information about their environment "distally" and they also appear to respond to the emotional inflection in speech, which will be discussed later. The use to which vocalizations are employed by the sexes are illustrated in Table 4 where Smith and Connolly (1972) show that boys make more noises, whereas girls use more speech. Utilization of vocal ability in verbal communication may result in findings at later ages (McCarthy, 1930; Harms & Spiker, 1959; Hull et al., 1971; Oetzel, 1967) that girls have greater clarity and quality of speech throughout childhood. This finding is strongly paralleled by girls' ability to sing in tune. Male monotonous outnumber females by about 6 to 1 (Bentley, 1968; Roberts, 1972).

TABLE 4
Distribution of Vocalizations as a
Function of Age and Sex

	Vocalizations		Talk to Child		Play Noise	
	Boys	Girls	Boys	Girls	Boys	Girls
3:9-4:9 years	82.9	82.4	47.0	65.6	27.7	7.6
2:9-3:9 years	52.8	54.9	24.3	36.7	19.8	8.2
Combined means	67.9	68.7	31.8	46.0	23.8	7.9

From Smith and Connolly (1972)

Sensory-motor integration in the child and adult

Garai and Scheinfeld (1968) have categorized the sex differences in response characteristics as perceptual-motor tasks, which favor males, and as clerical skills, which favor females. Others (Tyler, 1965; Hutt, 1972) have also accepted these distinctions without considering the part played by purely sensory or response characteristics. Two basic findings emerge when only response parameters are considered. Males are superior from mid-childhood onward in speed of reaction time. Because their ability largely parallels muscular development, causing an improvement over girls at about 10-11 years, reaching its asymptote at about 18 years and remaining stable throughout life (Noble et al., 1964; Simon, 1967; Fairweather & Hutt, 1972), it seems reasonable to assume that speed of response might be related to increasing muscle mass and force.

By contrast, females excel in manual dexterity involving discrete movements of the fingers and fine coordination. Using a test of finger dexterity, a peg-board task where subjects have to shift a peg along a series of holes as rapidly as possible, Annett (1970) found that females were superior over all ages tested (3½-15 years), using a sample of 219 subjects. Superiority for females at all ages in most tests of manual dexterity, particularly of fine motor skills, has been well documented (see Tyler, 1965).

It does appear, therefore, that males excel in speed of gross motor outflow, while females excel in speed of discrete and finely controlled motor responses.

When information must be processed before a response is made, the speed of output is then determined by both the type of information and the type of response required. When the information is in the form of a visual display, and the response requires large muscle units, males excel to an overwhelming degree. Cook and Shepard (1958) found that boys are superior when operating a lever to change direction of a spot of light at ages 5, 10 and 20 years. In a similar task where subjects had to displace a green disc to coincide with a red ring that appeared in 1 of 49 positions, boys and men, aged 5-70 years, consistently scored more correct matches over all ages. Ammons et al. (1955) also report that, in tracking tasks, boys' performance begins to diverge noticeably from the girls' at about 11-12 years and thereafter is consistently superior. In two further studies on adults (Noble & Hays, 1965; Shepard et al., 1962), males were found to be greatly superior in producing rapidly timed movements to visual displays. It has been suggested by Harris

(1976) that there is a spatial component in these tasks. This will be considered in the section on cognitive processes.

When information is in the form of symbolic or semantic material, and the response required demands attention to detail, females are superior. Tasks such as typing, cancellation tests, and others categorized as "clerical" (Garai & Scheinfeld, 1968) are always performed more efficiently by women (Tyler, 1965). The WISC and the WAIS coding and digit substitution tests are also consistently performed best by females.

It is possible that males and females utilize different types of environmental information preferentially, and in addition to this we note here that where gross differences arise, the response to the task is also relevant. The tasks which favor females generally require small and reasonably well-coordinated movement, while those which favor males incorporate larger motor processes. In order to disentangle stimulus effects from response effects, a female-typical response should be paired with a male-specific input, or vice versa.

The nearest approach to this type of experiment is that of Fairweather and Hutt (1972), where they varied information in bits in a choice reaction time test. These authors found that at ages 5-7 years, girls were faster in simple reaction time, a cross-over effect occurred where sexes were matched at about 8-9 years, and from then on boys were superior. However, when information was increased (choice reaction time), the girls were found to be superior at all ages and this difference increased as the information load (in bits) was increased. In their adult sample the difference largely disappeared, although no details of the size and age of this sample were given. Since we know that men are faster in simple reaction time, this finding would mean that females process information faster across all ages.

When assessing the types of tasks that favor women, such as clerical skills, it is important to recognize that certain of these tasks are, in fact, tests of choice reaction time. An example par excellence is typing, where information from a written or printed sheet is rapidly transferred by pressing the appropriate keys. Speed of typing reflects both manual dexterity and speed of information processing. As yet there are no conclusions as to what is involved in rapid information processing. It could be that attention span in females is somewhat greater than in males, and in our view this concept is interchangeable with some type of intermediate or short-term memory system. Holding a number of items in store simply refers to the amount of information one can *attend* to at any one time. We will therefore proceed to review the relevant literature on attention.

Sex Differences in Attention

In 1890 William James presented an extensive systematization of attentional characteristics in which he discussed the evidence for involuntary (reflex) and voluntary (selective) processes. Recently this type of analysis has been extended to present a comprehensive model of attention based upon both behavioral and physiological data (Pribram & McGuinness, 1975). Three basic attentional systems are considered in the model: *reflex attention* or arousal; *vigilant readiness* or activation; and *effort in which the input is coded to produce a change in a neuronal model*. These three systems have different sequences and organizations when different types of attention are operating. Thus a range is possible from open and unfocused attention during selection to a situation in which reflex arousal is inhibited to allow for the complex transformations essential in a reasoning task. Flexibility and inhibitory control are part of the developmental process in the young child.

In the quest for the organizing forces producing sex differences in perception, the emphasis in this section is on the development of these attentional systems in the infant, and how infants differ in stimulus preference. It appears, from the data, that at ages where infants have not as yet been affected by selective reinforcement, they nevertheless show an interest in certain stimulus characteristics and not others. Types of stimulus information are more salient to one sex than the other and, as will be shown, this salience relates to channel efficiency and subsequently to the way in which the developing child seeks to control and interpret his environment.

The data presented on infant attention are selected to illustrate the *common trends* in the literature. It must be emphasized that, when measuring attention in infants, their undeveloped control makes it difficult to replicate consistently. Thus it is in searching for commonalities that we can progress. As is often the case, the data which contribute towards this inductive process are not always those data the experimenter intended to produce, or even those he wished to emphasize.

One of the most consistent trends observed in a number of studies is that females are particularly attentive to certain types of auditory cues, and they appear to attend to the emotional and meaningful properties of sound. Simner (1971) found that 1-week-old females distinguished noticeably between the sound of an infant's cry and white noise played at the same volume. Although Simner could not replicate these findings entirely, the trends are consistent, and females were also found to be significantly more stable in their crying responses over time than males.

Watson (1969) investigated 14-week-old infants and found that girls could be trained to maintain visual fixation of a white circle when a tone was used as reinforcement, but not when a line drawing of a face was employed. Boys performed better with visual reinforcement. However, it must be noted that Ramey and Watson (1972) could not replicate this result.

In a comprehensive study, Kagan and Lewis (1965) found that 24-week-old girls responded more to music (complex input) on measures of motor and autonomic changes, whereas boys reacted more to tones (a simple repetitive input). In the same infants at 13 months, girls consistently reacted to verbal input with *high* inflection and a significant positive correlation was found for the girls who had high attention levels to music in the first experiment and who at 13 months paid most attention to the verbal input with the maximum uncertainty, illustrating that they noticed its novelty. It is possible that the reaction to high levels of inflection relates to the females' sensitivity to intensity differences illustrated in the preceding section. Girls were also found to vocalize more to auditory input than boys.

Bernstein and Jacklin (1973) found a significant effect favoring females in infants 3½ months of age. Females were more attentive to both social and non-social sounds. This result was replicated in a study by Cohen (1973) on infants 5 and 8 months old. He found that females looked significantly more at a sound source than males. There is also evidence in young children aged 1 year that loud frightening sounds are less effective with males than females, and particularly so at lower volumes (Maccoby & Jacklin, 1973).

The evidence on visual attention suggests that the sexes respond preferentially to two different categories of visual input, and that this has little to do with maturational factors affecting visual acuity (Fagan, 1972). Faces are a powerful stimulus for both sexes. However, from about 4 months, females show more interest and discriminability than males, whether exposed to masks of faces, photographs or line drawings (Lewis et al., 1966; Lewis, 1969; Fagan, 1972). Girls are able to distinguish between realistic and unrealistic line drawings and vocalize appropriately to the most realistic (Lewis, 1969) and are able to discriminate between photographs of two very similar faces (Fagan, 1972). Boys did not show this ability on any of the tasks using photographs.

By contrast, where sex differences are found, males from 4-6 months onwards respond preferentially to blinking lights, geometric patterns, colored photographs of objects and three-dimensional objects (Myers & Cantor, 1967; McCall & Kagan, 1970; Pancratz & Cohen, 1970; Cohen et

al., 1971; Kagan & Lewis, 1965; Cornell & Strauss, 1973). Boys had faster habituation (showing rapid coding) to non-social stimuli, and particularly produced consistent orienting responses to novel objects. This is an interesting contrast to the slower habituation of males to faces found in a study by Lewis (1969). Boys do not appear to differentiate between faces and objects in the amount of vocalizations they produce. In the Kagan and Lewis study, boys vocalized significantly more to the blinking light presentation, and findings by McCall and Kagan (1967) support the interpretation that in boys vocalization is part of a spontaneous motor outflow reflecting *interest*. In this study infants aged 4 months were shown a series of random patterns. When males exhibited a heart rate deceleration to a stimulus, indicating vigilant attention, this was almost always accompanied by vocalization. No such relationship was found for girls. These same sex differences in smiling responses to objects and to faces have been noted in some of the studies above, with the sexes not differing in the amount of smiling, but the males smiling equally at objects and faces, and females smiling only at faces.

These findings can be interpreted to suggest that girls give more appropriate and discriminating responses to social or socially affective stimuli—a reaction which is slightly stable in females, but not in males. This is also supported by the finding of Moss and Robson (1968) that girls' visual behavior is related to the amount of social interaction with the mother. Social responses were also present in the boys but not nearly to the same degree. Boys appear responsive to novel stimuli when it is non-social in character and especially when it is brightly colored or three-dimensional (McCall & Kagan, 1970; Pancratz & Cohen, 1970; Cornell & Strauss, 1973). Further work of Mitchell and Brandt (1970) shows a similar sex difference in looking and social behavior in the rhesus monkey.

Subtle differences in timing of responses found between the sexes reveal differences between the informational and meaningful properties of the stimulus. Information relates to the amount of uncertainty which is reduced by any particular input, while meaning is related to intention (Pribram, 1976). Any input that ultimately produces an intentional motor response rather than an unintentional one can be said to be meaningful. To clarify this point it was noted that frequently vocalizations and smiling responses for boys were unintentional or reflex motor responses. Heart rate deceleration and vocalization were found to correlate for boys, while heart rate deceleration and movement arrest correlate for girls (McCall & Kagan, 1967; Kagan & Lewis, 1965). Also, in a study by McCall (1972), boys were found to produce smiling responses

to novel input, while this reaction was not predictable for girls. Girls specifically smile and vocalize when stimuli are presented that are most likely to smile and vocalize back. This suggests that they distinguish stimuli, including a realistic face from an unrealistic one, on the basis of their functional significance or *meaningfulness*, and not only on the basis of their novelty, and that they relate their behavior appropriately. These findings provide convincing evidence that females are aware of the social and non-social implications of stimuli and that their response output is utilized intentionally for the purpose of communication. Boys' intentions are revealed by gross motor and manipulative action, as discussed below.

Studies on attention during childhood have concentrated exclusively on the response to novelty. However, the interpretation of this term is often misleading. In fact, all children in these experiments respond to the novel input; they notice its occurrence. It is rather what they choose *to do* about it that distinguishes their behavior. Another misconception is that only objects are novel. This sometimes leads to the inference that because boys are significantly more likely to show approaches to novel toys (Smock & Holt, 1962; Mendel, 1965; Hutt, 1970), they are more sensitive to novelty *per se*, as well as being more imaginative in devising ways of playing with the novel toys than girls.

Yet *people* can also be novel. In an observational study of newcomers entering a play group, McGrew (1972) reports that girls as young as 3 years of age responded to new children with affection, interest and comforting actions and verbalizations. The "novel" interlopers were initially ignored by the boys and were excluded from their games.

The object-social distinction between males and females appears pervasive throughout all age groups, but this dichotomy tends to be blurred when social interaction is investigated. Maccoby and Jacklin (1974) review the evidence and conclude that greater social orientation cannot be clearly demonstrated in females. What their review does suggest, however, is that people *mean* different things to males and females. People appear to be assessed by males more on the basis of their function or utility (can they play games or build a tree house?) than on the basis of their personal characteristics. Thus boys can often appear more social because they are group oriented, while females are found to seek out more intimate personal relationships. However, females do appear to be more interested in people, and certainly males show more interest in objects.

This distinction is clearly brought out in a study on adults using binocular rivalry by McGuinness and Symonds (in press). When photo-

graphs of objects were paired with photographs of people and presented stereoscopically, one to each eye, females spent significantly more time reporting people than objects, while males reported the opposite. Since it has frequently been observed that the effect of a disparate stereoscopic display is to produce attention to the most meaningful input (Bagby, 1957; Engel, 1956; Kleiven & Rommetveit, 1970), these results confirm the suggestion in the literature that males are more object oriented while females are more social.

An understanding of the quality of this difference can be provided by evidence from an early study by Jastrow (1891). High school and college students were asked to form word associations to a list of words. Jastrow categorized these associations and found that males and females were remarkably different in their associative processes. Table 5 sets out the sequence of word association categories in order of the most to the least frequently employed.

One of the most interesting findings was that the typical male response to an object is to provide its *action*, a response which did not occur in females. Instead, females responded to objects by naming their quality. This illustrates that objects interest males because of what they *do*. The female supplies the descriptive code which is most communicable. Also relevant to this distinction is the finding that males provide part association to a whole, whereas females provide whole associations to parts. Again, this is indicative of the inferred action stimulated by the word. Reducing objects to parts implies a manipulative tendency. Associating wholes to parts improves memory (chunking or categorization) and aids the communicative processes.

TABLE 5

Sex Differences in Categories of Word Associations
from Most to Least Common

Males	1. Homophone
	2. Whole → part
	3. Object → activity
	4. Activity → object
	5. Category
Females	1. Part → whole
	2. Object → quality
	3. Quality → object
	4. Unclassifiable—Ambiguous or remote

From Jastrow (1891)

Sex Differences in Cognitive Competencies

So far the literature reviewed in this chapter has provided evidence for consistent trends and biases between the sexes. The evidence on tactile sensitivity and manual dexterity for females shows how sensory information and response efficiency are integrated. Similarly, in the infant studies, the potency of social stimuli for females and non-social stimuli for males finds its mutual counterpart in subsequent behavior. The argument that these differences arise because of differential reinforcement is difficult to support when the following questions are posed: Why do males, who receive more affection and direct physical contact with their mothers, prefer objects to people? If female speech is supposed to be fostered by maternal behavior, how does the male response repertoire escape this influence? There are no adequate answers to these questions unless certain processes are assumed to be biased by differences in neural structures present in early life. In what fashion do these biases affect cognitive functioning?

Although space does not permit an extensive coverage of the evidence on differences in cognitive ability between the sexes, certain factors discussed in this section are relevant to the conclusions drawn in the final section. Two points are of interest. First, our view of a communicative female and a manipulative male will be expanded by new evidence on sex differences in other cognitive processes besides the classic linguistic and visual-spatial distinctions, such as memory, imagery, social intelligence and problem solving. These findings make up the content of this section. Secondly, to clarify the problem of how cognition is defined an excerpt from the paper "The Neurology of Thinking" (Pribram, 1959) illustrates that in cognitive processing two basic functions are involved: One deals with the programs that partition inputs into sets (categorization) and the second with a mechanism that evaluates outcomes (intention).

This distinction allows greater precision in the description of attitudinal factors: those related to differentiation can be redefined as a capacity to acquire information—to search through a large number of possible inputs (especially negative instances); those related to intention can be redefined as the capacity to choose one outcome (a positive instance) in the face of a large number of possible outcomes (Pribram, 1959, p. 282).

Cognitive processing often depends upon the dovetailing of these two modes of thought—the capacity to define sets and subsets of information and the capacity to choose efficiently and wisely between actions related to them. We have made the point throughout this presentation that,

due to certain sensory and response biases inherent in males and females, their capacities of differentiation and their intentions will be dissimilar. Thus we infer that primary perceptual processes and perceptual-motor integration are the building blocks of any cognitive system and that attentional controls furnish the programs or subroutines that determine the architecture of that system. Reasoning, or high-level cognition, occurs when the anticipation of the outcome is matched against the accuracy of categorization.

In characterizing the sexes as exhibiting dissimilar intentions, we have suggested that the male is biased to express his intention in action, and the female in communication. If this distinction is valid, it should be maintained at the cognitive level in two ways: First, the higher level skills pertaining to intentional behavior should function along similar output dimensions, and second, the information or knowledge available to the individual will be processed or "captured" by different categorical systems. A manipulative animal presumably would code the product of his actions and would be alert to information that allowed for sufficient scope for his manipulative tendencies. One would anticipate that visual images, particularly images in depth, would receive special attention. A communicative animal needs to receive and transmit all signs and symbols held in common by her species and to relay expressive movement. A further requirement is that she *remember* the information long enough to transmit it to another.

Clearly, we cannot maintain that the sexes are exclusively adapted to two entirely different modes of thought. We suggest merely that there is a difference of degree. It is not that the female is inactive, but that her activity is directed toward more communicative aims. The male also communicates, but as Jastrow's experiment on word association has shown, the male linguistic code has been biased toward action. Bearing these distinctions in mind, we set out briefly in this section a summary of the known data on sex differences in cognitive ability. In most cases the skill involved is more accurately subsumed under higher-level categorizations; in few others the ability is reflected in the efficiency of intended action when multiple outcomes are possible. In only two instances—verbal reasoning and problem solving—does the complex interaction of differentiation and intention occur to produce behavior that is perhaps most truly "cognitive."

Special abilities in females

Verbal and Auditory Skills. It was mentioned earlier that females aged 1-5 years are more proficient in linguistic skills, especially the earlier

onset of speech, and length of utterance. Perhaps the most notable distinction between the sexes at this early age is the use of speech by females for specifically communicative purposes. This was clearly brought out by the data of Smith and Connolly in Table 4. The early aptitude of females is fully documented in the review by Maccoby and Jacklin (1974).

However, this early advantage tends to fade during middle childhood. Again the reader is referred to Maccoby and Jacklin for a review of these studies. In particular, vocabulary tests fail to produce sex differences, though females retain a marginal advantage in overall language ability such as fluency, comprehension, verbal reasoning, and flexibility in handling verbal symbols (anagrams). Their superiority is mainly evident in large sample surveys, though they do perform outstandingly well in tests of reading skill. It is well known that remedial reading classes contain significantly higher proportions of males (Ounsted & Taylor, 1972; Maccoby & Jacklin, 1974).

In adolescence and adulthood, females once again clearly emerge as the superior sex and Maccoby and Jacklin suggest that this may be due to different phases of development. While this must remain a possibility, we would suggest that environmental factors may also be critical. First, as early schooling places greatest emphasis on verbal skills, these pressures could markedly improve male performance. Later, the insistence in maintaining static age groups in most schools may handicap females and retard progress. Thus the natural ability of the female is partially checked to emerge later when more complex verbal skills are needed. When subjects are introduced that are more specifically related to masculine aptitudes, like higher mathematics and science, females would again begin to demonstrate their linguistic advantage. Support for this view is given by the findings of the Stanford Research Institute survey on deprived families. Here females in middle childhood were noticeably ahead on all linguistic measures (see Maccoby & Jacklin, 1974). These results indicate, by negative inference, that a *good* environment can reduce the natural differences between the sexes in language ability. To anticipate a later discussion, we would like to point out that early emphasis on spatial-motor skills might produce a similar remedial effect for females.

Recently, behavioral data from McGuinness' laboratory have suggested that there are two components of a biasing process which facilitates language development. The first is involuntary attention to a specific mode, and the second is a further bias to the most competent subsystem within that mode. From our evidence it appears that what is noticed or

attended to by females in the auditory domain is a range of specifically *linguistic* cues. It will be recalled that *no* sex differences have been found in other auditory skills such as pitch discrimination, rhythmic aptitude, harmonic analysis, and so forth.

Two studies were carried out. The first (Biggs, unpublished) produced overwhelming evidence that females process verbal stimuli faster and more accurately than males. Biggs presented words just below threshold followed immediately by a masking stimulus. Subjects had to respond to the stimulus by naming the word and then by making various categories of inference about the word. The analyses focused upon the "subliminal" stimuli. The few correct replies were discarded as data. There were two major findings. For both sexes, *meaning* was processed more accurately than any other characteristics of the stimulus, such as identification of parts of speech (verb or noun), number of syllables (1 or 2), and upper or lower case characters. Subjects of both sexes performed well above chance when asked to provide an associative category and to rate words on Osgood's dimensions of evaluation and potency. The second result was that on every measure females were noticeably superior to males, with males performing at chance on the tasks requiring judgments of the physical characteristics of the stimulus. It must be noted that the sexes did not differ significantly in flash rate threshold, so one sex did not have an advantage in stimulus availability.

Biggs concludes from her data that word recognition is a sequential process in which meaning is extracted first, followed by the physical characteristics of the stimulus and finally by recognition and naming of the word in conscious awareness. She suggests that the sex differences occur because the sequence is accelerated in females. It is possible, however, that more parallel processing or attentional capacity is available to the females for linguistic material, though their scores on the various tasks followed the same linear trend as the males'.

In a suprathreshold experiment (McGuinness & Courtney, unpublished), male and female college students were tested in their speed and accuracy for both visual and auditory search. Subjects were asked to press a key to either a letter or a sound (A, or ā, I or i) in words presented visually and verbally. There was a further condition of distraction (auditory or visual) versus no distraction. Allowing for the faster simple reaction times found universally in males of this age, on the order of 50 milliseconds, males and females were equal in time to locate a letter or a sound in a word presented visually. In the auditory conditions females were superior. Also, the error scores for males in both auditory tasks were 2 to 3 times greater. In keeping with the findings on auditory

and visual sensitivity, males were found to be more distracted by visual stimuli (a series of complex random patterns) while processing auditory information. Females were not differentially affected by the distractors.

Both studies provide direct evidence that selective attention and, subsequently, cognitive processes are primed by neural competence. Males and females receive equal amounts of all types of auditory information from birth onwards, and one must conclude that the differences in processing capacity must be derived from innate competencies.

In concluding this section, we would like to emphasize that female skill in language reflects each aspect of the cognitive skills, in anticipating outcomes (intention), and also in the complex interaction of the two by virtue of their superior performance in tests of verbal reasoning (Herzberg & Lepkin, 1954; Lindzey & Goldberg, 1953).

Memory. Jastrow in 1891 carried out a word association test on large numbers of high school and college students. The results of the categories employed in association are reported in Table 5. Jastrow also asked that subjects return 48 hours later whence they were told to provide a list, unprompted, of all the words they had supplied during the test. Females scored a mean of 58%, males 40% correct. When the subjects were supplied with the cue word, the sex difference disappeared.

Recent work confirms these earlier findings showing females superior in most forms of visual and verbal memory. In tests of verbal recall presented both visually and aurally, Zahorsky (1969) found that in children, aged 8, 11, and 14, girls were superior at all ages in both modes of presentation. This result was similar to findings produced by Mittler and Ward (1970) and by Duggan (1950), who tested verbal and object recall in 14-16 year olds. Superior recall is also found in adult females for categorized and uncategorized items (Randhawa, 1972) and for visual and verbal information with both low and high imagery contents (Ernest & Paivio, 1971). Ernest and Paivio also report a female superiority in a subsequent test of incidental memory for which the subject was unprepared. Here female superiority increases particularly for the high imagery items. This result has been replicated in a study measuring recall for an array of several colored photographs in both adults and students by Marks (1973). Maccoby and Jacklin (1974) report that females are particularly superior in verbal recall.

In view of the results cited on social facility in females, memory for socially relevant information ought to be superior in females. Witryol and Kaess (1957) tested 170 students in three tests of social memory, which involved remembering names and faces either from photographs or in realistic group situations. The girls' scores were significantly higher

than the boys' on all three tests. In an even more realistic approach, Bahrck et al. (1975) tested social memory for face recognition and matching names and faces in students who had graduated from high school across a wide range of years. Women were found to be superior at remembering both the faces and the names of former classmates.

The data indicate that when the subject is instructed to remember the items, females are superior, but more importantly, even when not instructed females remain superior. This was demonstrated in the Jastrow study, and by Ernest and Paivio (1971). A test of incidental recall was also carried out in our laboratory (Chaplin, unpublished data) on school children, aged 16-18 years. Subjects were asked to rate lists of words or pictures projected onto a screen. Females were found to recall more of the words in all conditions, and improve noticeably when compared to males over subsequent recall trials.

Social. Guilford in 1967 outlined his factor theory of intelligence. While we do not wish to debate the merits of factor analysis, we do agree that his category of "behavioral intelligence" is important as well as neglected. Part of intellectual ability includes appropriate and efficient responses to social cues. Guilford defines this as the ability to extract information about the intentions, wishes and aims of the other person. Behavioral intelligence is therefore a higher-order *empathy*. Unfortunately, there are few studies that investigate this problem directly. As has already been noted, girls as young as 3 years respond appropriately to children in need (McGrew, 1972) and Hutt (1972) reports on the females' greater cooperative spirit. The Witryol and Kaess study shows that girls remember socially relevant stimuli more than boys. This has been strongly confirmed by Bahrck et al. (1975).

Goodenough (1957) has found that sensitivity to persons occurs in girls at 2-4 years. Girls included more persons in their drawings, while boys scarcely drew people. Also, girls were found to verbalize more about people in a test designed to elicit verbalization from abstract stimuli. Ninety-two percent of the girls talked about people as opposed to 38% of the boys. Oetzel (1967) lists 21 studies in which girls and women were reported to have a significantly greater interest in people and social matters than males.

However, while one might expect that a greater *interest* in people would bring about more intelligent behavior with respect to empathetic understanding, this remains an undocumented field. The most concrete support comes from studies which show that females use significantly more complex psychological categories or constructs in describing others

than males (Livesley & Bromley, 1978; Little, 1968; Yarrow & Campbell, 1963).

Special abilities in males

Spatial-Mechanical. The superiority of males in visual-spatial ability is well documented and need not be discussed extensively (Guilford, 1967; Tyler, 1965; Garai & Scheinfeld, 1968; Hutt, 1972; Buffery & Gray, 1972; Maccoby & Jacklin, 1974; Harris, 1976). Barratt (1955) reported that men had higher scores on all 10 of Thurstone's spatial tests, and were significantly superior on 8. Hutt (1972) has compiled a table for the main findings over several studies using the WAIS and WISC subtests. Males are more often superior on the object assembly test and, to a lesser degree, in block design and picture completion. Spatial ability is also highly related to mechanical ability, as measured by mazes, puzzle boxes, and assembly of small objects. In the Bennett mechanical comprehension test, a highly significant sex difference is found in favor of boys and men. Only one girl in 20 exceeded the male average (Bennett & Cruickshank, 1942). Males also experience considerably less disorientation in real space (La Grone, 1969). An extensive review of the tasks at which males excel is presented by Harris (1976). In general, their superiority is confined to abilities which relate to perception of objects in space.

A particular aspect of spatial ability at which males excel seems to be the capacity to rotate or isolate visual images into new planes and combinations. It is often observed that the solution to a mechanical problem is more readily resolved by looking rather than by continuous trial-and-error manipulations. However, if the theoretical views of Piaget (see Flavell, 1963) are correct, schemata are internalized only after a great deal of exploratory and manipulative behavior. The salience for males of novel objects and their exploratory tendencies have been noted earlier. It is possible that early manipulation will give rise to a high degree of three-dimensional spatial imagery.

In studies of "cognitive style," Witkin et al. (1962) have investigated certain performances in males and females designed to reflect "independence" or "dependence" on the field. Males fall into the "independent" category. The most reliable of Witkin's tests has been the Rod and Frame Test, in which the subject is asked to set a rod to the vertical when it is surrounded by a tilted frame. As the Rod and Frame correlates and forms a factor with block design, picture completion and object assembly on the WISC (Witkin's own data), then it seems reasonable to conclude

that the Rod and Frame Test is measuring certain aspects of spatial ability and that performance on the Rod and Frame Test has little to do with being "analytic," "global," or "independent" of the field as Witkin would suggest.

It is thus undeniable that men excel in the area of mechanical-spatial ability and that this can be demonstrated on a number of tasks. What is unacceptable to us and to others (Sherman, 1967; Bock & Kolakowski, 1973) is the assumption that performance on such tasks as the Rod and Frame Test is indicative of some higher-order capacity for analytic thought.

Another question arising from an assessment of visual-spatial differences between the sexes relates to the relative importance of genetic and environmental components. Young children do not exhibit the differences to any large extent and the advantage for males does not occur until mid-childhood or later (Witkin et al., 1962; Garai & Scheinfeld, 1968; Maccoby & Jacklin, 1974). A developmental change appears to occur due to either environmental or genetic factors. Recent findings (Berman, 1974) show that boys exhibit poorer spatial ability than normal in certain stressful environments, particularly where the father is absent. Thus environmental factors are implicated but the evidence for a genetic component is becoming more convincing (see Bock & Kolakowski, 1973). Harris (1976) summarizes the data for the genetic viewpoint, showing that there is evidence for a recessive gene on the X chromosome, but goes on to suggest that the genetic influence is primed by androgen. In the absence of certain minimum levels of circulating male hormones, spatial ability fails to develop, even when the genetic disposition is such that spatial skills should be high, as in the case of Turner's syndrome.

There is the additional evidence that certain spatial tasks, such as mechanical aptitude, aimed throwing, and, to a lesser extent, tracking speed and accuracy, are superior in males from quite early ages, as noted earlier. It is conceivable that, if a genetic basis for spatial ability exists, it is initially expressed in exploratory and manipulative behavior. It has never been demonstrated whether the more sophisticated cognitive tasks requiring spatial-rotational skills are related to earlier ability to perform in simpler mechanical tasks. If such a relationship were found, it would support the genetic theory, and would suggest that this genetic visual-spatial advantage could be developed by training.

Thus the later development of abilities in visual rotation of objects, maze learning, map reading and sense of direction could either evolve from differential learning or be accelerated by genetic releasing mecha-

nisms controlling male hormones—or both. Data from Berman on the effect of stress on boys' spatial ability (but not girls') could be interpreted to implicate both genetic and environmental factors: the stress producing a reduction in androgens through the link with the pituitary adrenal axis which controls cortico-steroids, and/or the effect produced by a female dominated environment.

Mathematical. While there is no difference between the sexes in mathematical ability until early teens (see Maccoby & Jacklin, 1974) it appears that, while males improve over females at this time, girls' mathematical ability actually *declines* from ages 11-15 with respect to their previous performance (Ross & Simpson, 1971). The available evidence would indicate that this is not entirely due to the emphasis in schools on mathematical ability being a "boys'" subject. The data suggest, however, that mathematical superiority in males occurs as the problems dealt with increase in their emphasis on spatial properties. Bock and Kolakowski (1973) note that spatial ability correlates with school geometry ($r = .57$) and quantitative thinking ($r = .69$), as well as with drafting, shop mechanics and watch repair. Werdelin (1961) studied performance on school tests of geometry on 148 male-female pairs matched for age, social class, reasoning, verbal and number abilities. He concluded that the inferior female skill is due to spatial factors. Sherman (1967) reviews some of the evidence on this problem and warns against grouping studies on problem-solving and mathematical ability without first assessing the spatial component involved in the problem.

Curiosity and Problem-Solving. The studies cited earlier on boys' distractibility by novel objects and their exploratory behavior suggest that "curiosity" may be the best summary term to reflect these behaviors, as it implies both awareness and activity. There is now fairly convincing evidence that this characteristic of curiosity in boys (but not in girls) leads to success in certain types of problem-solving tasks, usually those which require visual or manipulative solutions. Greenberger et al. (1971) found that problem-solving ability in boys was highly correlated to two tests of curiosity, while in girls the correlation was to verbal ability. These results and the confirming results of Kreidler et al. (1974) strongly suggest that where problem-solving involves the manipulation of objects and the ability to break set, to try a range of approaches, boys will be superior. That boys excel in problems which involve restructuring is now well documented (Garai & Scheinfeld, 1968; Hutt, 1972; Maccoby & Jacklin, 1974).

Thus it can be seen over all these abilities in which males excel that there are specific skills in categorizing spatial relations and in framing

appropriate intentions on the basis of successful manipulations. At later ages, this allows a high degree of three-dimensional visual imagery and produces success in reasoning tasks which require the interplay of action in relation to space.

Conclusions

The essential findings are these: Males respond to objects more than females, and most noticeably those which are geometric, brightly colored or three-dimensional. Novel visual input produces a range of responses which extends from spontaneous vocalizations in infancy to direct contact, manipulation and investigation in childhood. Boys generally appear more active and impulsive, and eventually are able to solve restructuring problems with greater alacrity. From years of early experience in contact with physical objects, they ultimately learn what can be done with objects and object relations. By puberty much of this ability is internalized and visual-spatial problems can be solved without manipulation by silent nonverbal transformations. Nevertheless, males consistently are attracted by objects, and enjoy the challenge of coming to grips with the physical environment.

Are these abilities a result of cultural influence, or do they arise from the young male infant's initial fascination with objects? There is no doubt that an interaction occurs, but mechanical ability must be derived from some early interest. The data show that this interest is predominantly found in males and that it is manifested as early as 4-5 months of age, before the infant can be selectively influenced by the tangible physical properties of his environment. Further, from early teens onwards, males possess keen visual acuity and fast efficient responses which correspond to their increasing physical strength. All of these attributes lend themselves to an all around superiority in exploratory and *manipulative action*.

The nearest one can come to describing a central trait for females is to subsume many of their skills under the heading of *communication*, though this does not capture the range of female capacities. The data on the youngest age group show that, in females, the auditory system is at first predominant. As was seen earlier, before visual discrimination is developed, females listen and respond meaningfully to a range of auditory inputs, whether in the form of an infant's cry, adult speech, or to music. By the age of 4-5 months they show a preference for faces over objects, and by 5 months are able to distinguish not only one person from another, but also photographs of people. Females also show a spe-

cific response pattern to auditory and visual information that captures their interest. Their motor activity slows, along with heart rate deceleration (Kagan & Lewis, 1965), and they smile and vocalize to social stimuli, whether their own mothers, or photographs of representations of socially meaningful stimuli. From these early and highly consistent behaviors, females continue through life to be more sensitive to certain categories of auditory input, in particular intensity changes and localization of sound (Pishkin & Blanchard, 1964; Pishkin & Shurley, 1965; Schaie et al., 1964), and to develop a strong interest in people and social situations. During this developing period they also display consistent superiority in handling speech and singing, at all levels of perception and production.

Apart from these findings, females also show greater tactile sensitivity from early childhood; this is later expressed in fine digital coordination which finds its outlet in delicate handwork and musical performance. It is assumed that fine motor control is a predominant contributory factor to "grace," as exhibited in the dance. Finally, females show ability in remembering verbal, visual and social information and display a greater degree of visual imagery than males. The data suggest that they can process more information initially (see Fairweather & Hutt, 1972) and respond with flexible selective programs more efficiently than males.

NEURAL SYSTEMS AND SEX DIFFERENCES

Introduction

The data reviewed in this chapter have been organized under the headings of cognitive, attentional and sensory-motor performance. In the introductory remarks to the attention and cognition sections we pointed out that it is difficult to disentangle the effects of sensory-motor constraints on control functions such as attention, or on higher-order processing involving the cognitive capacities of reasoning and abstraction. In this final section, we hope to make a case for the development of a brain organization distinguished on the basis of simple effector, i.e., motor and endocrine differentiation between the sexes. First, however, we will review the current neurophysiological theories which take as their starting point the *cognitive* dimension exclusively.

Cognitive Explanations Based on Brain Asymmetries

Almost without exception, physiological theories of sex differences in perceptual and cognitive skills concentrate on the linguistic-spatial dis-

inction between the sexes, and attempt to correlate these functions with the evidence that the left posterior hemisphere controls language in almost all right-handed and most left-handed people, while the right posterior hemisphere subserves certain spatial processes. These data are reviewed by Sperry (1974) and by Buffery and Gray (1972).

Levy (1971) proposes the most straightforward theory that females are left, and males are right hemisphere dominant. Buffery and Gray (1972) suggest that males show more equivalence between hemispheres, are more bilateral, while females are left hemisphere dominant; more recently the remaining possibility has been presented by Harris (1976) who interprets the data as indicating that the female is more bilateral for language specifically, and the male more asymmetric.

All of these theories share the common opinion that cognitive ability is pre-wired, and that the structures of the brain *initiate* the function, providing no gross deprivation has occurred. This view must at least in part be accurate, in that, unless brain tissue were competent to subserve and initiate language and other functions, these would not develop. It is a somewhat different question whether sex differences can be explained by genetically determined structural differences in *cortex* between the hemispheres: The substrates for all cognitive processes may well be present initially in both sexes, and differences may become developed through differential use. There are also crucial data which make the logic of a strict left-right dichotomy untenable, and force the conclusion that a new approach is essential.

The first difficulty with the three theories outlined above is that they all tend to cite identical anatomical evidence on structural asymmetries in adult and fetal brains, selectively interpreted to support each of the contradictory theories (see Geschwind & Levitsky, 1968; Carmon & Gombos, 1970; Matsubara, 1960). One of the most frequently cited is an investigation of 200 fetal and adult brains by Wada et al. (1975). The only sex difference to emerge was that females more often had an enlarged "Wernicke's" area in the *right* hemisphere. When the right hemisphere difference appeared, it was usually accompanied by a similar enlargement on the left. The converse was not the case. This evidence could be taken as support of a female brain which is bilateral for speech (Harris, 1976), thus making the female less at risk for language ability following left hemisphere trauma. The evidence could also be interpreted to explain the female's relatively superior ability in face recognition (Fagan, 1972; Bahrick et al., 1975), as it appears that the homologue of Wernicke's area in the right hemisphere is precisely the region that, following trauma, produces a loss in the ability to recognize faces

(Hécaen 1962; de Renzi & Spinnler, 1966). This example shows the difficulties of adopting this approach.

There is also damaging evidence to cortical theories when a volume of literature on sex differences in brain weight ratios is assessed. Sex differences in brain ratios were reported on hundreds of brains by top anatomists of the Victorian period. These findings, which have been summarized by Ellis (1896), are given in Table 6.

The general findings are that the frontal lobes in females have a

TABLE 6

Summary of Data on Brain Region Ratios to Total Cerebrum.
Collated from Data Presented by Ellis 1896

<i>Frontal Lobes</i>	<i>No. of Brains</i>	<i>Larger In</i>
Broca	360	Females
Clapham	450	No difference
Eberstaller	270	Females
Cunningham	Not specified	" (including infants)
<i>Parietal Region</i>		
Broca	Not given	Males
Meynert	"	"
Rudinger	"	"
Crichton-Browne	"	"
Tigges	"	"
<i>Occipital Cortex</i>		
Broca	Not given	No difference
Crichton-Browne	"	Females
<i>Basal Ganglia</i>		
Crichton-Browne	Not given	Females
Martin	"	"
Tigges	"	"
<i>Cerebellum (Ratio to Cerebrum, Medulla & Axial Portions)</i>		
Gall & Cuvier	Not given	Females
Broca	360	"
Rey	Using Broca data	" plus all centers below cerebrum
Boyd	188	"

small but consistently higher ratio to the remainder of the cerebrum, whereas the reverse is true of the parietal region, with males showing larger ratios in *both* hemispheres. One of the most noticeable sex differences is the greater ratio of basal ganglia and cerebellum to the cerebrum in women. There is always a temptation to infer that size of structure confers superiority, but Ellis warns against this, and supports his argument by listing the professions of the males and females who had the largest recorded brains. These range from Turgenev the novelist to an imbecile. The logical outcome of the classification given in Table 6 would be the suggestion that females are frontal lobe dominated and males are posterior creatures. This should (according to current dogma) give the males superiority in *both* language and spatial skill, particularly as lateralization seems more evident in posterior systems, but this is negated by further evidence that certain male abilities—object-assembly, rotation of forms, etc.—are also frontal lobe functions.

However, the most damaging evidence to any cortical "specialist" attitude is the simple fact that many of the so-called right hemisphere functions are superior in *women*. It has always seemed a puzzle to us that models of brain function in men and women have been postulated using only two pieces of information about differences in cognitive skills. The sexes differ in more than two abilities, as has been demonstrated throughout this paper. To illustrate this Table 7 has been compiled of all the available data from clinical patients with known brain damage, from studies on dichotic tasks, and from laterality experiments (Milner & Teuber, 1968; Milner, 1974; Buffery & Gray, 1972; Bogen & Gordon, 1971; Luria, 1966; Teuber, 1974; Hécaen, 1962; Sperry, 1974).

An inspection of the table reveals that perceptual-motor abilities which distinguish the sexes are to be found in nearly all parts of the brain—front-back, left-right, etc. These findings suggest that in order to arrive at some conclusions as to whether sex differences in performance can be explained by differences in functional location, subtler questions will be necessary. It can be seen that none of the hemisphere dominance theories can be maintained in the face of the evidence reviewed in the preceding sections and the findings reported on functional asymmetry. For example, all three theories would have to predict superior musical ability in males, whereas little has been demonstrated (Shuter, 1968). The only well documented sex differences in musical aptitude—singing in tune, and sensitivity to dynamic changes—are female specific abilities. Also, all theories would have to predict a male superiority in the following abilities: visual memory, imagery, face recognition, and drawing. When sex differences do occur in these aptitudes they generally show

TABLE 7

Perceptual Functions Affected by Lesions of
Different Regions of the Brain

M indicates tasks at which males are generally superior
 F indicates tasks where females are superior
 N is where no difference is found

RIGHT HEMISPHERE

<i>Right Temporal Lobe</i>		<i>Right Parietal Lobe</i>	
<i>Vision</i>			
Memory for Abstract Pictures		Memory for Objects	N
Geometric Figures	M	Drawing Figures	F
Incongruous Figures		Memory for Numbers	N
Maze Learning	M	Visual-spatial Tasks	M
		Location in Space	M
		Recognition of Faces	F
<i>Audition</i>			
Singing in Tune	F		
Tonal Memory (equivocal)			
Timbre: Perception of Tone Quality			
Musical Appreciation			
Dynamics and phrasing	F		

LEFT HEMISPHERE

<i>Left Temporal Lobe</i>		<i>Left Parietal Lobe</i>	
<i>Audition</i>			
Sound Localization	F	Naming Objects	F
Phonemic Coding	F	Categorization of Objects	
Word Memory	F	Concept Formation	
Verbal Sequences	F	Memory for Numbers	N

BILATERAL REPRESENTATION

Bilateral Temporal

Rhythmic Memory	N
Pitch Discrimination	N
Recognition of Bird Song	

Bilateral Frontal

<i>Vision</i>		<i>Audition</i>	
Figural Reversals	M	Programming Verbal Output	F
Spatial Figures:		Verbal and Tonal Memory	F
Gottschaldt Figures	M		
Poppelreuter's Figures	M		
3-D Object Recognition & Assembly	M		

females superior (Zahorsky, 1969; Randhawa, 1972; Goodenough, 1957; Fagan, 1972; Ernest & Paivio, 1971; Marks, 1973; Bahrck et al., 1975). The Buffery and Gray hypothesis (1972) suggests that because males are more bilateral this makes them superior at spatial tasks, while Harris (1976) argues for the opposite point of view, that the female's bilateral organization makes her *less* efficient at spatial tasks because she is using both hemispheres for language. However, neither explanation can answer the findings that females are superior at functions subserved by *both* hemispheres and little interference seems to occur as a result. There seems to be enough compatibility for sharing between a number of functions, and these can operate easily between both hemispheres.

The hemisphere dominance theories reviewed above not only ignore several well demonstrated "cognitive" differences between the sexes, none of which can be accommodated by any one explanation, but also fail to consider the contribution of any of the basic sensory or motor differences reviewed in this chapter. It is important, therefore, to return to the discussions concerning the meaning of cognitive functioning. Earlier, we defined cognition as a process whereby the capacity to make accurate categorizations was joined with the ability to evaluate outcomes or make accurate decisions. In the first case, *perceptual* skill is required, and in the second, *behavioral* skill forms a necessary prelude to eventual prediction.

Likewise, the control mechanisms which regulate attention during a task are crucial to appropriate cognitive functioning and appear to operate more fluently when sensory-motor aptitudes are high. As more information, both in the input and output domains, becomes coded and efficiently ordered (chunked), higher level processing (cognition) can be more readily achieved. William James (1890) has observed that genius arises not because of any capacity to bring a wandering attention back to the task (an imbecile can be obsessively attentive) but because the genius gains ever new and interesting insights (new combinations) from the same stimulation, which in turn maintains his attention.

Thus, we suggest that a more productive attitude in terms of understanding sex differences in brain organization is to focus on simpler elements. The critical issue is whether sensory-motor differences prime control systems regulating such processes as attention, or whether the control mechanisms themselves are the source of the major distinction between the sexes.

The Intensive Dimension and Protocritic Processes

When a question involving *either-or* is posed in connection with a

psychological or a neurophysiological process, the answer is almost inevitably paradoxical. Both alternatives are true and yet not true. This occurs first of all because of the impossibility of delineating biological mechanisms which are truly independent of one another. This dilemma, so clearly reflected in the attempts to tease apart nature and nurture, is also present when investigating both macro and micro structure of the brain. The brain is a mirror of the total organism/environment interaction.

Therefore, it is not surprising to find that attention is a function of both a control regulation *and* the organization due to intrinsic competence of sensory-motor systems. As an example, one cannot attend to visual stimuli if one is blind, but one cannot regulate attention to *any* modality if control systems are absent or malfunctioning. In short, our problem in attempting to specify the neurophysiological substrates for sex differences in higher-order processing becomes the problem of determining what portion of these differences is due to differences in the regulatory mechanisms or to differences in intrinsic sensory competences, or to their interaction.

A clue is available in evidence that has often been ignored in neurophysiology. This evidence suggests that the intensive dimension of experience is regulated by neural systems initially separate from those that process local sign (the patterning of spatial and temporal configurations). Henry Head (1920) distinguished such separate systems in the peripheral nervous system and christened them as epicritic (local sign) and protopathic (because the intensive dimension appeared undifferentiated when nerve regeneration first took place after sectioning). However, the intensive dimension of somatosensory stimulation, especially of the pain and temperature modalities, is processed in distinct systems in the spinal cord, and, as has been recently demonstrated (Chin et al., 1976), through the brainstem into the forebrain. The term protocritic is, therefore, a more appropriate partner for epicritic since both systems operate in normal, not just pathological, states.

Of interest here is the fact that the protocritic brain systems which process the intensive dimension of experience and behavior engage the very same systems (limbic and basal ganglia) that have been shown by other techniques to function in the control of attention (Pribram & McGuinness, 1975). We can, therefore, rephrase our initial question and ask whether the observed sex differences that have been reviewed in this chapter can be accounted for by differences in the protocritic—i.e., intensive and quantitative—dimension of sensory-motor function.

There is strong psychological evidence in support of the hypothesis

that the locus of sex differences lies in the intensive dimension of sensory-motor processes. An analysis of the data on sensory psychophysical experiments comparing the sexes reveals that the most consistent differences are found in performances utilizing stimuli which can be scaled quantitatively. This category of stimuli has been discussed by Stevens (1961), who distinguishes a *prothetic* dimension from one that is *metathetic*. Metathetically experienced stimuli are arranged spatially and give rise to qualitative differences (similar to Head's definition of episcritic) that can only be scaled nominally and ordinally. Prothetically experienced stimuli give rise to a quantitative (protocritic) dimension that obeys the power law—a ratio scale. Our central thesis is that differences in sensitivity to the intensive or quantitative dimension of a stimulus (produced by the amplitude of the signal) result in an early (even in utero) modality bias. As intensity is a central factor in producing arousal which allows a stimulus to be registered in the nervous system (Sokolov, 1963; Berlyne, 1970; Pribram & McGuinness, 1975), a more intense signal in one channel will produce a greater amount of arousal which becomes coupled to that input. This develops the competence of that channel by enhancing complexity (information processing capacity) through experience.

Experimental studies using Stevens' scaling technique with regard to sex differences have not yet begun. But, in assessing comfort levels, McGuinness (1972, 1973, 1976a) found different sensitivities for males and females in the visual and auditory modes. This is not the only sex-related distinction that arises. Threshold, also a quantitative dimension, is found to be highly sex-determined in all modalities. However, sex differences in subjective comfort (related to the power slope) and threshold are not correlated (McGuinness, 1972, 1976b). Since threshold is the non-linear portion of what ultimately becomes a linear power function, the two become dissociated, as Stevens (1961) has indicated. Thus, at least two independent processes are operating to determine the quantitative dimension: One regulates threshold, the other subjective magnitude. The question, therefore, arises whether the protocritic neural systems regulate both threshold and experienced magnitude or whether the protocritic systems are responsible only for the magnitude estimation functions. The answer to this question is the topic of current research.

On the motor side of sensory-motor processing, males and females also exhibit rather different patterns of behavior. Males with their ordinarily larger muscle masses, respond with more robust, vigorous and holistic movements. In females, the fine motor system is more efficient. These differences lead to others—such as the fact that males' more active move-

ments in space require precise judgments of speed and depth, while the females' fine movements necessitate precise timing of sequentially ordered acts. Further, in order to mobilize robust and vigorous movements of the extremities, the axial musculature of males must be held in relatively fixed postures. Females, freed from such rigidities, move their axial muscles more fluidly and develop their fine-motor midline systems—e.g., the tongue and vocal cords.

Much more research is required to categorize these differences in terms of brain mechanisms, but a few clues are available. Control over gross postural set is a function of the basal ganglia which, as noted above, are intimately involved in protocritic processes. If we assume that gross postural set is especially sensitive to spatial stimuli, this would account for a greater integration of visual cues into an action. Visually guided motor behavior can be characterized as "movement with objects," which is the male mode of action, as opposed to that of the female, which is typically "movement without objects."

"Movement without objects" appears related to linguistic aptitude. Kimura (1976), in a series of studies using populations of brain-damaged subjects, discovered a gross deficit in manual motor function in left but not right lesioned patients. Slowing of motor control was highly correlated with severity of aphasia. The deficit lay in the inability of subjects to make the transition from one movement to another and not in the sequencing per se. Ordering remained intact, but left hemisphere lesioned subjects took longer to execute each movement, often perseverating. This difficulty is reminiscent of monkeys with motor cortex removals (Pribram et al., 1955-56) and stutterers (more often males) who repeat the same phoneme again and again. Thus, fluency, not sequential ordering, is seen to be impaired by left hemisphere motor cortex lesions.

Both the female's fluency and the male's skill with objects (and their images) are epicritic processes. But, as we have noted, perceptual and mechanical skills with objects derive from protocritic origins in the development of the basal ganglia. In a similar fashion, fluency depends initially on another protocritic system which centers on the amygdala, a basal ganglion-like structure which forms part of the limbic forebrain. Protocritic processes involving the amygdala regulate arousal (as measured by the orienting reaction) and thus the transition from one act to another. And the amygdala is one of the major brain locations sensitive to the action of sex hormones. But more of this in a moment.

Research has not as yet been performed to test the hypothesis that the sex-related differences in motor function are due to some difference in a quantitative dimension. But, as suggested above, a few leads are

available. The large *vs.* fine motor system distinction is, after all, a quantitative one and can, therefore, by way of feedback, directly influence the prothetic, protocritic processing mechanisms of the brain which in turn may modify the development of epicritic functions.

Sex Differences in Core Brain Systems and Their Influence on the Development of Sensory-Motor Processing

To determine whether or not there are neurophysiological or neurochemical differences in neural organization of protocritic processes which could account for sex differences in experience and behavior, it is useful to begin with an assessment of non-human primates. One can assume that here sex differences are largely acultural, particularly when they are observed in all non-human primate species. When hormonal or endocrine involvement is found in such fundamental behaviors as aggression or nurturance, the question is raised as to whether the more subtle distinctions between the sexes discussed throughout this paper could have a similar basis.

Sexual dimorphism in primates is one of the most noticeable characteristics of the species. Sex differences are observed in size and intra-group aggression as well as in the more obvious differences in mating behavior and child rearing which are also common to other species. In all primate societies the division of labor by gender creates a highly stable social system, the dominant males controlling territorial boundaries and maintaining order among lesser males by containing and preventing their aggression, the females tending the young and forming alliances with other females (see Eaton, 1976). Human primates follow this same pattern so remarkably that it is not difficult to argue for biological bases for the type of social order that channels aggression to guard the territory which in turn maintains an equable environment for the young.

The critical question arises: Do these pervasive differences which undoubtedly reflect differences in hormonal regulation by sub-cortical brain systems lead to differences in attention and cognition because of innate biases on sensory-motor systems, or does the behavioral interaction with the environment produced by these sub-cortical differences subsequently alter cortical structures by producing differential sensory input? This question may be rephrased: Do perceptual and cognitive gender differences arise *solely* because of *intrinsic* brain properties, or through an *extrinsic behavior/environment interaction* producing sensory-motor modification?

Our thesis will be that innate sex differences can be shown to occur in some of the structures that subserve protocritic processes (as discussed above) and that these differences differentially bias sensory-motor behavior. Different behaviors, in turn, alter the anatomical structure of other portions of the developing brain—portions which control epicritic processes. Thus, specific behaviors tend to engage one sensory modality rather than another, by virtue of the nature of the action: e.g., gross movements tend to engage the visual system because of radical alterations in the appearance of the visual environment, while the fine movements activate touch via dexterity and auditory sensitivity via the mechanisms for speech.

The problem lies in determining which protocritic core-brain mechanisms prime this process. We might begin with portions of the hypothalamus (a core-brain control system) which is functionally dissimilar in male and female brains. The circulatory system of normal males and females contains proportions of all sex hormones. However, recently it was shown by Fox (1975) that cells of the preoptic hypothalamic region of the brain contain macromolecules which bind either androgen or estrogen alone or proportions of both androgens and estrogens, the estrogen generally acting as an androgen inhibitor. Fox concludes that both androgens and estrogens are important to both sexes and states:

We propose that the brain receptor mechanisms for "sex steroid" hormones function by direct detection of the relative concentrations of androgen and estrogen rather than by independent detection of the absolute levels of the respective hormones.

Studies on the development of behavioral patterns which arise from hormonal activation have also demonstrated that specific hormone binding ratios are essential during critical periods to give rise to sex-specific behaviors. Hormone ratios, therefore, mobilize systems which are in fact available in both sexes, but can remain dormant. By priming a dormant system with the appropriate hormone concentration, male behavior can be elicited from females and vice versa (see Strand, 1975).

In addition to the preoptic hypothalamic cells, receptor sites for sex hormones are concentrated largely in the amygdala, which is the fore-brain focus for the brain systems that control arousal (see Morrell et al., 1975). As noted earlier, Pribram and McGuinness (1975), in an extensive review, discerned three major systems that control attention: an arousal system that organizes phasic responses to input (based on a "Stop" or "Interrupt" satiety mechanism); an activation system that organizes the tonic readinesses or sensory-motor sets of the organism (based on a "Go"

or "Initiate" appetitive mechanism); and an *effort* system that coordinates arousal and activation. The forebrain focus for each of these systems is anatomically distinct: amygdala for phasic arousal, basal ganglia for readiness, and hippocampus for effort. Neurochemically the systems are also clearly distinct: As noted above, the arousal system contains (among other sensitivities such as those for serotonin and for norepinephrine) receptors sensitive to the ratio of sex steroid hormones; the activation system is characteristically dopaminergic; and the effort system is centered on receptor sensitivity to adrenal cortical steroids. This last system has recently become of special interest because it is regulated centrally, i.e., within the brain, as well as peripherally (at the adrenal cortex) by the amount of circulating adreno-cortico-trophic hormone (ACTH), a polypeptide secreted by the pituitary gland. Adrenal cortical steroids related chemically to the steroids androgen and estrogen are known to enhance transmission in the sensory input systems: Henkin (1970) has demonstrated that thresholds for taste, smell and hearing are significantly lower and that suprathreshold discrimination is abnormal in patients with Addison's disease in which the absence of adrenal function prevents the secretion of corticosteroids. Conversely, in the past several years, ACTH and other closely related polypeptides have been shown to act as a ligand for morphine, i.e., they bind the receptor sites that engage morphine to produce analgesia and enhance comfort. In fact, there is good evidence that organisms, including man, ordinarily secrete a polypeptide which protects against pain and effort—a substance named enkephalin whose active portion is called endorphin (see review by Pribram, 1977).

Another line of evidence on anatomical substrates for primary sensory differences has been demonstrated in animal studies that auditory preferences over visual, and vice versa, are largely eliminated by tectal and pretectal lesions (in placements not too far removed from the site of action of morphine and enkephalin), but not at higher levels (Jane et al., 1962; Thompson et al., 1963). In the Jane et al. study neither cortical nor thalamic ablations, nor lesions of 90% of the auditory fibers leading from the colliculi, eliminated cats' preference for a low intensity sound over a bright flashing light—while a restricted lesion in the inferior colliculus abolished this prepotency effect. Thompson et al. discovered a pathway in which visually (but not auditory) conditioned responses could be decoupled. They propose that pretectal sites are involved in visual-motor integration (brightness discrimination was not affected).

Also relevant, although somewhat more remote phylogenetically, is the finding that sex hormone receptor sites have been discovered in the

nucleus intercollicularis in birds (see Morrell et al., 1975). Both autoradiographic and behavioral data indicate that this testosterone activated region is essential to the production of song. While this comparison between birds and mammals may be spurious, it does point to the possibility that auditory/visual and vocal mechanisms which do distinguish the sexes may have an anatomical substrate in the chemically sensitive brainstem region around the tectum.

Thus, it is clear that hormones have a powerful central nervous system effect on altering sensory sensitivities and, consequently, behavior. The question arises whether the neural systems centered on the preoptic hypothalamus and amygdala, which contain the sex hormone receptor sites, can account for *all* the sex differences in sensory-motor performances—and therefore secondarily for the sex differences in attention and cognition—that we have reviewed here.

The answer to this question devolves on the possibility of demonstrating that sex differences result from differences in the mechanisms of arousal, since we have shown the amygdala to be the center of the forebrain regulatory mechanisms for arousal. We defined arousal in terms of the orienting reaction: a phasic, i.e., short-lived response to sensory input which habituates rapidly. The orienting reaction ordinarily involves the visceromotor response system and after amygdectomy the visceromotor components of orienting are no longer sensitive to repetitions of the input (they either fail to occur at all or fail to habituate), while the behavioral components invariably fail to habituate. We interpreted these findings as showing that the arousal system ordinarily modulates the organism's sensitivities to recurring sensory inputs—i.e., the arousal system is responsible for modulating reactions (orienting and habituation) to the intensive dimensions of sensory stimulation.

But the arousal system interacts with another—the readiness system which is centered on the basal ganglia—and the coordination of arousal with readiness centers on the hippocampal circuit and takes effort. The fact that there are sex differences in peripheral motor function (males tend to act robustly, while females tend to interact with the environment via their fine muscle systems) must influence the development of the readiness system, which becomes progressively more competent in providing the muscular sets which enable these acts.

Thus, differences between the sexes in arousal and in readiness can be expected on the basis of their physiological differences in both types of effector mechanisms—their different relative concentrations of sex hormones and their different organization of muscle competences. As

noted above, these differences are fed back into the central nervous system, differentially organizing those parts of the brain which are involved in processing the intensive aspects of sensory experience. Our hypothesis, therefore, should take into account sex differences in both arousal and readiness, and perhaps even in the relation between the two as expressed in effort.

From Protocritic Control to Cortical Organization

The cortical terminus of the arousal, readiness and effort systems is the anterior portion of the frontal lobe; the protocritic systems have a cortical representation in the frontal extremity of the brain just as the sensory projections to specific thalamic regions are re-represented at cortical sites in the posterior part of the brain. Part of our understanding of sex differences in the organization of protocritic processes stems, therefore, from the way in which the frontal lobes function.

Goldman et al. (1974) have discovered sizeable sex differences in the rate of development of frontal lobe function in non-human primates. Resections of the orbital frontal cortex (that portion which is especially related to the limbic forebrain) were found to impair male monkeys in infancy (2½-15 months) on tasks involving object reversal, delayed response and delayed alternation. Females were uninfluenced by frontal lesions until 2 years of age, when both sexes were affected similarly. Goldman's data run counter to the proposal (Hutt, 1972; Buffrey & Gray, 1972) that the human male is, in general, developmentally retarded both physically and intellectually.

Goldman's data can, however, account for the observation that an assortment of male abilities that develop early because of their dependence on gross muscular control are noticeably affected by frontal lesions. These abilities are usually classed as visual-spatial aptitudes and Table 7 reviews the evidence that frontal lobe function is implicated in the performance of tasks that tap these aptitudes. After frontal lesions, the pattern of figure reversal (e.g., with Necker cubes) is disturbed, with normal baselines either exceeded or reduced. Object assembly is significantly impaired and various spatial-mechanical tasks similarly affected. Goldman's data suggest that the earlier maturation of their arousal-readiness coordination (the effort) mechanism gives males an advantage in behavior depending on spatial-mechanical relationships.

This early advantage could transform the characteristic mode of male behavior which, as we have seen, is holistic and robust to something essentially discrete (object thrown, struck or turned). This transformation would come about by the early coordinated interaction of the two

systems we have been discussing: a readiness mechanism makes possible the tracking of a stimulus and an arousal mechanism that stops the tracking when the outcome of the movement matches the visual-spatial input that initiated it. To learn to do this efficiently produces a process in which simultaneous use of both hemispheres is essential: a left hemisphere motor outflow (including frontal eye field activity) and right hemisphere visual analysis. Two hemispheres work in parallel and the protocritic systems and frontal lobe function to integrate the process.

Yen (unpublished Ph.D. thesis) tested a large number of subjects of both sexes on a battery of spatial-mechanical tasks. The results showed that right-handed males were significantly superior to left-handed males. This suggests that for the male, visual-spatial skill is greater when the two hemispheres do not compete in processing. In males, an image of the performance appears to be constructed in the left hemisphere motor system, and at the same time, the visual feedback is separately monitored by the right hemisphere. Such a trade-off in hemispheric function is irrelevant to females who attempt to solve spatial problems *verbally*. In the Yen study, no difference was found for handedness in females, who consistently performed more poorly than the left-handed males. Behavioral data support this view.

Perseveration and deficits in ordering behavior are also produced by frontal lobe lesions (see Pribram, 1971). The later maturation of frontal cortex and perhaps the protocritic processes as a whole in the female may bias her towards more frontal lobe involvement in the temporal than the spatial domain. Thus, the female, who tends to fluidity which develops gradually towards a dominance of linguistic analyses, has another hemisphere available for visual imagery. Because the two processes do *not* engage similar systems, but operate independently, this allows the female to shift flexibly from one to the other. Such flexibility in control is a demonstrated function involving the mature frontal lobe (Pribram et al., 1964) and is the basis for proper sequencing of behavior. The data of McGuinness and Courtney (unpublished) reported earlier indicate that the primary male deficit in the perception and translation of speech to written language is an ability to transfer rapidly from an auditory image to its visual counterpart. Once shifted to an auditory mode, they cannot readily engage a visual representation.

Support for the view that females have the capacity to shift flexibly between hemispheres is provided by studies on control of alpha rhythm. Davidson et al. (1976) report significant differences between the sexes in alpha rhythm control during biofeedback. Females are highly asymmetric at rest, but show a significantly greater ability to enhance or

diminish alpha power in one or the other hemisphere independently, as well as an ability equal to males to maintain a symmetric bilateral integration of either alpha-ON or alpha-OFF.

A further investigation (Tucker, 1976) showed that the balance of alpha power between the hemispheres is unrelated to females' success in a variety of tasks ranging from verbal to spatial. Males were more efficient at the spatial tasks during greater right hemisphere desynchrony, while left hemisphere desynchrony was correlated to verbal performance. These data, in effect, suggest that when males are operating in the auditory-motor mode they are effectively locked out of a visual-motor mode.

Conclusion

Thus, the relationship between sex differences and hemisphere specialization need no longer be so bewildering. A flood of data has shown beyond doubt that such a relationship exists. Still, the origin of the relationship on any reasonable physiological basis has remained a mystery. Our proposal can be phrased in terms of two hypotheses which rest on plausible consequences of clearly demonstrated sex differences: 1) The demonstrated hormonal sex differences in the arousal mechanism (amygdala-frontal) predispose females to greater flexibility in the control of hemispheric function so that they excel in tasks demanding ordered flexible shifts between hemispheric functions. When no such competition between functions is involved, males demonstrate superiority. 2) Because of a more massive musculature, the male readiness (basal ganglia-frontal) system predisposes to spatial-mechanical (object) aptitude which then engages the visual mode. By contrast, the female, because of her finer muscular organization, becomes more proficient in auditory-verbal (fluent, communicative) performance.

These two hypotheses can readily be tested both at the neuropsychological and neurophysiological level. We doubt that they will account for all the biologically based differences in experience and behavior that distinguish the sexes—but at least they provide a starting point for understanding the *mechanism* by which the distinctions are produced.

We believe that sex differences in cognitive processes are derived from early biases produced by these two demonstrated distinctions in effector function. The theory could account for the slow development of those sensory-motor skills which have best contributed to the enormous success of the species *Homo sapiens*. The theory also leaves room for adaptive change in both neural structure and behavioral function when demands on skills change with changing cultures.

REFERENCES

- AMMONS, R. B., ALPRIN, S. I., and AMMONS, C. H. Rotary pursuit performance as related to sex and age of pre-adult subjects. *Journal of Experimental Psychology*, 1955, 49, 127-133.
- ANNETT, M. The growth of manual preference and speed. *British Journal of Psychology*, 1970, 61, 545-558.
- ARANOFF, D. Relationship between immobilization and autokinetic movement. *Perceptual and Motor Skills*, 1973, 36, 411-414.
- AXELROD, S. *Effects of Early Blindness. Performance of Blind and Sighted Children on Tactile and Auditory Tasks*. New York: American Foundation for the Blind, 1959.
- BACBY, J. W. A cross-cultural study of perceptual predominance in binocular rivalry. *Journal of Abnormal and Social Psychology*, 1957, 54.
- BAHRICK, H. P., BAHRICK, P. O., and WITTLINGER, R. P. Fifty years of memory for names and faces: A cross-sectional approach. *Journal of Experimental Psychology (General)*, 1975, 104, 54-75.
- BAILEY, E. H. S. and NICHOLS, E. L. On the delicacy of the sense of taste. *Science*, 1888, p. 145.
- BARRATT, E. S. The space-visualization factors related to temperament traits. *Journal of Psychology*, 1955, 39, 279-287.
- BELL, R. Q. and COSTELLO, N. S. Three tests for sex differences in tactile sensitivity in the newborn. *Biologia Neonatorum*, 1964, 7, 335-347.
- BENNETT, G. K. and CRUIKSHANK, R. M. Sex differences in the understanding of mechanical problems. *Journal of Applied Psychology*, 1942, 26, 121-127.
- BENTLEY, A. *Monotones*. London: Novello & Co., 1968.
- BERLYNE, D. E. Attention as a problem in behavior. In: D. I. Mostofsky (Ed.), *Attention: Contemporary Theory and Analysis*. New York: Appleton Century Crofts, 1970.
- BERMAN, L. R. Sex differences in intellectual development: Are boys more vulnerable. *Reports of Psychol. Lab. University of Stockholm*, 1974, #417.
- BERNSTEIN, R. C. and JACKLIN, C. N. The 3½ month-old infant: Stability of behavior, sex differences and longitudinal findings. Unpublished Masters Thesis, 1973.
- BIRCH, H. G. and BELMONT, L. Auditory-visual integration in normal and retarded readers. *American Journal of Orthopsychiatry*, 1964, 34, 852-861.
- BOCK, R. D. and KOLAROWSKI, D. Further evidence of sex-linked major-gene influence on human spatial visualizing ability. *The American Journal of Human Genetics*, 1973, 25, 1-14.
- BOGEN, J. E. and GORDON, H. W. Musical tests for functional lateralization with intracarotid amobarbital. *Nature*, 1971, 230, 524.
- BROWNFIELD, M. K. Sex and stimulus time differences in after image durations. *Perceptual and Motor Skills*, 1965, 21, 446.
- BUFFERY, A. W. H. and GRAY, J. A. Sex differences in the development of spatial and linguistic skills. In: C. Ounsted and D. C. Taylor (Eds.), *Gender Differences: Their Ontogeny and Significance*. Edinburgh: Churchill Livingstone, 1972.
- BURG, A. Visual acuity as measured by dynamic and static tests: A comparative evaluation. *Journal of Applied Psychology*, 1966, 50, 460-466.
- BURG, A. and HULBERT, S. Dynamic visual acuity as related to age, sex, and static acuity. *Journal of Applied Psychology*, 1961, 45, 111-116.
- CARMON, A. and GOMBOS, G. M. A physiological vascular correlate of hand preference: Possible implications with respect to hemisphere cerebral dominance. *Neuropsychologia*, 1970, 8, 119-128.
- CARTER, R. B. An analysis of ten thousand cases of disease or disturbance of the eyes, seen in private practice. *Lancet*, October 1892.
- CHAFLIN, J. P. Sex differences in the perception of autokinetic movement. *Journal of General Psychology*, 1955, 52, 149-155.

- CHIN, J. H., PRIBRAM, K. H., DRAKE, K., and GREENE, L. O., JR. Disruption of temperature discrimination during limbic forebrain stimulation in monkeys. *Neuropsychologia*, 1976, 14, 293-310.
- COHEN, L. B., GELBER, E. R., and LAZAR, M. A. Infant habituation and generalization to differing degrees of stimulus novelty. *Journal of Experimental Child Psychology*, 1971, 11, 379-89.
- COHEN, S. E. Infant attentional behavior to face-voice incongruity. Paper presented at meeting of Society for Research in Child Development, Philadelphia, 1973.
- COLLINS, D., KESSEN, W., and HAITH, M. Note on an attempt to replicate a relation between stimulus unpredictability and infant attention. *Journal of Experimental Child Psychology*, 1972, 13, 1-8.
- COOK, T. W. and SHEPARD, A. H. Performance on several control-display relationships as a function of age and sex. *Perceptual and Motor Skills*, 1958, 8, 339-345.
- CORAH, N. L. and BORFFA, J. Perceived control, self observation and response to aversive stimuli. *Journal of Personality and Social Psychology*, 1970, 16, 1-4.
- CORNELL, E. H. and STRAUSS, M. S. Infants' responsiveness to compounds of habituated visual stimuli. *Developmental Psychology*, 1973, 2, 73-78.
- CORSO, J. F. Age and sex differences in thresholds. *Journal of the Acoustical Society of America*, 1959, 31, 498-507.
- DAVIDSON, R. J., SCHWARTZ, G. E., PUGASH, E., and BROMFIELD, E. Sex differences in patterns of EEG Asymmetry. *Biological Psychology*, 1976, 4, 119-138.
- DE RENZI, E. and SPINLER, H. Visual recognition in patients with unilateral cerebral disease. *Journal of Nervous and Mental Diseases*, 1966, 142, 515-525.
- DUGGAN, L. An experiment on immediate recall in secondary school children. *British Journal of Psychology*, 1950, 40, 149-154.
- EAGLES, E. L., WISHIK, S. M., DÖEFLER, L. G., MELNICK, W., and LEVINE, H. S. *Hearing sensitivity and related factors in children*. Pittsburg: University of Pittsburg Press, 1963.
- EATON, G. G. The social order of Japanese Macaques. *Scientific American*, 1976, 235, 97-106.
- EISENBERG, R. Unpublished data reviewed by Korner, 1971, 1972.
- ELLIOTT, C. D. Noise tolerance and extraversion in children. *British Journal of Psychology*, 1971, 62, 325-330.
- ELLIS, H. *Man and Woman: A Study of Human Secondary Sexual Characteristics*. London: Walter Scott, Ltd., 1896 and 1930 (6th Ed.).
- ENGEL, E. The role of content in binocular resolution. *Amer. J. Psych.*, 1956, 69.
- ENGEL, R., CROWELL, C., and NISHIJIMA, S. Visual and auditory response latencies in neonates. In: *Facilitation Volume in Honour of C. C. de Silva*. Ceylon: Kularatne and Company, 1968.
- ERNEST, C. H. and PAVIO, A. Imagery and sex differences in incidental recall. *British Journal of Psychology*, 1971, 62, 67-72.
- FAGAN, J. F. Infants' recognition memory for faces. *Journal of Experimental Child Psychology*, 1972, 14, 453-476.
- FAIRWEATHER, H. and HUTT, S. J. Sex differences in a perceptual motor skill in children. In: C. Ounsted and D. C. Taylor (Eds.), *Gender Differences: Their Ontogeny and Significance*. Edinburgh: Churchill Livingstone, 1972.
- FLAVELL, J. H. *The Developmental Psychology of Jean Piaget*. Toronto: D. Van Nostrand Co. Inc., 1963.
- FOX, T. O. Androgen and estrogen-binding macromolecules in developing mouse brain: Biochemical and genetic evidence. *Proceedings of the National Academy of Sciences, U.S.A.*, 1975, 72, 4303-4307.
- FREIDES, D. Human information processing and sensory modality. Cross modal functions, information complexity, memory and deficit. *Psychol. Bull.*, 1974, 81, 284-310.
- FRIEDMAN, S., NÁCY, A. N., and CARPENTER, G. C. Newborn attention: Differential

- decrement to visual stimuli. *J. Exp. Child Psychol.*, 1970, 10, 44-51.
- GARAI, J. E. and SCHEINFELD, A. Sex differences in mental and behavioral traits. *Genetic Psychological Monographs*, 1968, 77, 169-299.
- GESCHWIND, N. and LEVITSKY, W. Human brain: Left-right asymmetries in temporal speech region. *Science*, 1968, 161, 186-187.
- GOLDBERG, S. and LEWIS, M. Play behaviour in the year old infant: Early sex differences. *Child Development*, 1969, 40, 21-31.
- GOLDMAN, P. S., CRAWFORD, H. T., STOKES, L. P., GALKIN, T. W., and ROSVOLD, H. E. Sex-dependent behavioural effects of cerebral cortical lesions in the developing Rhesus monkey. *Science*, 1974, 186, 540-542.
- GOODENOUGH, E. W. Interest in persons as an aspect of sex differences in the early years. *Genetic Psychological Monographs*, 1957, 55, 287-323.
- GREENBERG, D. J. Accelerating visual complexity levels in the human infant. *Child Devel.*, 1971, 42, 905-918.
- GREENBERG, D. J. and O'DONNELL, W. J. Infancy and the optimal level of stimulation. *Child Devel.*, 1972, 43, 639-645.
- GREENBERG, D. J. and WEIZMANN, F. The measurement of visual attention in infants: A comparison of two methodologies. *J. Exp. Child Psych.*, 1971, 11, 234-243.
- GREENBERGER, E., O'CONNOR, J., and SORENSEN, A. Personality, cognitive and academic correlates of problem-solving flexibility. *Developmental Psychology*, 1971, 4, 416-424.
- GUILFORD, J. P. *The Nature of Human Intelligence*. New York: McGraw-Hill, 1967.
- GULLICKSEN, G. R. and CROWELL, D. H. Neonatal habituation to electrocutaneous stimulation. *Journal of Experimental Child Psychology*, 1964, 1, 388-396.
- HARMS, I. E. and SPIKER, C. C. Factors associated with the performance of young children on intelligence scales and tests of speech development. *Journal of Genetic Psychology*, 1959, 94, 3-22.
- HARRIS, L. J. Sex differences in spatial ability: Possible environmental, genetic and neurological factors. In: M. Kinsbourne (Ed.), *Hemispheric Asymmetries of Function*. Cambridge, England: Cambridge University Press, 1976.
- HEAD, H. *Studies in Neurology*. Oxford: Oxford Medical Publications, 1920.
- HÉCAEN, H. Clinical symptomatology in right and left hemisphere lesions. In: V. G. Mountcastle (Ed.), *Interhemispheric Relations and Cerebral Dominance*. Baltimore: John Hopkins, 1962.
- HENKIN, R. I. The neuroendocrine control of perception. In: D. A. Hamburg, K. H. Pribram, and A. T. Stunkard (Eds.), *Perception and Its Disorders*. Baltimore: Williams and Wilkins, 1970, 123-138.
- HERZBERG, F. and LEPKIN, M. A. A study of sex differences on the primary mental abilities test. *Educational and Psychological Measurement*, 1954, 14, 687-689.
- HULL, F. M., MIELKE, P. W., TIMMONS, R. J., and WILLEFORD, J. A. The national speech and hearing survey: Preliminary results. *ASHA*, 1971, 3, 501-509.
- HUTT, C. Curiosity in young children. *Science Journal*, 1970, 6, 68-72.
- HUTT, C. Neuroendocrinological behavior and intellectual aspects of sexual differentiation in human development. In: C. Ounsted and D. C. Taylor (Eds.), *Gender Differences: Their Ontogeny and Significance*. Edinburgh: Churchill Livingstone, 1972.
- IMMERGLUCK, L. and MEARINI, M. C. Age and sex differences in response to embedded figures and reversible figures. *Journal of Experimental Child Psychology*, 1969, 8, 210-221.
- IMPOLITOV, F. V. Interanalyser differences in the sensitivity-strength parameter for vision, hearing and cutaneous modalities. In: V. D. Nebylitsyn and J. A. Gray (Eds.), *Biological Bases of Individual Behavior*. London: 1972, 43-61.
- JAMES, W. *Principles of Psychology*. London: Routledge and Kegan Paul, 1890.
- JANE, J. A., MASTERTON, R. B., and DIAMOND, I. T. The function of the tectum for

- attention to auditory stimuli in the cat. *Journal of Comparative Neurology*, 1962, 125, 165-191.
- JASTROW, (not known). A statistical study of memory and association. *Educational Review*, 1891, December.
- JASTROW, (not known). Studies from the laboratory of experimental psychology of the University of Wisconsin. *Am. J. Psychol.*, 1892, April.
- KAGAN, J. and LEWIS, M. Studies of attention in the human infant. *Merrill-Palmer Quarterly*, 1965, 11, 95-127.
- KIMURA, D. Motor functions in the left hemisphere. Paper delivered at the 21st International Congress, Paris, 1976.
- KLEIVEN, J. and ROMMETVEIT, R. Meaning and frequency in a binocular rivalry situation. *Scand. J. Psych.*, 1970, 2.
- KORNER, A. F. Visual alertness in neonates: Individual differences and their correlates. *Perceptual and Motor Skills*, 1970, 31, 499-509.
- KORNER, A. F. Individual differences at birth: Implications for early experience and later development. *American Journal of Orthopsychiatry*, 1971, 41, 608-619.
- KORNER, A. F. Sex differences in newborns with special references to differences in the organization of oral behavior. *Journal of Child Psychology*, 1973, 14, 19-29.
- KORNER, A. F. and THOMAS, E. B. Visual alertness in neonates as evoked by maternal care. *Journal of Experimental Child Psychology*, 1970, 10, 67-68.
- KREITLER, S., KREITLER, H., and ZIGLER, E. Cognitive orientation and curiosity. *British Journal of Psychology*, 1974, 65, 43-52.
- LA GRONE, C. W. Sex and personality differences in relation to feeling for direction. *Journal of General Psychology*, 1969, 81, 23-33.
- LEVY, J. Lateral specialization of the human brain: Behavioral manifestations and possible evolutionary basis. Paper presented at 32nd Annual Biology Colloquium. Oregon State University 1971.
- LEWIS, M. Infants' responses to facial stimuli during the first year of life. *Developmental Psychology*, 1969, 1, 75-86.
- LEWIS, M. State as an infant-environment interaction: An analysis of mother-infant interaction as a function of sex. *Merrill-Palmer Quarterly*, 1972, 18, 95-121.
- LEWIS, M., KAGAN, J., and KALAFAT, J. Patterns of fixation in the young infant. *Child Development*, 1966, 37, 331-341.
- LINDSAY, P. H. Multichannel processing in perception. In: D. I. Mostofsky (Ed.). *Attention: Contemporary Theory and Analysis*. New York: Appleton Century Crofts, 1970.
- LINDZEY, G. and GOLDBERG, M. Motivational differences between males and females as measured by the TAT. *Journal of Personality*, 1953, 22, 101-117.
- LIPSITT, L. P. and LEVY, N. Electroactual thresholds in the neonate. *Child Development*, 1959, 30, 547-554.
- LITTLE, B. R. Factors affecting the use of psychological versus non-psychological constructs on the Repetory Test. *Bulletin of the British Psychological Society*, 1968, 21, 34.
- LIVESLEY, W. J. and BROMLEY, D. G. *Person Perception in Childhood and Adolescence*. London: Wiley & Sons, 1973.
- LURIA, A. R. *Higher Cortical Functions in Man*. London: Tavistock, 1966.
- MACCOBY, E. E. and JACKLIN, C. N. *The Psychology of Sex Differences*. Stanford: Stanford University Press, 1974.
- MACCOBY, E. E. and JACKLIN, C. N. Stress, activity and proximity seeking: Sex differences in the year old child. *Child Development*, 1973, 44, 34-47.
- MARRS, D. F. Visual imagery differences in the recall of pictures. *British Journal of Psychology*, 1973, 64, 17-24.
- MATSUBARA, T. An observation on cerebral phlebograms with special reference to changes in superficial veins. *Nagoya Journal of Medical Science*, 1960, 23, 86-94.

- McCAll, R. B. Smiling and vocalization in infants as indices of perceptual cognitive processes. *Merrill-Palmer Quarterly*, 1972, 18.
- McCAll, R. B. and KAGAN, J. Attention in the infant: Effects of complexity, contour perimeter and familiarity. *Child Development*, 1967, 38, 989-952.
- McCAll, R. B. and KAGAN, J. Individual differences in the infant's distribution of attention to stimulus discrepancy. *Development Psychology*, 1970, 2, 90-98.
- McCARTHY, D. Language development of the preschool child. *Institute of Child Welfare Monograph No. 4*. Minneapolis: University of Minnesota Press, 1930.
- McGREW, W. C. Aspects of social development in nursery school children with emphasis on introduction to the group. In: E. Blurton-Jones (Ed.), *Ethological Studies of Child Behavior*. London: Cambridge University Press, 1972, pp. 129-156.
- McGUINNESS, D. Hearing: Individual differences in perceiving. *Perception*, 1972, 1, 465-478.
- McGUINNESS, D. Cardiovascular responses during habituation and mental activity in anxious men and women. *Biological Psychology*, 1973, 1, 115-123.
- McGUINNESS, D. Perceptual and cognitive differences between the sexes. In: B. Lloyd and J. Archer. *Explorations in Sex Differences*. New York: Academic Press, 1976a.
- McGUINNESS, D. Away from a unisex psychology: Individual differences in visual perception. *Perception*, 1976b, 5, 279-294.
- McGUINNESS, D. and LEWIS, I. Sex differences in visual persistence: Experiments on the Ganzfeld and the after image. *Perception*, 1976, 5, 295-301.
- McGUINNESS, D. and SYMONDS, J. Sex differences in choice behavior: The object-person dimension. *Perception* (in press).
- McKITTRICK, K. G. Bodily activity and perceptual activity. *Percept. and Mot. Skills*, 1965, 20, 1109-12.
- MENDEL, G. Children's preference for differing degrees of novelty. *Child Development*, 1965, 35, 452-465.
- MESSER, S. B. and LEWIS, M. Social class and sex differences in the attachment and play behaviour of the year old infant. *Merrill-Palmer Quarterly*, 1972, 18, 295-300.
- MILNER, B. Hemisphere specialization: Scope and limits. In: F. O. Schmitt and F. G. Worden (Eds.), *The Neurosciences Third Study Program*. Cambridge, Mass.: MIT Press, 1974.
- MILNER, B. and TEUBER, H.-L. Alteration of perception and memory in man: Reflection on Methods. In: L. Weiskrantz (Ed.), *Analysis of Behavior Change*. New York: Harper & Row, 1968.
- MITCHELL, G. and BRANDT, E. M. Behavioural differences related to experience of mother and sex of infant in the Rhesus monkey. *Development Psychology*, 1970, 3, 149.
- MITTLER, P. and WARD, J. The use of the Illinois test of psycholinguistic abilities on British four-year old children: A normative and factorial study. *British Journal of Educational Psychology*, 1970, 40, 43-54.
- MORRELL, J. I., KELLEY, D. B. and PFAFF, D. W. Sex steroid binding in the brains of vertebrates. In: K. M. Knigge, D. E. Scott, H. Robayashi, Kiura-gi and S. Ishi (Eds.), *Brain-Endocrine Interaction II*. Basel: Karger, A. G., 1975.
- MOSS, H. A. Sex, age and state as determinants of mother-infant interaction. *Merrill-Palmer Quarterly*, 1967, 15, 19-35.
- MOSS, H. A. and ROBSON, K. S. Maternal influences and early social visual behaviour. *Child Development*, 1968, 39, 401-408.
- MYERS, W. J. and CANTOR, G. N. Observing and cardiac responses of human infants to visual stimuli. *Journal of Experimental Child Psychology*, 1967, 5, 16-25.
- NICHOLS, E. L. and BAILEY, E. H. S. Letter in *Nature*, 1886, 25th November.
- NOBLE, C. E., BAKER, B. L., and JONES, T. A. Age and sex parameters in psychomotor learning. *Perceptual and Motor Skills*, 1964, 19, 934-945.
- NOBLE, C. E. and HAYS, J. R. Discrimination reaction performance as a function of anxiety and sex parameters. *Perceptual and Motor Skills*, 1965, 23, 1267-1278.

- OETZEL, R. M. Annotated bibliography. In: E. Maccoby (Ed.), *The Development of Sex Differences*. London: Tavistock Publications, 1967.
- OTTOLENGHI (not known). L'Olfatto nei Criminali. *Archivio di Psichiatria*, 1888, 9, Fasc. 5.
- OUNSTED, C. and TAYLOR, D. C. *Gender Differences: Their Ontogeny and Significance*. Edinburgh: Churchill Livingstone, 1972.
- PANCRATZ, C. N. and COHEN, L. B. Recovery of habituation in infants. *Journal of Experimental Child Psychology*, 1970, 9, 208-216.
- PHILLIPS, J. R. Syntax and vocabulary of mothers speech to young children. Age and sex comparisons. *Child Development*, 1973, 44, 182-185.
- PISHKIN, V. and BLANCHARD, R. Auditory concept identification as a function of subject, sex and stimulus dimensions. *Psychonomic Science*, 1964, 1, 177-178.
- PISHKIN, V. and SHURLEY, J. T. Auditory dimensions and irrelevant information in concept identification of males and females. *Perceptual and Motor Skills*, 1965, 20, 673-683.
- POHL, W. and CALDWELL, W. E. Towards an analysis of a function deficit. *Journal of General Psychology*, 1968, 79, 241-255.
- PRIBRAM, K. H. On the neurology of thinking. *Behav. Sci.*, 1959, 4, 265-284.
- PRIBRAM, K. H. *Languages of the Brain*. Englewood Cliffs, N.J.: Prentice-Hall, 1971.
- PRIBRAM, K. H. Self-consciousness and intentionality. In: G. E. Schwartz and D. Shapiro (Eds.), *Consciousness and Self-Regulation*, Vol. 1. New York: Plenum Publishing Corporation, 1976.
- PRIBRAM, K. H. Peptides and protocritic processes. In: L. H. Miller and C. L. Sandman (Eds.), *The Neuropeptides*, 1977.
- PRIBRAM, K. H., AHUMADA, A., HARTOG, J., and ROOS, L. A progress report on the neurological process disturbed by frontal lesions in primates. In: I. M. Warren and K. Akert (Eds.), *The Frontal Granular Cortex and Behavior*. New York: McGraw-Hill Book Company, Inc., 1964, pp. 28-55.
- PRIBRAM, K. H., KRUGER, L., ROBINSON, F., and BERMAN, A. J. The effects of precentral lesions on the behavior of monkeys. *Yale J. Biol. and Med.*, 1955-56, 28, 428-443.
- PRIBRAM, K. H. and MCGUINNESS, D. Arousal, activation and effort in the control of attention. *Psychology Review* (1975), 82, 116-149.
- RAMEY, C. T. and WATSON, J. S. Nonsocial reinforcement of infant's vocalizations. *Devel. Psychol.*, 1972, 6, 558.
- RANDHAWA, B. S. A case for the uses of multivariate analysis in concept grouping, dominance level, and sex, as related to verbal recall. *Multivariate Behavior Research*, 1972, 7, 193-201.
- ROBERTS, E. Poor pitch singing. Ph.D. dissertation, Liverpool University, 1972.
- ROBERTS, J. Binocular visual acuity of adults. Washington: U.S. Department of Health, Education and Welfare, 1964.
- ROSS, J. M. and SIMPSON, H. R. The national survey of health and development: 1. Educational attainment. *British Journal of Educational Psychology*, 1971, 41, 49-61.
- RUBENSTEIN, J. Maternal attentiveness and subsequent exploratory behavior in the infant. *Child Development*, 1967, 38, 1089-1100.
- SANDER, L. W. and CASSEL, T. Z. An empirical approach to the study of interactive regulation in the infant-caretaking system and its role in early development. Paper presented at the meetings of the Society for Research in Child Development, Philadelphia, 1973.
- SCHAE, K. W., BALTES, P., and STROTHER, C. R. A study of auditory sensitivity in advanced age. *Journal of Gerontology*, 1964, 19, 453-457.
- SHEPHARD, A. H., ABBEY, D. S., and HUMPHRIES, M. Age and sex in relation to perceptual-motor performance on several control display relations on the ICC. *Perceptual and Motor Skills*, 1962, 14, 103-118.

- SHERMAN, J. Problem of sex differences in space perception and aspects of intellectual functioning. *Psychology Review*, 1967, 74, 290-299.
- SHERMAN, J. *On the Psychology of Women: A Survey of Empirical Studies*. Springfield, Illinois: Thomas, 1971.
- SHUTER, R. P. G. An investigation of hereditary and environmental factors in musical ability. Ph.D. dissertation, University of London, 1964.
- SHUTER, R. *The Psychology of Music*. London: Methuen, 1968.
- SIMNER, M. L. Newborn's response to the cry of another infant. *Developmental Psychology*, 1971, 5, 136-150.
- SIMON, J. R. Choice reaction time as a function of auditory S-R correspondence, age and sex. *Ergonomics*, 1967, 10, 659-664.
- SIMPSON, W. E. and VAUGHT, G. M. Visual and auditory autokinesis. *Perceptual and Motor Skills*, 1973, 36, 1199-1206.
- SKOFF, E. and POLLACK, R. H. Visual acuity in children as a function of hue. *Perception and Psychophysics*, 1969, 6, 244-246.
- SMITH, P. K. and CONNOLLY, K. Patterns of play and social interaction in pre-school children. In: N. Blurton-Jones (Ed.), *Ethological Studies of Child Behavior*. Cambridge: Cambridge University Press, 1972.
- SMOCK, C. D. and HOLT, B. G. Children's reaction to novelty: An experimental study of curiosity motivation. *Child Development*, 1962, 33, 631-642.
- SOKOLOV, E. N. Higher nervous function, the orienting reflex. *Annual Review of Physiology*, 1963, 25, 545-580.
- SPEARS, W. C. and HOHLE, R. H. Sensory and perceptual processes in infants. In: Y. Brackbill (Ed.), *Infancy and Early Childhood*. London: Collier MacMillan, 1967.
- SPERRY, R. W. Lateral specialization in the surgically separated hemispheres. In: F. O. Schmitt and E. G. Worden (Eds.), *The Neurosciences: Third Study Program*. Cambridge, Mass.: MIT Press, 1974.
- SPINELLI, D. N. and PRIORRAM, K. H. Changes in visual recovery function and unit activity produced by frontal cortex stimulation. *Elec. Clin. Neurophysiol.*, 1967, 22, 143-149.
- STEVENS, S. S. In: W. Rosenblith (Ed.), *Sensory Communication*. Cambridge: MIT Press, 1961.
- STRAND, F. L. The influence of hormones on the nervous system. *Bioscience*, 1975, 25, 568-577.
- TEUBER, H. L. Why two brains? In: F. O. Schmitt and E. G. Worden (Eds.), *The Neurosciences: Third Study Program*. Cambridge, Mass.: MIT Press, 1974.
- THOMPSON, R., LESSE, H., and RICH, I. Dissociation of visual and auditory habits following prefrontal lesions in rats and cats. *Journal of Comparative Neurology*, 1963, 121, 161-171.
- THOMAS, A., CHERR, S., and BIRCH, H. G. *Temperament and Behaviour Disorders in Children*. New York: New York University Press, 1969.
- TUCKER, D. M. Sex differences in hemispheric specialization for synthetic visuospatial functions. *Neuropsychologia*, 1976, 14, 447-454.
- TYLER, L. *The Psychology of Human Differences*. New York: Appleton Century Crofts, 1965.
- VOTIL, A. C. Individual differences in the autokinetic phenomenon. *Journal of Experimental Psychology*, 1941, 24, 306-322.
- WADA, J. A., CLARK, R., and HAMM, A. Asymmetry of temporal and frontal speech zones in 100 adult and 100 infant brains. *A.M.A. Archives of Neurology*, 1975.
- WARNER, F. (No title available). *British Medical Journal*, March 1893.
- WATSON, J. S. Operant conditioning of visual fixation in infants under visual and auditory reinforcement. *Development. Psychology*, 1969, 1, 508-516.
- WEINSTEIN, S. and SERSEN, E. A. Tactile sensitivity as a function of handedness and laterality. *Journal of Comparative and Physiological Psychology*, 1961, 54, 665-669.

- WERDELIN, I. *Geometric Ability and the Space Factors in Boys and Girls*. Sweden: University of Lund, 1961.
- WEST, I. *American J. of Psychol.*, August 1892.
- WILSON, W. P. and ZUNG, W. K. Attention, discrimination and arousal during sleep. *Archives of General Psychiatry*, 1966, 15, 523-528.
- WITKIN, H. A., DYK, R. B., FATERSON, H. F., GOODENOUGH, D. R., and KARP, S. A. *Psychological Differentiation*. New York: Wiley & Sons, 1962.
- WITRYOL, S. L. and KAES, W. A. Sex differences in social memory tasks. *Journal of Abnormal and Social Psychology*, 1957, 54, 343-346.
- WOLFE, P. H. The natural history of crying and other vocalizations in early infancy. In: B. M. Foss (Ed.), *Determinants of Infant Behavior*, Vol. 3. London: Methuen, 1969, pp. 113-138.
- YARROW, M. R. and CAMPBELL, D. J. Person perception in children. *Merrill-Palmer Quarterly*, 1963, 9, 57-72.
- YEN, W. M. Sex-linked major gene influences on human spatial abilities. *Dissertation Abstracts*, 1974, 34B, 566-567.
- ZAHORSKY, T. Short-term memory in children as a specific function of different sensory modalities. *Psychologia a Patopsychologia Dietata*, 1969, 4.
- ZANER, A. R., LEVEE, R. F., and GUNTA, R. R. The development of auditory perceptual skills as a function of maturation. *Journal of Auditory Research*, 1968, 8, 313-322.