

5

Sex Hormones, Brain Development, and Spatio-Perceptual Strategies in Turner Syndrome

Women with Turner syndrome (TS) typically encounter severe difficulties when asked to solve various spatial ability tasks. Despite numerous attempts, agreement has not been reached about the specific nature or cause(s) of their spatial deficits. In this chapter some aspects of this dilemma will be illustrated, and possible solutions proposed. The first half of the chapter involves a detailed examination of the spatio-perceptual strategies used by TS women in the Rod-and-Frame Test (RFT), a measure of field dependence-independence. In the second half, I discuss specific hormonal factors that may explain not only the spatio-perceptual deficits exhibited by TS women in the RFT, but also a number of other phenomena concerning sex-related variations in spatial skills.

FIELD DEPENDENCE-INDEPENDENCE

In a series of studies, my colleagues and I demonstrated clearly that TS women score highly field dependent on tasks like the RFT and the Embedded-Figures Test (Nielsen, Nyborg, & Dahl, 1977; Nyborg & Nielsen, 1981a). How should this finding be interpreted? Over a number of years, the creators of the field dependence-independence dimension revised their description of field dependence (Asch & Witkin, 1948; Witkin, 1964; Witkin & Asch, 1948; Witkin, Dyk, Faterson, Goodenough & Karp, 1962/1974; Witkin & Goodenough, 1977a; 1977b; 1981; Witkin et al., 1954; Witkin & Oltman, 1967). The traditional way of scoring performance in the RFT was criticized, and new methods suggested (Arbuthnot, 1972; Gruen, 1957; Haller, 1981; Haller & Edgington, 1982a, 1982b; Lester, 1968, 1971; McGarvey, Maruyama, & Miller, 1977; Nyborg, 1977). Because the old scoring method was shown to confound a number of variables, it became rather problematic to determine the meaning of being classified as field dependent.

To find out more about the meaning of field dependence in the RFT, I began a series of conceptual and methodological studies (Nyborg, 1971a, 1971b, 1972, 1974a, 1974b; Nyborg & Isaksen, 1974). These studies yielded an alternative interpretation of task demands in the RFT along with a new method for scoring performance in this

Witkin, H. A., Oltman, P. K., Raskin, E., & Karp, S. A. (1971). A Manual for the Embedded Figures Tests. Palo Alto, CA: Consulting Psychologists Press, Inc.

task. Subsequently, it was shown that the new scoring method could be modified to study spatio-perceptual strategies in the RFT (Nyborg, 1977). The results of this series of studies provide the basis for the present attempt to discover more about what makes the RFT such a difficult task for many TS women.

The following sections contain brief descriptions of the RFT procedure and content analyses of the task (see Nyborg, 1977 for more details). The original RFT Turner data from the Nielsen et al. (1977) study are subjected to a developmental reanalysis, and the outcome is compared with preliminary norms for RFT scores. The reanalysis concentrates on mapping age differences in the two major response parameters of the RFT. The two response-parameter values are combined in a subsequent analysis to indicate the type of spatio-perceptual strategy used by an individual in trying to cope with the experimentally-induced perceptual conflict. Finally, age differences in the spatio-perceptual strategies of TS women are compared to those of unaffected schoolgirls.

Subjects

Data from 45 women with Turner syndrome (Turner, 1938) were available. Twenty-one had a 45,X karyotype, while the other 24 showed either a loss of part of the second X chromosome or mosaicism (for details, see Nielsen et al., 1977). Fifty percent lived in Copenhagen, while the rest lived in smaller towns or rural districts of Denmark. Their ages ranged from 7.1 to 38 years with a mean of 20.9. They were arbitrarily divided into five age groups: (1) younger than 15, (2) 15-19, (3) 20-24, (4) 25-29, and (5) older than 30. The mean ages for the five groups were 12.11, 17.7, 22.6, 27.0, and 34.9 years, respectively. About half of the subjects had received cyclic estrogen-gestagen therapy for various periods of time, and duration of treatment has been shown to be related to the expression of spatial ability (Nyborg & Nielsen, 1981a).

The control group consisted of Danish schoolgirls aged 8, 10, 12, 14, and 16 years (plus or minus one month) who volunteered to be studied with the RFT. These girls were similar to the Turner sample in SES.

Instrument and Procedure

A transportable RFT apparatus was used with the subject placing her head at one end of the box so that her view was restricted to the inside. A square frame with a movable rod inside was visible at the other end of the box. The rod and the frame were then tilted initially 28 degrees to the right or to the left of gravitational vertical in all possible combinations over four trials. This was repeated once to obtain a total of eight measures. The subject's task was to adjust the rod to a physically vertical position within the stationarily tilted frame.

Content analysis. A content analysis of the RFT has shown that the following variables account for most of the variance in performance: (1) the potentially misleading frame tilt information (frame effect: *phi*), (2) the effect of the rod-starting-position (rod effect: *rho*), (3) some subjects' permanently deviating perception of the physical upright (subject error: *mu*), (4) the subject's degree of response consistency to identical rod-frame tilt conditions (response consistency: *sigma*) (Nyborg, 1974a, 1977; Nyborg & Isaksen, 1974).¹

Quantitative scoring method. The Witkin group recommends the unsigned deviation (USD) or absolute error scoring method for the RFT. However, the USD method has been shown to confound the four variables mentioned above. Therefore, a new method of scoring the RFT, the analytic component (AC) method, was developed (Nyborg, 1974a) and subsequently tested (Jahoda & Nielsen, 1986; Nyborg & Isaksen, 1974; O'Connor & Shaw, 1978). It was applied and developed further in the present study.

With the AC method, the direction of the deviation of the rod from gravitational vertical is recorded to calculate a signed deviation score. A record is kept of whether the rod is adjusted to the same side to which the frame is tilted or to the opposite side. The "emphasis" a subject put on the potentially misleading frame tilt information for the final adjusted position of the rod (frame effect: *phi*) is calculated in degrees from the data on signed deviation of rod setting from gravitational vertical. The tendency of a subject to adjust the rod consistently to one side of physical vertical (subject error: *mu*) is noted. The tendency of a subject to see the rod as vertical even though it is still inclined toward its originally tilted position (rod effect: *rho*) is recorded. In this way the AC method partials out the single most important spatial variables in the RFT, thereby permitting the specific sources of each subject's deviation to be traced. Each of these variables has been shown to contribute independently to a subject's overall score (Nyborg, 1974a, 1974b, 1977; Nyborg & Isaksen, 1974).

The *mu* and *rho* values were subtracted from the subject's mean overall signed deviation score. By doing so, the effect of the potentially misleading frame tilt information (i.e., the unweighted *phi*-value) is separated from other possible effects. The AC method also allows for an estimate of each subject's response consistency (*sigma*), which is a measure of the "stability" with which the subject responds to comparable conditions on initial rod-and-frame tilt. The significance of the unweighted *phi*-values can be assessed further by the AC method. This is accomplished by relating unweighted *phi* to *sigma* according to the formula $\phi/\sigma (2/\sqrt{2})$ (see Nyborg, 1974a; Nyborg & Isaksen, 1974). If the weighted *phi* value is significantly different from zero ($p < .05$), the subject is classified as "significantly emphasizing misleading frame tilt information." In other words, the weighted *phi* score provides an index of the degree of significance the subject put on the misleading frame tilt information with respect to her degree of response consistency.

Task analysis. Because the traditional USD method of scoring the RFT confounds the above-mentioned variables, it easily leads to an inadequate understanding of the stimulus situation and to ambiguity in the basic concept of field independence-dependence. For example, consider a person classified as "field independent" who must depend on the gravitational information for successful performance in the RFT. There simply is no other way to get the information needed for achieving a low error score in the RFT. The problem with the traditional field-dependence concept is that it focused almost exclusively on the impact of the visual information. Consequently, field dependence became synonymous with visual field dependence, and the aspect of gravitational information was deemphasized. Through use of the following task analysis, I attempt to redress the balance and show that the RFT is a test of spatial ability (e.g., Linn & Petersen, 1985; Nyborg, 1974a, 1977).²

The task analysis makes it possible to appraise which spatio-perceptual strategy a given subject adopted in order to cope with the RFT. This appraisal rests upon the following four assumptions: (1) The subject uses one of four different kinds of spatio-perceptual strategies in her attempt to solve the experimentally-induced conflict between the optic and the vestibular-somesthetic information in the RFT, (2) the *phi* and the *sigma* values provide both the necessary and sufficient information for determining which particular strategy the subject actually used, (3) the particular spatio-perceptual strategy used reflects the degree to which one is able to capitalize on vestibular-somesthetic information in the cross-modal matching with visual information, and (4) in general, as a child gets older she will be able to master still more adequate strategies. For example, it is expected that most school beginners will either respond very inconsistently to the various frame and rod tilt conditions or will be systematically and heavily influenced by the tilted visual framework. However, as they mature they become steadily more able to counter the misleading frame tilt information by gaining access to the more reliable vestibular-somesthetic information.

The spatio-perceptual strategies were calculated in the following way. Subjects were first classified in accordance with each individual's *sigma* value. Those with *sigma* above 3 degrees (an arbitrarily defined cutoff point on the response consistency-inconsistency dimension) were assigned to a category of inconsistently responding subjects. The rationale for this procedure was that regardless of the actual size of the unweighted frame tilt score, *phi*, the degree of response inconsistency was so considerable that little reliance could be put on the *phi* score; there is no way to ensure whether the *phi* value was obtained purely by chance. The high *sigma* score was taken to indicate that the subject used one or another of a variety of unsystematic D strategies (for details, see Nyborg, 1977).

The remaining systematically responding subjects (i.e., with *sigma* values below three degrees) were then classified into one of the

following three categories in accordance with the size of their *phi* value:

- (1) Subjects with a *phi* value above eight degrees. The combination of a low *sigma* score and a high *phi* score was taken to indicate that such subjects are consistently and significantly misled by the frame tilt information. They are said to have used a non-optimal, optically dominated C strategy.
- (2) Subjects with a *phi* value between two and eight degrees. The low *sigma* score, combined with a moderately-sized *phi* score was taken to indicate that the subject consistently made a compromise between the optical and the vestibular-somesthetic information. Such subjects are said to use a near-optimal, compromise B strategy.
- (3) Subjects with a *phi* score less than two degrees. A low *sigma* score combined with a low *phi* score was taken to indicate that the subject consistently was able to exploit the reliable vestibular-somesthetic information in her attempt to set the rod to a physical vertical position in the presence of potentially misleading visual tilt information. Such a subject was said to use an optimal vestibular-somesthetic A strategy.

Data analysis. By examining the RFT performance in unaffected girls age 8 to 16 years, it was possible to establish preliminary norms of age changes in spatio-perceptual strategies in the RFT from early childhood to the attainment of a stable adult level. This provided a baseline for comparing age changes in TS females.

Results

Changes in unweighted *phi* scores. Changes with age in the ability to draw upon vestibular-somesthetic information (i.e., group mean unweighted *phi* value) in the RFT are shown in Figure 5.1. Inspection of this figure reveals that the age distribution of mean unweighted *phi* scores for TS women tends to differ from that of unaffected girls. While unaffected girls attain their optimal performance somewhere between 12 and 14 years of age, the performance of TS women peaks somewhere between 18 and 26. A slight increase in group mean unweighted *phi* is seen in both groups after the two curves reached their minimum. However, a chi-square test indicated that the age distribution of unweighted *phi* of TS women did not differ significantly from that of the unaffected girls.

Changes in response consistency, *sigma*. Figure 5.2 shows changes with age in response consistency (*sigma*) in TS women and in unaffected girls. The age distribution indicates that mean *sigma* value is at its lowest at 14 years in unaffected girls, and at a similar level around age 22 in TS women. However, there is not much variation over time in *sigma*, and no statistically significant differences between the two groups.

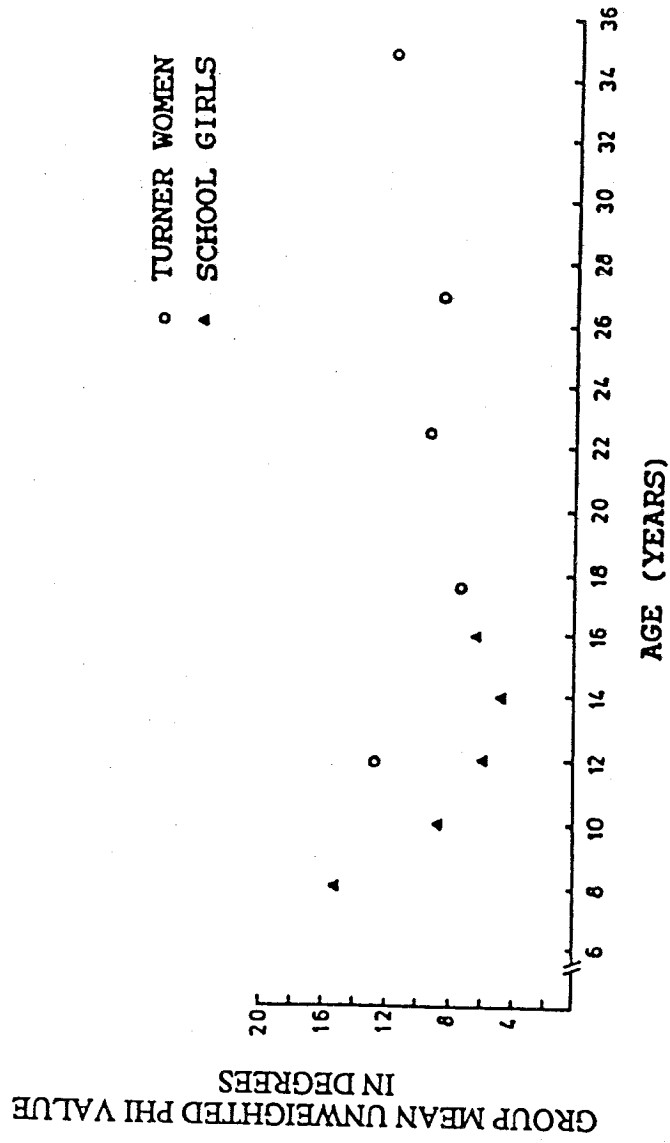


Figure 5.1 Changes with age in group mean unweighted phi value for Turner women and school girls.

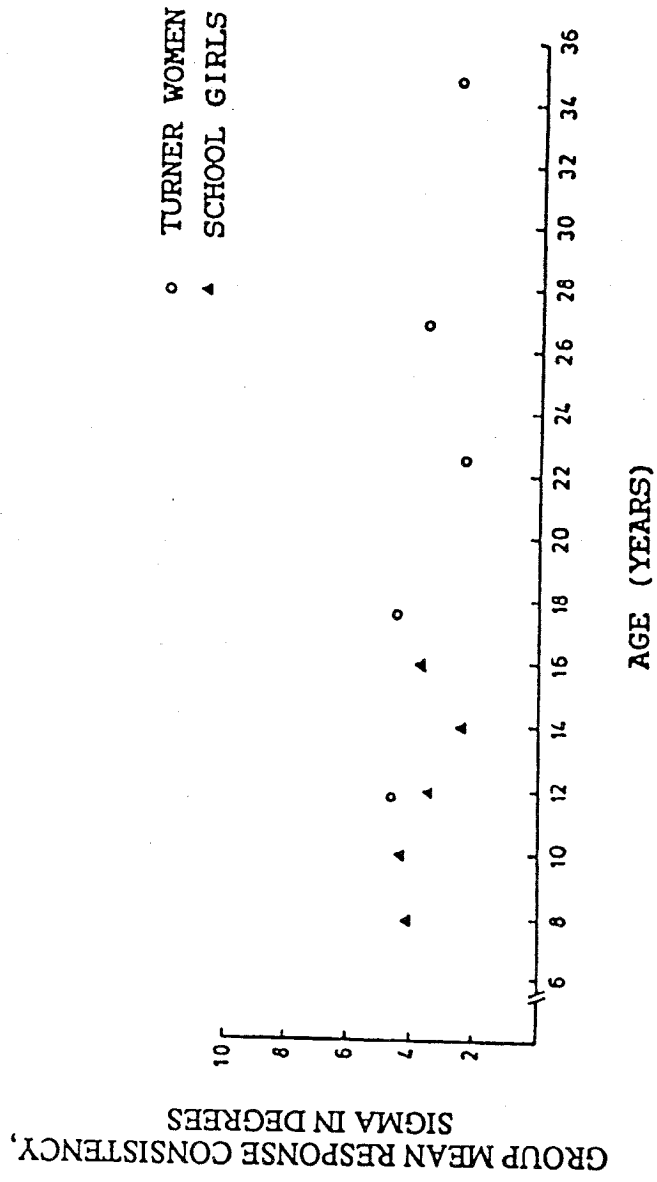


Figure 5.2 Changes with age in group mean response consistency (sigma) for Turner women and school girls.

Changes in weighted ϕ scores. Table 5.1 shows the number and percentages of subjects in each of the age groups who were unable to benefit from vestibular-somesthetic information and accordingly could not dispense with the misleading frame tilt information (i.e., who obtained a weighted ϕ value significantly different from zero, $p < .05$). The proportion of the TS women with a significant weighted ϕ score did not change much over time. More than 70% of the TS women put significant emphasis on the misleading frame tilt information throughout the age range studied. By contrast, a clear age change can be seen in the unaffected girls. Thus, while 87% of the 8-year-old girls emphasized frame tilt information, this proportion decreased in a fairly linear way with age to less than 50% at 16 years. The distribution of weighted ϕ scores for TS women differs significantly from that of the unaffected girls ($X^2 = 10.87$, $p < .05$).

Changes in type of spatio-perceptual strategy used. Table 5.2 presents changes with age in spatio-perceptual strategy used. A clear and consistent age change in response consistency can be observed in the unaffected girls, with a smaller proportion using one of the unsystematic D strategies with increasing age. The proportion of TS women applying an unsystematic D strategy also became smaller with age. However, this age change was delayed relative to that of the unaffected girls. While the proportion of unaffected girls who applied one of the unsystematic D strategies decreased to below 50% in the age range of 10 to 12 years, a similar decrease in the use of D strategies by TS women is first noticeable years later.

Another age difference in the distribution of strategies between TS women and the unaffected girls is shown in Table 5.2. Almost all (93%) of the 8-year-old unaffected girls used non-optimal strategies (i.e., either an unsystematic D strategy or a systematic but strongly optically dominated C strategy). However, at the ages of 14 and 16 less than half of the unaffected girls (47% and 40%, respectively) applied a C or a D strategy. In contrast, 71% of the 15- to 19-year-old TS women, and 75% of those over 30 were still using these non-optimal spatio-perceptual strategies. The age distribution of the TS women using non-optimal D and C strategies in preference to the optimal or near-optimal B and A strategies differs significantly from that of the unaffected girls ($X^2 = 35.76$, $p < .001$).

Discussion

The present analyses of RFT performance yielded four observations. First, the proportion of unaffected girls that could deemphasize the potential impact of misleading frame tilt information (weighted ϕ) by effective reference to vestibular-somesthetic information becomes smaller with age. Second, the number of TS women who either responded inconsistently to the frame tilt information, or were systematically misled by it did not diminish with age. Third, the new way of analyzing performance in the RFT indicated that normal age changes in spatio-perceptual

TABLE 5.1
Mean Weighted Phi Values for TS Women and Schoolgirls

AGE	TURNER WOMEN				SCHOOLGIRLS		GROUP		
	MEAN	SD	N	Π	Π^*	Π	Π^*	N	AGE
< 15 YR.	1211	25	14	2 (14%)	12 (86%)	7 (47%)	8 (53%)	15	8 YR
15 - 19 YR.	177	16	7	2 (29%)	5 (71%)	8 (53%)	7 (47%)	15	10 YR
20 - 24 YR.	226	14	11	2 (18%)	9 (82%)	8 (53%)	7 (47%)	15	12 YR
25 - 29 YR.	270	15	9	2 (22%)	7 (78%)	8 (53%)	7 (47%)	15	14 YR
> 30 YR.	349	35	4	0 (0%)	4 (100%)	8 (53%)	7 (47%)	15	16 YR

*p < .05

TABLE 5.2
Changes with Age in Spatio-Perceptual Strategies Used by TS Women and Schoolgirls

AGE	MEAN	SD	TS WOMEN				SCHOOLGIRLS				N	AGE		
			OPTIMAL OR NEAR-OPTIMAL STRATEGY		NON-OPTIMAL STRATEGY		OPTIMAL OR NEAR-OPTIMAL STRATEGY		NON-OPTIMAL STRATEGIES					
			A	B	C	D	A	B	C	D				
< 15 YR	12 ¹¹		2 ⁵	14	0 (0%)	3 (21%)	4 (29%)	7 (50%)	0 (0%)	1 (7%)	5 (33%)	9 (60%)	15	8 YR
15 - 19 YR	17 ⁷		1 ⁶	7	1 (14%)	1 (14%)	1 (14%)	4 (57%)	1 (7%)	0 (0%)	5 (33%)	9 (60%)	15	10 YR
20 - 24 YR	22 ⁶		1 ⁴	11	2 (18%)	3 (27%)	3 (27%)	3 (27%)	5 (33%)	3 (20%)	1 (7%)	5 (33%)	15	12 YR
25 - 29 YR	27 ⁰		1 ⁵	9	1 (11%)	4 (44%)	2 (22%)	2 (22%)	5 (33%)	3 (20%)	1 (7%)	6 (40%)	15	14 YR
> 30 YR	34 ⁹		3 ⁵	4	0 (0%)	1 (25%)	2 (50%)	1 (25%)	6 (40%)	3 (20%)	2 (13%)	4 (27%)	15	16 YR

Stat A: Systematic vestibular dominated compromise strategy.

Stat B: Systematic vestibular compromise strategy.

Stat C: Systematic optic dominated compromise strategy.

Stat D: Unsystematic strategy.

strategies in the RFT follow this pattern: Most 8- and 10-year-old unaffected girls use either an inconsistent non-optimal D strategy or a consistent optically dominated, non-optimal C strategy. However, by age 12 many girls have already become able to use a near-optimal compromise B strategy or even to master an optimal vestibular-somesthetic dominated A strategy. Fourth, it was observed again that TS women do not normally pass through these phases. The majority of TS women persist in using non-optimal D or C strategies for a long time after a considerable proportion of unaffected girls have turned to the more successful B or A strategies.

Recall that about half of the TS women studied had received cyclic estrogen-gestagen therapy for various periods for time. Duration of treatment was shown to be related to the expression of spatial ability in such a way that short-term treated TS women had normal spatial ability, while untreated and long-term treated individuals had equally low spatial ability (Nyborg & Nielsen, 1981a). However, it is not likely that differences in duration of treatment can explain the present Turner age distribution, because the three treatment types were nearly equally represented in the various age groups. This reduces the error score equally in the age groups and leads to a conservative estimate of the size of the error score in TS women. An exception to the equal representation of differently-treated TS women is the youngest group of Turner girls in which none were treated before the age of 14. While this group contained some of the short-term treated girls, the average error score of the total group was very high.

The observations suggest that during the prepubertal period, most young children developed ways of systematically and effectively handling the information available to them in the RFT situation. Thus, although first being confused or overwhelmingly misguided systematically by the illusion creating optical tilt information, they gradually were able to make a stable compromise between conflicting optical and vestibular-somesthetic sources of information or a clear perceptual preference for one type. After puberty, 40% of the unaffected girls were able to maximally exploit the reliable vestibular-somesthetic information in the RFT situation. This enabled these individuals to cope adequately with the perceptual conflict. TS women do not seem to pass normally through these phases. They either stagnate in an early phase of spatio-perceptual strategy development or develop at a much slower pace than normal girls.

A tendency for some unaffected girls to regress in spatial ability to a prepubertal stage sometime between 14 and 16 years of age was observed in the present study as it has been in other studies (e.g., Witkin, Goodenough, & Karp, 1967). Albeit slight, this regression has interesting theoretical implications because it appears at the same time as the pubertal regression in areas believed to be related to spatial ability, such as nonverbal IQ, mathematics, physics, and science achievement (for a review, see Nyborg, 1983a). Obviously,

we need much more extensive, longitudinal data before we can confirm that the slight, cross-sectionally-derived age regression in RFT performance found in this study reflects a genuine developmental regression. However, the youngest (then 8-year-old) girls from the large cross-sectional study have been retested together with two other groups in a cohort-sequential study with the RFT at regular intervals since 1976. A preliminary analysis of these longitudinal data indicates that the regression in the present study and that observed by the Witkin group do in fact reflect a genuine developmental trend.

The findings raise a number of questions. Have TS women really lost the genetic potential for the full expression of spatial ability with the loss of X chromosome material? I do not think so, and I defend this position in the following sections. However, if TS women have the genes necessary for spatial ability, it follows that the slowdown or the arrest in spatio-perceptual development has to be explained by ontogenetic factors capable of inhibiting the expression of the genes. This also raises questions. Are these ontogenetic factors the same as those responsible for pubertal regression in the spatio-perceptual development of normal girls as estimated by the RFT (Witkin et al., 1967)? I think they are. What, then, is the nature of these factors and how do they exert their influence?

In an attempt to answer these questions I examine first the results of previous research on the localization of agents believed to be important for the expression of spatial ability. I go on to propose a neuroendocrinological alternative.

FACTORS INFLUENCING THE EXPRESSION OF SPATIAL ABILITY

There have been many diverse attempts to determine the factors that influence the expression of spatial ability (see Chapter 3 in this volume for a more thorough review). Waber (1976, 1977a, 1977b, 1979a, 1979b) speculated that cerebral reorganization at puberty inhibits spatial ability, and furthermore, she suggested that defective visuo-motor coordination and difficulties with manual sequences are related to inhibition of the expression of spatial ability. McGlone (1985) found a positive correlation between decreased somatosensory threshold of the left palm and spatial ability, but was unable to support the conclusion that the neuropsychological deficits of TS women are due to a focal brain dysfunction. Netley (1977) conjectured that the cerebral hemispheres of TS women are bilaterally organized more than usual for both verbal and spatial ability. The intrahemispheric verbal-spatial competition is believed to thwart the expression of spatial ability (Levy, 1969). Nevertheless, there is still a lack of evidence that would unequivocally link spatial ability with degree of cerebral asymmetry in TS women (e.g., McGlone, 1985; Waber, 1979b) or in unaffected individuals (Kimura, 1987).

The expression of spatial ability has also been explained by an X-linked, recessive gene theory (O'Connor, 1943; Stafford, 1961, 1963, 1972). However, more recent evidence does not support the theory (Boles, 1980; Bouchard & McGee, 1977; Corley, DeFries, Kuse, & Vandenberg, 1980; DeFries et al., 1976; Guttman, 1974; Loehlin, Sharan, & Jacoby, 1978; McGee, 1979, 1982; Nyborg & Nielsen, 1981b; Vandenberg & Kuse, 1979). In fact, the X-linked, recessive gene theory predicts that TS women should have high spatial ability; but this prediction obviously runs counter to all available evidence (e.g., Nyborg & Nielsen, 1981a).

According to Moor (1967), excess of X chromosome material suppresses higher cognitive functions in man. However, it could just as well be argued that lack of X chromosome material suppresses the expression of spatial ability in TS women. Moreover, the expression of spatial ability does not vary much within Turner syndrome across karyotypes differing with respect to the amount of X chromosome material present (Nielsen et al., 1977). Suggestions that the sheer amount of X chromosome material or heterochromatin may have impact on a phenotypical trait begs questions about the location of action and about details of the mechanisms (Nyborg, 1986b).

On the whole, the research to date still leaves open the question of whether TS women have lost the genetic potential for normal spatial ability. Furthermore, it is not particularly helpful in illustrating the nature and the mechanisms of the ontogenetic factor(s) that are powerful enough to diminish the expression of spatial ability. Finally, the research has not yet clarified whether the factors controlling the expression of spatial ability in TS women are identical to those controlling it in unaffected women. Consequently, the field is in need of both a comprehensive theory and research designed specifically to solve these intricate problems.

SEX HORMONES AND THE EXPRESSION OF SPATIAL ABILITY

In an early attempt to deal simultaneously with these difficult questions I suggested that (1) most, if not all, sex-dimorphic traits are sex-limited rather than sex-linked, and (2) estradiol (a biologically potent sex steroid in the estrogen group) plays a major role in regulating the expression of many of them, partly by modulating DNA products on autosomal chromosomes and partly by influencing the working conditions of neurotransmitters (Nyborg, 1979, 1981, 1983a, 1983b, 1984, 1985, 1986a, 1986b, 1987a, 1987b, 1987c, 1987d, 1987e).

In the following sections I examine four lines of evidence indicating that life-history variations in estradiol do indeed cause alterations in the expression of spatial ability and of other abilities as well: (1) sex steroid changes at puberty; (2) sex hormone substitution therapy of TS women; (3) the effects of menstrual changes; and (4) sex hormone substitution therapy of postmenopausal

women. The effects of these four steroid perturbations on the expression of spatial ability are examined with regard to predictions resulting from the General Trait Covariance-Androgen/Estrogen (GTC-A/E) balance model illustrated in Figure 5.3 (Nyborg, 1987b).

Changes at Puberty

Continuity of development characterizes the expression of spatial ability as measured by the RFT during the extensive prepubertal period. Despite tremendous individual differences, most children tend to take up a stable position within the spatial ability dimension relative to the prototypic developmental trend (Witkin et al., 1967). This picture of smooth development of spatial ability changes abruptly at puberty, when discontinuity of development becomes a prominent feature (Witkin et al., 1967). The onset of discontinuity coincides with radical changes in plasma estradiol concentrations. The pubertal discontinuity typically takes one of two forms. Either the developmental curve reaches an asymptote, in which case the child's relative position within the ability dimension remains constant, or an actual reduction of ability takes place. In the latter case each child changes its relative position in accordance with the force of the inhibiting agent.

Consistent with the GTC-A/E balance model the pubertal modulation of spatial ability is moderately related to the degree of development of secondary sexual characteristics. Thus, while late maturing children have been observed to reach their spatial asymptote late in puberty, early maturing children seem characterized by a tendency toward postpubertal inhibition of the expression of spatial ability. The pubertal inhibition or, more appropriately, regression of spatial ability in early maturing children seems to take place irrespective of sex. This regression can also explain why highly androgenized men and highly estrogenized women tend to exhibit low spatial ability, while late maturing "androgynous" men and women tend to show high spatial ability (Crockett & Petersen, 1985; Linn & Petersen, 1985; Maccoby & Jacklin, 1974; Petersen, 1976, 1979; Waber, 1976, 1977a, 1977b, 1979a).

According to the model, the sexually most differentiated individuals "overshoot" the range of brain estradiol concentrations for the optimal expression of spatial ability, while the sexually less differentiated individuals remain below or within this range. In reality, things are more complicated. For example, we know that both men and women are able to convert (aromatize) testosterone to estradiol, and that they probably do so in different amounts in different tissues at different ages. However, I shall minimize the account of biochemical details in order to illustrate better the major principles of the GTC-A/E balance model. (In addition to dealing with covariant development of hormonal, bodily, and spatial ability traits, the GTC-A/E model also strives to explain covariant personality development [Nyborg, 1983a, 1983b, 1984, 1987a, 1987b,

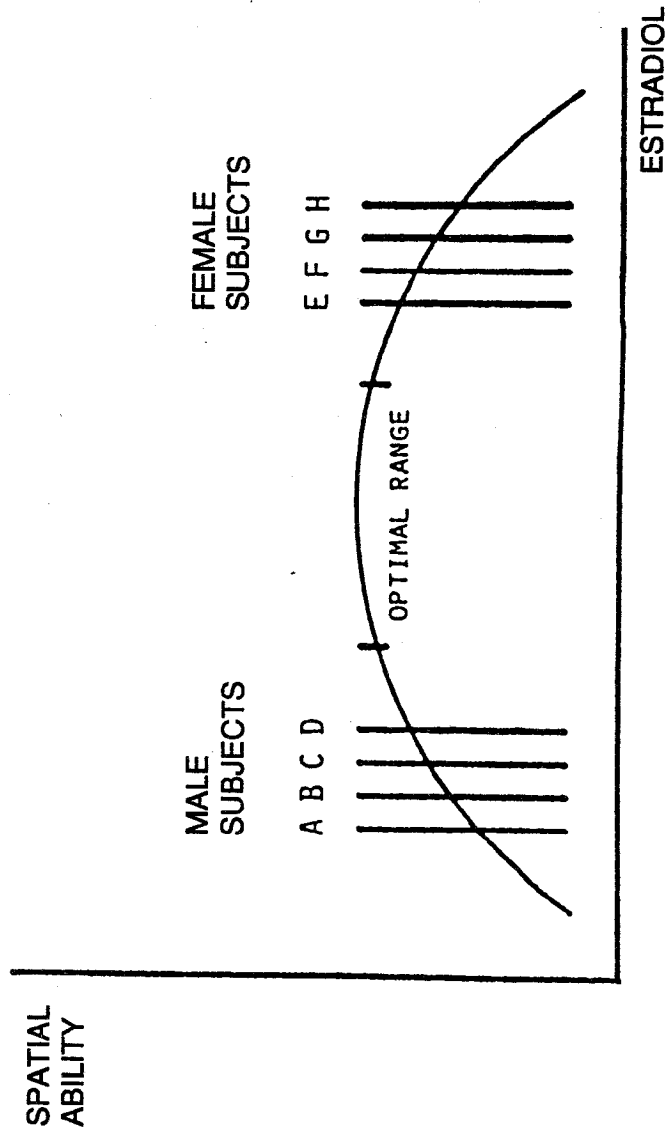


Figure 5.3 Expression of spatial ability at different plasma estradiol concentrations as predicted by the General Trait Covariance-Androgen/Estrogen (GTC-A/E) balance model.

1987c, 1987d, 1987e], although an account of this aspect of the model is outside the scope of this chapter.)

Sex Hormone Substitution Therapy in Turner Women

Another perturbing life-history event is that of receiving supplementary sex hormone therapy. Effects of estrogen therapy can be studied in a quasi-experimental design with TS women who receive treatment to compensate for their unusually low secretion of gonadal hormones. We performed a retrospective study of such women, in which the duration of treatment figured as the independent variable (Nyborg & Nielsen, 1981a). We found that TS women receiving short-term cyclic estrogen/gestagen treatment for between three months and two years (1.1 year average) obtained spatial ability scores identical to those of their age-matched chromosomally normal sisters on a number of spatial ability tasks, including the RFT. The groups of untreated TS women and long-term treated TS women (with an average of about eight years of treatment) both scored way below the short-term treated women.

We recognized that the methodological weaknesses inherent in such a retrospective study seriously limit the findings. Nevertheless, the observations make sense under the assumptions that (1) untreated TS women do not secrete enough gonadal hormones to reach the estradiol concentrations necessary for proper brain development and for the optimal expression of spatial ability, and (2) short-term cyclic estrogen-gestagen therapy exerts beneficial organizational effects on somatic as well as on estrophilic brain tissues, albeit in a highly atypical manner. In addition, the treatment brought the estradiol concentrations close to or within the range for optimal expression and thus exerted a positive activational effect on the brain for the expression of spatial ability. Given that high plasma estradiol concentrations impede the expression of spatial ability, and that high doses (Toran-Allerand, 1984) and perhaps also prolonged treatment can have neurotoxic effects, the GTC-A/E model suggests that the long-term treated TS women either suffered under steroid brain intoxication or overshot the optimal range, and thus suffered an estradiol-induced inhibition of the expression of spatial ability. The doses used for the long-term cases were likely to have been excessive by today's standards. However, whether the actual treatment had neurotoxic effects remains to be confirmed. Fortunately, there is now an acute awareness of the need to drastically reduce the amount of estradiol prescribed in order to avoid unwanted side effects.

With these caveats in mind, I think the minimalist conclusion is that the above-mentioned findings are at least compatible with the idea that spatial ability is a sex-limited trait, the expression of which can be regulated up or down as a function of estradiol uptake. Another permissible conclusion is that TS women actually possess the genes required for the full expression of spatial ability irrespective of their well-documented lack of X-chromosome material. This

conclusion rests upon the observations that short-term treated TS women obtain a spatial ability score identical to that of their sisters with a normal X-chromosome complement, and that short-term treated TS women with a 45,X karyotype obtain spatial ability scores identical to those of short-term treated TS women with other karyotypes.

Perturbations Associated with Menstruation

Menstruation is hormonally a profoundly perturbing monthly event. For example, the ovarian secretion of estradiol changes markedly from a no-production state at menstruation to a peak value at ovulation. This is a typical situation in which the GTC-A/E balance model allows for a number of testable predictions about the expression of spatial ability. For example, it can be determined whether the expression of spatial ability is maximal at the time when the plasma estradiol concentration is minimal, and vice versa (see Figure 5.3). In other words, the GTC-A/E balance model predicts that the ordinary expression of female spatial ability will cycle dynamically up and down as an inversely related function of the monthly downs and ups in the availability to the brain of estradiol. This cycling phenomenon has been observed in several studies where it was found that spatial ability was high when estrogen was low, and vice versa (Anderson, 1972; Dor-Shav, 1976; Ho, Gilger & Brink, 1986; Klaiber, Broverman, Vogel, & Kobayashi, 1974). Recently, Hampson and Kimura (1987) confirmed this cycling nature of the expression of spatial ability in an RFT and embedded-figures test study of normally menstruating women.

It has been suspected for some time that fine motoric abilities, some of which women excel in compared to men, may also be under hormonal influence. For example, using a double-blind crossover, Latin-square tap test design, Itil and Herrmann (1978) demonstrated that estrogen influences motor skills by finding that their estrogen treatment group achieved significantly more taps than a placebo group in 32-second test periods at both one and three hours after medication. Moreover, Hampson and Kimura (1987) were able to show that some manual abilities cycle with variations in estradiol in such a way that when manual skills were at their highest, spatial skills were at their lowest, and vice versa.

In fact, the GTC-A/E model presupposes such a dynamic dissociation between the cyclic changes in the expression of spatial and manual skills, as the basic assumption of the GTC-A/E model is that all traits showing sexual dimorphism can be ascribed primarily to permanent or to transient effects of gonadal hormones (Nyborg, 1981, 1984). From this basic rule it follows that traits whose expression are influenced by transient activational hormonal effects will change whenever the hormones change, while traits dependent on organizational hormonal effects will be present phenotypically in a more stable manner. However, it should not be forgotten that the

expression of some traits may depend on a combination of organizational and activational effects, while the expression of other traits may seem organizationally stabilized only because the level of activational gonadal hormones remains constant. For example, women on oral contraceptives show less of the phase-related changes in the expression of a number of traits that presumably depend on activational effects (e.g., Bardwick, 1976; Diamond, Diamond, & Master, 1972; Wuttke et al., 1975).

Perturbations at Menopause

A glance at the curvilinear GTC-A/E balance model (Figure 5.3) will immediately raise the expectation that postmenopausal women who have experienced a decline in plasma estradiol concentrations will obtain a higher spatial ability score than they did in their premenopausal-postpubertal life-span. This prediction has yet to be tested. However, a number of climacterical women suffer from various postmenopausal symptoms that can be eased by estrogen replacement therapy. Rosenthal and Kimura (1987) exploited this situation by examining the effects of gonadal hormones on the expression of spatial and motor abilities. They localized a group of postmenopausal women who were on an on-off estrogen replacement therapy and found that while the expression of spatial ability (figure disembedding task) and praxic motor ability (manual-sequence task) were high in the estrogen treatment phase, the converse occurred in the off-therapy phases when steroid levels were believed to be lower.

When considered together, these four lines of evidence strongly suggest that certain spatial and fine motoric abilities are sex-limited and that estradiol regulates their expression. Moreover, the GTC-A/E balance model seems remarkably efficient in accounting for the intricate dynamic and static aspects of the quantitative relationships among estradiol, body maturation, and spatial and motor abilities. That is, in terms of relatively simple principles, the model can explain (1) the expression of low spatial ability encountered in untreated TS women; (2) the expression of a normal level of female spatial ability in short-term treated TS women; (3) the expression of low spatial ability in long-term treated TS; (4) the regression in spatial ability in unaffected girls at puberty; (5) the debut of the often observed adult sex-related difference in spatial ability; (6) the dynamic menstrual and postmenopausal changes in the expression of a number of abilities in adult women, along with the oral contraceptive or noncyclic fixation of these abilities; and (7) the noncyclic nature of spatial and motoric abilities in men.

I have suggested elsewhere (Nyborg, 1981) that there exists a range of estradiol values optimal for the expression of certain verbal abilities (e.g., verbal fluency), and that this range is inversely related to that for the expression of spatial ability. This suggestion fits nicely with Lynn's (1987) recent argument for the existence of a negative correlation between spatial and verbal abilities once "g" is

controlled. Lynn speculated that the correlation somehow relates to maturational rate.

In their study of postmenopausal women, Rosenthal and Kimura (1987) actually tested the prediction of the GTC-A/E balance model that verbal memory and verbal fluency scores were affected by higher levels of estrogen in the on-therapy phase as compared to the off-therapy phase; however, Hampson (1986) found the same phase-related patterns of change for speeded manual coordination in her speech-articulatory data. Perhaps the substitution-therapy-related level of plasma estrogen concentration in the on-therapy phase of the Rosenthal and Kimura study was too low to modulate the expression of verbal ability.

The assumption of the GTC-A/E balance model that genetic potential for the expression of spatial ability is coded in DNA material located on autosomal chromosomes also appears to be supported by, or at least not incompatible with, available data on TS subjects. Neither the complete absence of one X chromosome in all cell lines, nor abnormalities of the second X chromosome interferes with the full expression of spatial ability in TS women, so long as their estradiol deficiency is corrected (Nyborg & Nielsen, 1981a).

THE NEUROPHYSIOLOGY OF SPATIO-PERCEPTUAL STRATEGIES

Perception of the upright in the RFT depends on whether the optical information can be successfully integrated with the gravitational field information. Optical information alone is insufficient, because the retinal information about directions in space cannot be evaluated unless the position of the eye in the environmental coordinate system is known. The undisturbed access to gravitational information enables the subject to collect such information and to establish and maintain a veridical perception of the upright. Under normal terrestrial conditions this poses no problem because the equivalent optical and gravitational information is congruent. However, in the RFT the optical and the gravitational information is experimentally rendered incongruent by tilting the visual framework. Therefore, the subjects must solve the perceptual conflict between the optical and the vestibular-somesthetic information before successful perception of the upright can be accomplished. Solution requires effective cross-modal matching of information arising from different perceptual systems, and the spatio-perceptual strategies are believed to reflect the kind of solution to this conflict found in the RFT.

Obviously, the complex optic-vestibular-somesthetic, cross-modal matching of afferent information required in the RFT situation must be accomplished by the central nervous system (Bischof, 1974a; Nyborg, 1977). The cross-modal matching causes problems for TS women who suffer from an estradiol deficit, but not for those having

received short-term supplementary estrogen therapy. This means, logically, that untreated TS women either have less access to or are less able to process the bodily information derived from the gravitational field force and collected through the vestibular and somesthetic systems.

Available neurophysiological and neurological evidence does not allow us to draw final conclusions about the localization of the putative brain disturbances responsible for the abnormal spatio-perceptual development in TS women (e.g., McGlone, 1985; Reske-Nielsen, Christensen, & Nielsen, 1982). However, whatever the locus of the brain malfunctioning, a case can be made for testing the hypothesis that the damage is a more or less direct result of their abnormally low, plasma estradiol concentration.

We still have a long way to go before we know what goes wrong with brain development in untreated TS women. Nevertheless, we have reasons to remain optimistic. Provided that the assumptions of the GTC-A/E balance model are valid (i.e., that DNA material required for the build-up of brain tissues subserving spatial information processing is located on autosomal chromosomes, and further that the expression of spatial ability is regulated by estradiol), we should be able to correct the spatio-perceptual deficits in TS women by stimulating brain growth via the same estrogen substitution therapy that is called for to stimulate the development of their secondary sexual bodily characteristics. To grasp the details of this possibility, brain development and functioning must be closely monitored before, during, and after estrogen treatment.

This goal would be easier to attain if we succeed in establishing a protocol for an internationally coordinated, large-scale study to examine the structural and neurophysiological changes that take place in estrophilic brain areas as a function of low-dosage estrogen substitution therapy in TS women. Such a protocol should involve modern regional cerebral blood-flow techniques, as well as NMR brain imaging and spectroscopical studies, in addition to perceptual, intellectual, and personality test batteries. Inclusion also of anthropometric measures would add information about how gonadal hormones manage to procure covariant body, brain, and behavioral-trait development. Finally, the protocol should pay due respect to individual differences in preceding prenatal and postnatal endogenous and exogenous endocrine conditions, and should acknowledge information about patterns of inheritance for the traits in question.

NOTES

1. When Asch and Witkin (1948) constructed the RFT, they assumed that the test measured individual differences in how well people solve the experimentally-induced conflict between the visual and the postural information regarding the physical vertical. Later,

the Witkin group (e.g. Witkin et al., 1962/1974) became conceptually more embracing and constructed an elaborated psychological framework to account for performance in the RFT. They postulated that successful performance in the RFT directly reflects the degree of field independence in the sense of being capable of freeing oneself from contextual (read visual) perceptual influences and being able to "disembed" the rod when adjusting it to a physically vertical position. When it gradually became evident that field-independent persons also tend to behave in an independent manner in social settings, and that field-dependent persons tend to be more easily influenced by their social surroundings, much like they are by the perceptual context, the Witkin group invoked the higher order construct of psychological differentiation. It became customary to think that the simple error scores in the RFT more or less directly reflect the extent of psychological differentiation of personality. The four variables comprising the content analysis are believed to reflect the functioning of neurophysiological factors underlying spatial ability rather than personality characteristics.

2. It is interesting to note that the Witkin group (Witkin & Goodenough, 1981) also came to a similar conclusion that, ironically, is very similar to the original Asch and Witkin (1948) interpretation of RFT performance.

REFERENCES

- Anderson, E. I. (1972). Cognitive performance and mood change as they relate to menstrual cycle and estrogen level. Dissertation Abstracts, 33, 1758-B.
- Arbuthnot, J. (1972). Cautionary note on measurement of field independence. Perceptual and Motor Skills, 35, 479-488.
- Asch, S. E. & Witkin, H. A. (1948). Studies in space orientation. I. Perception of the upright with displaced visual fields. Journal of Experimental Psychology, 38, 325-337.
- Bardwick, J. M. (1976). Psychological correlates of the menstrual cycle and oral contraceptive medication. In: E. J. Sachar (Ed.), Hormones, behavior, and psychopathology. Raven Press: New York.
- Bischof, N. (1974). Optic-Vestibular orientation to the vertical. I: H. H. Kornhuber (Ed.). Vestibular systems, Part 2: Psychophysics, applied aspects and general interpretations, (pp. 155-190). Berlin: Springer-Verlag.
-

- Boles, D. B. (1980). X-Linkage of spatial ability: A critical review. Child Development, *51*, 625-635.
- Bouchard, T. J., Jr., & McGee, M. G. (1977). Sex differences in human spatial ability: Not an X-linked recessive gene effect. Social Biology, *24*, 332-335.
- Corley, R. P., DeFries, J. C., Kuse, A. R., & Vandenberg, S. G. (1980). Familial resemblance for the identical blocks test of spatial ability: No evidence for X linkage. Behavior Genetics, *10*, 211-216.
- Crockett, L. J., & Petersen, A. C. (1985). Pubertal status and psychosocial development: Findings from the early adolescence study. In R. M. Lerner & T. T. Foch (Eds.), Biological-psychosocial interactions in early adolescence: A life-span perspective. Hillsdale, NJ: Erlbaum.
- DeFries, J. C., Ashton, G. C., Johnson, R. C., Kuse, A. R., McClearn, G. E., Mi, M. P., Rashad, M. N., Vandenberg, S. G., & Wilson, J. (1976). Parent-offspring resemblance of specific cognitive abilities in two ethnic groups. Nature, *261*, 131-133.
- Diamond, M., Diamond, A. L., & Master, M. (1972). Visual sensitivity and sexual arousal levels during the menstrual cycle. The Journal of Nervous and Mental Disease, *155*, 170-176.
- Dor-Shav, N. K. (1976). In search of pre-menstrual tension: Note on sex-differences in psychological-differentiation as a function of cyclical physiological changes. Perceptual and Motor Skills, *40*, 683-693.
- Gruen, A. (1957). A critique and re-evaluation of Witkin's perception and perception-personality work. The Journal of General Psychology, *56*, 73-93.
- Guttman, R. (1974). Genetic analysis of analytical spatial ability: Raven's Progressive Matrices. Behavior Genetics, *4*, 273-284.
- Haller, O. (1981). A new procedure for determining components of field dependency. Perceptual and Motor Skills, *53*, 795-798.
- Haller, O., & Edgington, E. S. (1982a). Scoring rod-and-frame tests: Quantitative and qualitative considerations. Perceptual and Motor Skills, *55*, 587-593.
- Haller, O., & Edgington, E. S. (1982b). Interpretations of rod-and-frame test scores: An application of pattern analysis. Perceptual and Motor Skills, *54*, 1339-1342.
-

- Hampson, E. (1986). Variations in perceptual and motor performance related to phase of the menstrual cycle. Canadian Psychology, *27*, 268.
- Hampson, E., & Kimura, D. (June, 1987). Reciprocal effects of hormonal fluctuations on human motor and perceptuo-spatial skills. Research Bulletin, (No. 656). Department of Psychology, The University of W. Ontario, London, Canada, 1-20.
- Ho, H. Z., Gilger, J. W., & Brink, T. M. (1986). Effects of menstrual cycle on spatial information-processes. Perceptual and Motor Skills, *63*, 743-751.
- Itil, T. M., & Herrmann, W. M. (1978). Effects of hormones on computer-analyzed human electroencephalogram. In M. A. Lipton, A. Diamscio, & K F. Killam (Eds.), Psychopharmacology: A generation of progress. New York: Raven Press.
- Jahoda, G., & Nielsen, I. (1986). Nyborg's analytical Rod-and-Frame scoring system: A comparative study in Zimbabwe. International Journal of Psychology, *21*, 19-29.
- Kimura, D. (1987). Are men's and women's brains really different? Canadian Psychology, *28*, 133-147.
- Klaiber, E. L., Broverman, D. M., Vogel, W., & Kobayashi, Y. (1974). Rhythms in Plasma MAO Activity, EEG, and Behavior during the Menstrual Cycle. In M. Ferin, F. Halberg, R. M. Richart, & R. L. van de Wiele (Eds.), Biorhythms and human reproduction, (pp. 353-367). New York: John Wiley.
- Lester, G. (1968). The Rod-and-Frame Test: Some comments on methodology. Perceptual and Motor Skills, *26*, 1307-1314.
- Lester, G. (1971). Subjects' assumptions and scores on the Rod-and-Frame test. Perceptual and Motor Skills, *32*, 205-206.
- Levy, J. (1969). Possible basis for the evolution of lateral specialization of the human brain. Nature, *224*, 614-615.
- Linn, M. C., & Petersen, A. C. (1985). Emergence and characterization of sex differences in spatial ability: A meta-analysis. Child Development, *56*, 1479-1498.
- Loehlin, S., Sharan, S., & Jacoby, R. (1978). In pursuit of the "spatial gene": A family study. Behavior Genetics, *8*, 27-42.
-

- Lynn, R. (1987). The intelligence of the Mongoloids: A psychometric, evolutionary, and neurological theory. Personality and Individual Differences, 8, 813-844.
- Maccoby, E. E., & Jacklin, C. N. (1974). The psychology of sex differences. Stanford, CA: Stanford University Press.
- McGarvey, B., Maruyama, G., & Miller, N. (1977). Scoring field dependence: A methodological analysis of five Rod-and-Frame scoring systems. Applied Psychological Measurement, 1, 433-446.
- McGee, M. G. (1979). Human spatial abilities: Psychometric studies and environmental, genetic, hormonal, and neurological influences. Psychological Bulletin, 86, 889-917.
- McGee, M. G. (1982). Spatial abilities: The influence of genetic factors. In M. Potegal (Ed.), Spatial abilities: Development and physiological foundations, (pp. 199-222). New York: Academic Press.
- McGlone, J. (1985). Can spatial deficits in Turner's syndrome be explained by focal CNS dysfunction or atypical speech lateralization. Journal of Clinical and Experimental Neuropsychology, 7(4), 375-394.
- Moor, L. (1967). Niveau intellectuel et polygonosomie: Confrontation du caryotype et du niveau mental de 374 malades dont le caryotype comporte un excès de chromosomes X ou Y. Revue de Neuropsychiatrie infantile, 15, 325-348.
- Netley, C. (1977). Dichotic listening of callosal agensis and Turner's syndrome patients. In S. J. Segalowitz & F. A. Gruber (Eds.), Perspectives in neurolinguistics and psycholinguistics language development and neurological theory. New York: Academic Press.
- Nielsen, J., Nyborg, H., & Dahl, H. (1977). Turner's syndrome. A psychiatric-psychological study of 45 women with Turner's syndrome, compared with their sisters and women with normal karyotype, growth retardation, and primary amenorrhoea. Aarhus: Acta Jutlandica, Medicine Series 21, Aarhus.
- Nyborg, H. (1971a). Tactile stimulation and perception of the vertical: I. Effects of diffuse versus specific tactile stimulation. Scandinavian Journal of Psychology, 12, 1-3.
- Nyborg, H. (1971b). Tactile stimulation and perception of the vertical: II. Effects of field dependency, arousal, and cue function. Scandinavian Journal of Psychology, 12, 135-143.
-

- Nyborg, H. (1972). Light intensity and perception of the vertical: Two experiments with the rod-and-frame test. Scandinavian Journal of Psychology, 13, 1-13.
- Nyborg, H. (1974a). A method for analysing performance in the rod-and-frame test. I. Scandinavian Journal of Psychology, 15, 119-123.
- Nyborg, H. (1974b). Light intensity in the rod-and-frame test reconsidered. Scandinavian Journal of Psychology, 15, 236-237.
- Nyborg, H. (1977). The rod-and-frame test and the field dependence dimension: Some methodological, conceptual, and developmental considerations. Copenhagen: Dansk Psykologisk Forlag.
- Nyborg, H. (1979). Sex chromosome abnormalities and cognitive performance. V: Female sex hormone and discontinuous cognitive development. Paper presented in the symposium on "Cognitive Studies" at the Fifth Biennial Meeting of the International Society for the Study of Behavioral Development, Lund, Sweden, June 25-29.
- Nyborg, H. (1981). Hormonal correlates of spatial ability development. Paper presented at the Sixth Congress of The International Society for the Study of Behavioral Development, Toronto, Canada, August. (Symposium chaired by H. Nyborg and L. Harris).
- Nyborg H. (1983a). Spatial ability in men and women: Review and new theory. Advances in human research and therapy, Vol. 5, (pp. 39-140). Monograph Series, London: Pergamon Press.
- Nyborg, H. (1983b). Covariant intellectual and personality development in 14 hormonally different groups: A psychoneuroendocrinological model. Paper presented at the "Inaugural Meeting of the International Society for the Study of Individual Differences." London, July.
- Nyborg, H. (1984). Performance and intelligence in hormonally-different groups. In: G. J. de Vries, J. P. C. de Bruin, H. B. M. Uylings, & M. A. Corner (Eds.). Sex differences in the brain. Progress in brain research. Vol. 61, (pp. 491-508). Amsterdam: Elsevier Biomedical Press.
- Nyborg, H. (1985). Orchestration of body, brain, and behavioral development. Lecture presented at the University of Calgary, Department of Psychology, Calgary, Canada, May.
-

- Nyborg, H. (1986a). Sexual differentiation of the brain. Paper presented at the International Conference on "Knowledge and Learning -- Ideas in Cerebral Palsy" organized by the International Cerebral Palsy Society with Spastics Society, Athens, Greece, April.
- Nyborg, H. (1986b). Sex chromosomes, sex hormones, and developmental disturbances: In search of a model. Paper presented at the 152nd Annual National Meeting of the American Association for the Advancement of Science, Philadelphia, USA, May 25-30.
- Nyborg, H. (1987a). Individual differences or different individuals? That is the question. Behavioral and Brain Sciences, 10, 34-35.
- Nyborg, H. (1987b). Covariant trait development across races and within individuals: Differential K theory, genes, and hormones. Paper presented in the symposium on "Biology-Genetics" at the Third Meeting of the International Society for the Study of Individual Differences," Toronto, Canada, June 18-22.
- Nyborg, H. (1987c). Mathematics, animosity, and sex hormones. Behavioral and Brain Sciences. (Submitted).
- Nyborg, H. (1987d). Principles of sex hormonal regulation of body, brain, and behavioral development. Behavioral and Brain Sciences. (Submitted).
- Nyborg, H. (1987e). Sex hormones, behavioral development, and reproduction rates: A covariant pattern. Paper presented at the First International Capri Conference on Brain and Female Reproductive Function: Basic and Clinical Aspects, Capri, Italy, May 25-29.
- Nyborg, H., & Isaksen, B. (1974). A method for analyzing performance in the rod-and-frame test. II. Test of the statistical model. Scandinavian Journal of Psychology, 15, 124-126.
- Nyborg, H., & Nielsen, J. (1981a). Sex hormone treatment and spatial ability in women with Turner's syndrome. In: W. Schmid & J. Nielsen (Eds.), Human behavior and genetics, (pp. 167-182). Amsterdam: Elsevier/ North-Holland.
- Nyborg, H., & Nielsen, J. (1981b). Spatial ability of men with Karyotype 47,XXY, 47,XYY, or normal controls. In: W. Schmid & J. Nielsen (Eds.), Human behavior and genetics, (pp. 167-182). Amsterdam: Elsevier/ North-Holland.
-

- O'Connor, K. P., & Shaw, J. C. (1978). Field dependence, laterality and the EEG. Biological Psychology, 6, 93-109.
- Petersen, A. C. (1976). Physical androgyny and cognitive functioning in adolescence. Developmental Psychology, 12(6), 524-533.
- Petersen, A. C. (1979). Hormones and cognitive functioning in normal development. In M. A. Wittig & A. C. Petersen (Eds.), Sex-related differences in cognitive functioning: Developmental issues. New York: Academic Press.
- Reske-Nielsen, E., Christensen, A. L., & Nielsen, J. (1982). A neuropathological and neuropsychological study of Turner's syndrome. Cortex, 18, 181-190.
- Rosenthal, K., & Kimura, D. (1987). Hormonal influences on cognitive ability patterns. Research Bulletin, No. 653, March. Department of Psychology, The University of W. Ontario, London, Canada, 1-20.
- Stafford, R. E. (1961). Sex differences in spatial visualization as evidence of sex-linked inheritance. Perceptual and Motor Skills, 13, 428.
- Stafford, R. E. (1963). An investigation of similarities in parent-child test scores for evidence of hereditary components. Educational Testing Service, Princeton.
- Stafford, R. E. (1972). Hereditary and environmental components of quantitative reasoning. Review of Educational Research, 42, 183-201.
- Toran-Allerand, C. D. (1984). On the genesis of sexual differentiation of the central nervous system: Morphogenetic consequences of steroidal exposure and possible role of alpha-fetoprotein. In G. J. de Vries, J. P. C. de Bruin, H. B. M. Uylings & M. A. Corner (Eds.), Sex differences in the brain. Progress in brain research, Vol. 61. Amsterdam: Elsevier Biomedical Press.
- Turner, H. (1938). A syndrome of infantilism, congenital webbed neck, and cubitus valgus. Endocrinology, 23, 566-574.
- Vandenberg, S. G., & Kuse, A. R. (1979). Spatial ability: A critical review of the sex-linked major gene hypothesis. In M. A. Wittig & A. C. Petersen (Eds.), Sex-related differences in cognitive functioning: Developmental issues, (pp. 67-95). New York: Academic Press.
-

- Waber, D. P. (1976). Sex differences in cognition: A function of maturation rate. Science, 192, 572-574.
- Waber, D. P. (1977a). Sex differences in mental abilities, hemispheric lateralization, and rate of physical growth at adolescence. Developmental Psychology, 13, 29-38.
- Waber, D. P. (1977b). Biological substrates of field dependence: Implications of the sex difference. Psychological Bulletin, 84, 1076-1087.
- Waber, D. P. (1979a). Cognitive abilities and sex-related variations in the maturation of cerebral cortical functions. In M. A. Wittig & A. C. Petersen (Eds.), Sex-related differences in cognitive functioning, (pp. 161-186). New York: Academic Press.
- Waber, D. P. (1979b). Neuropsychological aspects of Turner's syndrome. Developmental Medicine and Child Neurology, 21, 58-70.
- Witkin, H. A. (1964). Origins of cognitive style. In C. Scheerer (Eds.), Cognition: Theory, research, promise. New York: Harper and Row, 172-205.
- Witkin, H. A., & Asch, S. E. (1948). Studies in space orientation. IV. further experiments on perception of the upright with displaced visual fields. Journal of Experimental Psychology, 38, 762-782.
- Witkin, H. A., Dyk, R. B., Faterson, H. F., Goodenough, D. R., & Karp, S. A. (1974). Psychological differentiation. Potomac, Md: Erlbaum (Originally published, 1962).
- Witkin, H. A., & Goodenough, D. R. (1977a). Field dependence and interpersonal behavior. Psychological Bulletin, 84, 661-689.
- Witkin, H. A., & Goodenough, D. R. (1977b). Field dependence revisited. Research Bulletin, RB-77-16.
- Witkin, H. A., & Goodenough, D. R. (1981). Cognitive styles: Essence and origins. New York: International Universities Press.
- Witkin, H. A., Goodenough, D. R., & Karp, S. A. (1967). Stability of cognitive style from childhood to young adulthood. Journal of Personality and Social Psychology, 7(3), 291-300.
- Witkin, H. A., Lewis, H. B., Hertzman, M., Machover, K., Meissner, P., & Wapner, S. (1954). Personality through perception. New York: Harper.
-

Witkin, H. A., & Oltman, P. K. (1967). Cognitive Style. International Journal of Neurology, 6, 119-137.

Wuttke, W., Arnold, P., Becker, D., Creutzfeldt, O., Langestein, S., & Tirsch, W. (1975). Circulating hormones, EEG, and performance in psychological tests of women with and without oral contraceptives. Psychoneuroendocrinology, 1, 141-151.

Witkin, H. A., Oltman, P. K., Raskin, E., & Karp, S. A. (1971). A Manual for the Embedded Figures Tests. Palo Alto, CA: Consulting Psychologists Press, Inc.
