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Palmar Dermatoglyphics of Dyslexia

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ABSTRACT Palmar dermatoglyphic prints were taken of 261 dyslexics (173 males and 88 females) and compared against those of 707 controls (372 males and 335 females). Dyslexics of both sexes were found to exhibit greater complexity in terms of ridge count and pattern location than controls, particularly on the left hand. Specifically, both male and female dyslexics exhibited higher left a-b counts, wider atd angles on both palms, and higher frequencies of pattern in left interdigital area IV. Additionally, male dyslexics also had higher right a-b counts and greater frequency of pattern in the left hypothenar area. Dyslexics of both sexes were also found to have more distally located axial triradii, and investigation of bilateral asymmetry found dyslexics to exhibit more directional asymmetry than controls in the variable of a-b count, with the left value for both groups being greater than the right.

It was concluded that the study evidenced strong support for the hypothesis that some causative factor relating to the development of dyslexia is operating during the time period in which dermatoglyphic features are formed. The relevance of these findings in terms of the Geschwind hypothesis and the possible importance of prenatal testosterone are discussed.

Dyslexia is a learning disability evidenced by an extreme difficulty in learning to read despite an individual's average or above-average intelligence and adequate opportunity for conventional instruction (Gaddes, 1980). In contrast to acquired dyslexia, which is believed to be of peri- or postnatal environmental origin, the developmental form is typically considered to result from an anomaly in the development of the central nervous system sometime during the early fetal period (Benton, 1975; Cruickshank, 1983). The Geschwind hypothesis (Geschwind and Behan, 1982; Geschwind and Galaburda, 1985) suggests that excess circulating prenatal testosterone may represent a causal factor in the development of this type of learning disorder as well as in other central nervous system irregularities, such as stuttering, migraine, autoimmune disease, and possibly also left-handedness and mathematical giftedness. Geschwind proposed that the excess testosterone operates by slowing down the development of the left hemisphere of the brain and perhaps also accentuating that of the right hemisphere.

Interest in dyslexia and the Geschwind hypothesis for dermatoglyphics research arises from the fact that prenatal testosterone is circulating in both male and female fetuses (Wilson et al., 1981; Zaaijer and Price, 1971) during the period of dermal ridge formation. Male fetuses begin producing testosterone at approximately 10 gestational weeks and females do so within a few weeks afterwards, although females typically produce a far smaller amount. Testosterone is also secreted in organs other than the gonads, particularly the placenta, and significant amounts are derived from maternal sources as well (Benagiano et al., 1967; Levitz et al., 1967; Geschwind and Galaburda, 1985), thus adding to the variability in avail-

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able concentrations of this hormone for fetuses of both sexes. Since dermal ridge formation occurs before the 19th gestational week (Cummins, 1929; Hale, 1949, 1952; Mulvihill and Smith, 1969; Penrose and Ohara, 1973), there is more than adequate time for the presence of this steroid in the circulation of both sexes to affect their ridge development.

A potential mechanism for a testosterone effect on dermatoglyphics might lie in the fact that the hormone serves as a stimulus to the production of both nerve growth factor (NGF) and epidermal growth factor (EGF) (Levi-Montalcini and Angeletti, 1963; Greene, 1977; Korsching and Thoenen, 1983; Bynny et al., 1972). NGF is a protein required for the growth and maintenance of sympathetic and dorsal nerves; it functions to induce differentiation and branching and may also serve as a chemical gradient (Chamley et al., 1973). EGF is functional in skin development and its relationship to dermatoglyphic formation is intuitively acceptable. But nerve growth factor as well has a conceivable connection to ridge formation: One of the earliest theories regarding factors which influence ridge pattern direction was that of Bonnevie (1929, 1932), who argued that ridges develop along the paths of the underderlying peripheral nerves. Hirsch and Schweichel (1973) expanded this theory, and it has recently gained additional support from the convincing argument of Dell and Munger (1986), indicating that afferent nerve fibers might serve as guides to dermal ridge arrangement.

Since dermatoglyphic formation occurs during a definite developmental time period, it is less subject to environmental exigencies than many other phenotypic characters—only those factors operating prior to the 19th week following conception can possibly affect ridge development. The fact that testosterone is present in the fetus during the critical time period and furthermore that a mechanism can be suggested for its possible action on dermatoglyphic pattern formation, makes it a viable candidate for testing its dermatoglyphic effect. The problem, of course, arises in that fetal humans cannot be manipulated experimentally for scientific exploration. However, if the Geschwind hypothesis has validity, the dermatoglyphic investigation of affected groups, such as dyslexics, might lead to the identification of prenatal testosterone as a causative factor in dermatoglyphic variation.

MATERIALS AND METHODS

For this study, the experimental sample was composed of dermatoglyphic data on a total of 173 male and 88 female dyslexic students attending three dePaul Schools, in Louisville, Kentucky; Baton Rouge, Louisiana; and Bloomington, Indiana. The dePaul Schools, with special instruction geared to teaching the reading disabled child from preschool through high-school age, are private institutions administered by the Catholic Church. Admission to the system is based upon referral from another school system or testing bureau, but parental request is also considered. All applicants are given an established series of tests to determine IQ and reading, spelling, math, and writing ability; auditory and spatial perception tests are also administered. The children included in the present research were Americans of European extraction and ranged in age from 6 to 16 years. Although both digital and palmar prints were taken on each subject, only the palmar findings will be presented here.

Since there is great disagreement on the definition and diagnosis of dyslexia (Adams, 1969; Hagerman, 1984; Ames, 1983), a somewhat arbitrary categorization was made for this investigation, with the intent of obtaining as homogenous a sample as possible. All students attending the dePaul Schools are classified as dyslexic, but there is considerable variation in the extent of the disorder. In order to define this disability more clearly, the concept of reading quotient, or RQ, was utilized (Watson and Goldgar, 1988; Myklebust, 1968; Rudel, 1985). This score is calculated by adding the child's scores from the oral reading and spelling tests and dividing the total by the combined chronological and mental ages (the latter derived from the IQ test results). Only those individuals scoring at .90 or below were utilized in the present research. A score of .90 means that the combination reading-and-spelling score was at least 10% below that predicted by the combined chronological and mental ages. Furthermore, in order to minimize the likelihood of including dyslexics whose disability was acquired rather than developmental in origin, a parental questionnaire had been administered at the time of the permission request. Children whose parents indicated known or suspected brain injury were excluded from the analysis. The final restricted sample consisted of 131 males and 55 females.

Hand prints of the entire sample of 261 dePaul students were taken with a method using volcanic ash and tape (Robertson-Neufeld and Murray, 1978). The control sample, consisting of unmarked prints of 372 male and 335 female Introductory Anthropology students attending the University of Tennessee, was provided by Richard L. Jantz of that university. To ensure comparability with the experimental sample, only prints of Americans of European extraction were analyzed for the present research. In order to control for interobserver error, all dermatoglyphic data collection related to this investigation, of both the experimental sample and the control sample, was made by the present researcher, using a modified version of the Penrose-Loesch topological technique (Penrose, 1965; Penrose and Loesch, 1970; Loesch, 1983; modifications in Sorenson Goodson and Meier, 1986; Sorenson Goodson, 1986; and Sorenson Jamison, 1987).

Since handedness has been determined to be of significance in some dermatoglyphic studies (e.g., Jantz et al., 1979; Rife, 1943, 1955; Cromwell and Rife, 1942), and further, since left-handedness is so frequently found to be coexistent with dyslexia, this factor was deemed to be of importance for the present research. Lateral preferences of the experimental subjects relating to hand and foot choice were determined at the time the prints were taken, using a modified Oldfield (1971) methodology. For the control subjects, assessment of handedness had been made on the basis of response to questions of hand preference at the time of their participation.

RESULTS

The results presented here represent a summary of the major findings of the investigation. Complete statistical results, including those of additional analyses and specific topologically defined loops, can be found elsewhere (Sorenson Jamison, 1987). Sexes were analyzed separately, and initially without regard to the factor of lateral preference.

Chi-square analyses

Males. The three sections of Table 1 summarize the results of chi-square analysis of the male frequency variables on the palm. Table 1a presents the results related to the total number of loops in the five palmar areas, by hand, between dyslexics and controls. Significant differences ($P < .05$) were found

TABLE 1. Chi-square results comparing male dyslexics (N = 131) with male controls (N = 372) by hand

	Left palm			Right palm		
	χ^2	p	df	χ^2	p	df
a. Palmar loop frequencies						
Loops						
I,I^r,I	3.58	N.S.[1]	3	2.78	N.S.	3
II	0.18	N.S.	1	2.81	.09	1
III,III^r	2.58	N.S.	2	0.22	N.S.	2
IV,$\hat{I}$V	5.83	.02	2	0.29	N.S.	2
H,$\hat{H}$,H^r, T^r,T^u	9.67	.02	3	6.25	N.S.	3
b. Palmar triradii frequencies						
Triradii						
e	4.41	N.S.	2	0.38	N.S.	2
f	4.04	N.S.	3	3.86	N.S.	3
t	6.36	.04	2	6.20	.01	1
t′	12.13	.00	2	9.19	.01	2
t^b	4.68	.03	1	1.92	N.S.	2
t^u	2.47	N.S.	2	1.98	N.S.	2
z,z′,z″	0.06	N.S.	1	0.42	N.S.	1
c. Palmar digital triradii and A-line exits						
Digital triradii	0.33	N.S.	4	2.34	N.S.	4
A-line exit	25.49	.00	4	0.95	N.S.	4

[1]N.S. = not significant.

demonstrating dyslexics to have higher frequencies of pattern both in interdigital area IV and in the hypothenar area of the left palm. Examination of results of individual hypothenar loops (not included in the table) revealed that only the frequency of loop H (the peripherally opening one) was significantly different in frequency between the groups. For the right palm, while none of the variables demonstrated the groups to be significantly different, the difference approached significance ($p < .10$) in interdigital area II.

Table 1b includes results of triradial frequencies. Here the differences between the groups are found in the axial locations, showing dyslexics to be less likely on both palms to have a simple t triradius, which is defined as being located in a position that is less than 15% of the axial line (Ford Walker, 1957). Instead, on both palms, dyslexics were more likely to have a t′ triradius, that is, one that is more distally located. Dyslexics were also more likely than controls to have an extralimital triradius (t^b), although this finding was only apparent on the left palm. Since t^b is typically associated with a hypothenar loop, such a finding is concordant with the one above showing dyslexics to be more likely to have a higher frequency of these loops on

the left hand. However, the other type of hypothenar triradius, t^u, did not differ in frequency between the two groups.

Table 1c shows the results of two other palmar variables, the number of digital triradii, and the A-line exit. As can be seen, the number of digital triradii in males did not vary significantly between groups, nor did the A-line exit on the right palm. However, the A-line exit of the left palm demonstrated highly significant differences between the two groups, in the direction of dyslexics having greater frequencies of transverse exits (numbers 4 and 5, and fewer exits 1 and 2, not included in the table) than controls.

Females. The three sections of Table 2 summarize the chi-square results for females. Again, the majority of significant findings are on the left hand, although on the whole, females did not exhibit as many differences as males. As can be seen in Table 2a, dyslexic females, as was also true of dyslexic males, were more likely to have patterns in interdigital area IV of the left hand. The increased frequency of pattern in the thenar area of the dyslexics is of borderline significance. The differences regarding interdigital area III are somewhat equivocal: in the right palm, dyslexics have a significantly higher frequency of pattern, while the opposite is true of the left palm.

Table 2b shows that dyslexic females do not mimic dyslexic males in being more likely than controls to have a more distally placed axial triradius *when it is defined categorically*. The only triradius in either hand that did achieve a significant frequency difference is that of f, the proximal thenar triradius; and again, this reflects the higher frequency of loops in the thenar area. The extralimital triradius (t^b), which had been significantly higher in frequency for dyslexic males, approaches significance in the same direction on the female left palm.

In Table 2c, it can be seen that the A-line exit of the female left palm differentiates as effectively between the two groups as it did on the male palm. Again, there was a highly significant tendency for these individuals to have this line extend in a transverse fashion, terminating most frequently at exit 4. Dyslexic females were less likely than controls to have an A-line exit in region 1, but exits 2, 3, and 5 were similarly represented in both groups. In addition, for the females, a significant difference in frequency of the number of digital triradii was found in the left palm. This variable is related to the number of interdigital loops and is not affected by patterns in the thenar or hypothenar areas; thus it may or may not also show up in the variable of pattern intensity. As will be demonstrated below, it does not. According to topological theory, there commonly are four of these triradii, and indeed, this was the modal category for both groups (the percentage of control females having four digital triradii was 80.3, while that of dyslexics was 70.9). The importance of the present finding lies in the indication that dyslexic females are more likely than controls to have other than the typical number of interdigital loops (but not total loops). Dyslexics did not simply have more interdigital loops, they also had *fewer* patterns in these regions. The latter is an interesting result because it implies that zygodactylous triradii (e.g., "missing c") were present, although the analyses for these (z, z′, z″, in Table 2b) failed to demonstrate significant differences between groups. Thus, the statistical significance appears to lie in a general deviation from the modal category, rather than in a specific directional deviation.

TABLE 2. Chi-square results comparing female dyslexics (N = 55) with female controls (N = 335) by hand

	Left palm			Right palm		
	χ^2	p	df	χ^2	p	df
a. Palmar loop frequencies						
Loops						
I,Ī,I	7.33	.06	3	2.81	N.S.	2
II	0.01	N.S.	1	0.29	N.S.	1
III,III^r	3.71	.05	1	6.11	.05	2
IV,Ī̂V	9.01	.01	2	0.33	N.S.	2
H,Ĥ,H^r, T^r,T^u	3.66	N.S.	2	0.93	N.S.	3
b. Palmar triradii frequencies						
Triradii						
e	0.96	N.S.	2	0.15	N.S.	1
f	6.59	.04	2	2.20	N.S.	2
t	1.42	N.S.	1	1.12	N.S.	1
t′	0.67	N.S.	1	2.16	N.S.	1
t^b	3.00	.08	1	0.52	N.S.	1
t^u	0.54	N.S.	2	0.72	N.S.	2
z,z′,z″	0.46	N.S.	1	0.35	N.S.	1
c. Palmar digital triradii and A-line exits						
Digital triradii	10.26	.04	4	4.11	N.S.	4
A-line exit	13.64	.01	4	5.49	N.S.	4

t-test analyses

Males. Table 3 lists the t-test results of interval level variables for males, separately by

TABLE 3. Results of t-tests on interval level variables: males

Variable	Dyslexics (N = 131) Mean	S.D.	Controls (N = 372) Mean	S.D.	t-value	p
Left palm						
a-b count	42.53	5.55	39.54	5.54	5.29	<.00
atd angle	44.58	5.66	40.87	5.62	6.46	<.00
Axial index	15.77	7.05	14.98	7.37	1.03	N.S.
Pattern intensity	1.86	0.97	1.67	0.95	2.02	.04
Maximum atd	46.66	8.46	42.20	7.27	5.36	<.00
Right palm						
a-b count	40.72	5.78	38.66	5.44	3.66	<.00
atd angle	44.71	7.04	40.71	5.20	5.92	<.00
Axial index	16.48	8.01	14.77	7.07	2.19	.03
Pattern intensity	1.85	0.96	1.61	0.86	2.63	.01
Maximum atd	46.90	9.14	42.57	7.34	4.87	<.00

TABLE 4. Results of t-tests on interval level variables: females

Variable	Dyslexics (N = 55) Mean	S.D.	Controls (N = 335) Mean	S.D.	t-value	p
Left palm						
a-b count	42.66	6.89	40.29	5.49	2.43	.02
atd angle	43.55	6.05	41.89	5.75	1.96	.05
Axial index	18.56	8.30	16.07	7.81	2.14	.03
Pattern intensity	1.66	0.91	1.59	0.92	0.52	N.S.
Maximum atd	44.76	7.39	43.89	8.63	0.71	N.S.
Right palm						
a-b count	39.87	6.07	39.38	5.51	0.61	N.S.
atd angle	43.29	6.19	41.66	5.67	1.96	.05
Axial index	17.78	8.74	15.95	7.29	1.53	N.S.
Pattern intensity	1.60	0.96	1.52	0.81	0.69	N.S.
Maximum atd	45.60	7.89	43.72	8.17	1.58	N.S.

palm. As can clearly be seen, there were differences between the means of dyslexics and controls for all measures except the axial index of the left palm. In this analysis, "atd" refers to the proximal, and "maximum atd" to the distal, angle measurement when more than one t triradius is present (Wright et al., 1972). In each of the interval variables, the dyslexics' value was higher than that of the controls.

Females. Table 4 presents results of the interval-level variables for females. Here, there were four measures, *including* the left axial index, that reached significance. This latter finding indicates that female as well as male dyslexics do have a more distally located axial triradius, even though the chi-square analysis failed to indicate statistical significance for the relevant categorical variables. For males, the distal placement of the left axial triradius is only observed statistically when it is measured categorically, while for females, the variable only reaches significance when it is measured continuously. Again, for all the interval-level variables, it should be noted that in every case, just as was found in males, the dyslexics' value is greater than that of controls. It should also be emphasized that even though only four variables were found to differentiate significantly between the groups, three of these were on the left palm.

Handedness. When the additional factor of handedness was taken into consideration, surprisingly little new information was gained, possibly owing, in part, to reduced sample size, particularly of left-handers. In these tests, groups of the same sex and hand preference were tested against each other. First, in the interval-level variables, right-handers (control males, N = 311; dyslexic males, N = 108; control females, N = 240; dyslexic females, N = 45) maintained essentially the same results as those found when handedness was not a factor. For left-handers (control males, N = 61; dyslexic males, N = 23; control females, N = 95; dyslexic females, N = 10), the significance levels generally declined and the male dyslexics no longer exhibited a significant difference in a-b count on the right palm and the female dyslexics lost the significant left axial index and right atd angle.

Secondly, in chi-square tests, male left-handed dyslexics had a significantly higher frequency of loops in the thenar and hypothenar areas, and also of triradius f, on the left hand than left-handed controls. Right-handed male dyslexics had significantly higher frequencies of left hypothenar loops, t′ triradii, and lower frequencies of t triradii on both palms, and also exhibited more transverse endings of A-line exits on the left palm than right-handed controls.

Left-handed female dyslexics had a significantly higher frequency of t′ and f triradii, and a more transverse ending of the right A-line exit, although the A-line exit of the left palm did not differentiate significantly between left-handers in the two groups. Right-handed female dyslexics exhibited a significantly higher incidence of interdigital area IV loops and also a greater difference in number of digital triradii, both on the left palm, than right handed controls. Interest-

TABLE 5. Asymmetry of a-b count[1]

a. paired t-tests between hands (left-right), within groups

	Males				Females			
	Left		Right		Left		Right	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Dyslexics	42.53	5.55	40.72	5.78	42.66	6.89	39.87	6.07
	$t = 4.72$		$p < .00$		$t = 3.94$		$p < .00$	
Controls	39.54	5.56	38.65	5.45	40.34	5.46	39.38	5.51
	$t = 4.28$		$p < .00$		$t = 4.59$		$p < .00$	

b. t-tests to determine significant between-groups asymmetry

	Males				Females			
	Dyslexics		Controls		Dyslexics		Controls	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
	1.81	4.39	0.89	3.99	2.78	5.24	0.96	3.81
	$t = 2.19$		$p = .03$		$t = 2.48$		$p = .02$	

[1]Dyslexics: males, N = 131; females, N = 55. Controls: males, N = 372; females, N = 335.

ingly, neither handedness group exhibited a significant difference in the frequency of interdigital area III loop, on either hand.

Bimanual asymmetry. Differences in bimanual asymmetry were tested using a-b count and pattern intensity. There were no significant results for either males or females for the variable of pattern intensity with respect to either directional or fluctuating asymmetry. However, as can be seen in the paired t-test results of Table 5, for both males and females, the variable of a-b count demonstrated highly significant directional asymmetry in both dyslexics and controls. Furthermore, when the groups were compared to each other with t-tests to determine whether there was significant difference in the amount of directional asymmetry, a positive result was again found: Dyslexics exhibited significantly more bimanual asymmetry than controls in both males and females. It also can be seen that in all tests, the value for the left palm was greater than that of the right.

DISCUSSION

The present study would firmly indicate support for the hypothesis that some causative factors relating to the development of dyslexia are operating during the time period in which dermatoglyphic features are formed. The condition of dyslexia clearly evidences itself in a statistically significant dermatoglyphic manner in both sexes, although for females, the effect is less than that for males (one factor of which might be smaller sample size).

While the connection between dyslexia and dermatoglyphics thus appears to be established, the presumed relationship of prenatal testosterone to both must still remain hypothetical. However, the present study does serve to strengthen the Geschwind hypothesis because the significant dermatoglyphic results can be explained on a theoretical basis, through the mechanistic action of testosterone. Direct confirmation of the dermatoglyphic effect of testosterone must await future research.

Particular indirect support for the Geschwind hypothesis can be found in the facts that, firstly, males demonstrated greater dermatoglyphic effect than females and, secondly, that the majority of the significant findings occurred on the left side of the body. As was indicated in the introduction, Geschwind and Galaburda (1985) maintain that a central effect of testosterone is to slow the development of the left side of the brain. Perhaps the dermatoglyphic findings might indicate that the left side of the body, as well, develops at a different pace from the right. Since the left side of the brain typically develops at a slower pace than the right (Chi et al., 1977; Thatcher et al., 1987), and since normal Caucasians have higher frequencies of palmar pattern in interdigital area IV of the left palm (e.g., Schaumann and Alter, 1976), the fact that dyslexics show increases in pattern frequency in this area of the left palm supports this hypothesis. A third find-

ing that is supportive of the Geschwind hypothesis is the fact that while both dyslexics and controls demonstrated significant directional asymmetry of a-b count in the direction of the left value being greater than the right, dyslexics were more asymmetrical than controls.

Further implication of the developmentally retarding and dermatoglyphic effect of testosterone might be found in studies of maturational timing. Males typically mature at a slower rate than females during the fetal period and continue to do so through puberty (Lowrey, 1986), although there are some exceptions to this general rule (e.g., Garn et al., 1974). Males also grow for a longer time period (and thus become larger). In a study of early and late maturers, Meier et al. (1987) demonstrated that the tendency toward later maturation is expressed dermatoglyphically by an increased complexity of ridge count and pattern formation in both males and females. Male late maturers were found to have increased complexity in digital patterns and ridge counts, while female late maturers had more palmar patterns in interdigital area III and more transverse A-line exit endings. Thus, if as has been claimed by many experts in the field of dyslexia (Bender, 1957; Ingram et al., 1970), this disorder results from a maturational or developmental lag, then dyslexics represent one subgroup of late maturers—a group that at a critical prenatal point suffered a disruption in their ongoing rate of maturation.

If testosterone is a critical factor in dermatoglyphic development, it would seem that is must exercise its effect in one of three ways: 1) by directing the course of epidermal ridges, 2) by exerting an enlarging effect upon the volar pads, or possibly 3) retarding their naturally occurring regression. Jantz and Hunt (1986) suggested that sex chromosomes affect dermatoglyphic development by controlling tissue sensitivity, and Barlow (1973) indicated that sex chromosomes affect the rate of mitotic division. Penrose and Loesch (1967) hypothesized a "dosage effect" of sex chromosomes which might affect water balance in the volar pads, resulting in longer-lasting pads. Each of these suggestions offers a possible solution to the problem by identifying a mechanism through which testosterone might affect dermatoglyphic formation. Any of them could result in the requisite dermatoglyphic effect, either by acting alone or in concert with one or more of the other processes.

Dermatoglyphic "complexity" is often used in reference to both ridge count and pattern type. On the digits, there is a direct relationship between the two types of variables, although to an extent (as was argued by Meier et al., 1987) this is an artifact of the definition. Arches have no ridge count because they have no triradius, although they clearly do have ridges. The relationship between complexity of pattern and magnitude of ridge count in the palmar area is even less straightforward than it is on the digits. Again, the artifactual nature of the definition might be a major factor. On the digits, the count is made from the triradius, which forms an integral part of the pattern. On the palms, however, the ridge count is made between digital triradii, landmarks which typically are present whether or not a pattern is also present (leaving out cases of "missing c"). Furthermore, when there is a pattern, the ridge count is decreased, and thus for palms, complexity of pattern and ridge count clearly do not mean the same thing.

An explanation might be found in the possibility that ridge number and ridge direction (and thus their "complexity") are influenced by different, although quite possibly related, factors, or by an interaction of factors having differing combined effects dependent upon, for instance, maturational timing. It is hypothesized here that ridge *quantity* is initially a function of the frequency and arrangement of sensory nerves developing in the appendages (as in Dell and Munger, 1986). These, in turn, are directly dependent upon the presence of nerve growth factor, and testosterone. The *course* of the ridge alignment is, at first, dependent upon the presence of the nerves as well, but given nerve presence and initial direction, the ridges may then be manipulated topologically by other forces into pattern formations (according to topological theory, e.g., Loesch, 1983). These forces (related to the size and shape of the volar pad, as in Babler, 1987) may work in concert with the earlier factors, or they may oppose them, or possibly, they may have no effect at all, depending upon the relative timing of their occurrence.

It is conceivable that the volar pad also is affected by testosterone, perhaps only indirectly, as a result of its developmentally retarding (and/or enlarging) effect. The significant points here are that complexity of ridge number and complexity of pattern ar-

rangement are not necessarily the same thing, and furthermore, they might well be affected by different influences. There appears to be an adequate basis for hypothesizing a direct causal effect of testosterone (probably via nerve growth factor, and possibly epidermal growth factor as well) upon the former process, but the relationship of the steroid to pattern development is probably more indirect, though still theoretically defensible.

SUMMARY AND CONCLUSIONS

To summarize briefly, this investigation found significant differences in pattern and triradial presence and location and also in interval variable values between both male and female dyslexics and controls. The left palm of both sexes exhibited a greater number of significant differences. The most consistent findings related to the location of the axial triradius, the value and asymmetry of the a-b count, the size of the atd angle, the presence of pattern in interdigital area IV on the left palm, and the direction of the A-line. These results support the contention that factors leading to dermatoglyphic variation and developmental dyslexia are operative during the same prenatal time period. The Geschwind hypothesis, which suggests that exposure of the fetus to an excess of testosterone causes asymmetrical developmental retardation, combined with the theoretical implication of testosterone in dermal ridge formation, is presented as a possible explanation of the between-groups dermatoglyphic differences found in this study.

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LITERATURE CITED

Adams, RB (1969) Dyslexia: A discussion of its definition. J. Learn. Disabilities *2*:616–633.

Ames, LB (1983) Learning disability: Truth or trap? J. Learn. Disabilities *16*:19–20.

Babler, WJ (1987) Prenatal origins of human dermatoglyphic variation. Paper presented at the 56th Annual Meeting of the American Association of Physical Anthropologists, New York City, April 2–5.

Barlow, P (1973) The influence of inactive chromosomes on human development. Humangenetik *17*:105–136.

Benagiano, G, Kincl, FA, Zielske, F, Wiqvist, N, and Dicfalusy, E (1967) Studies on the metabolism of C-19 steroids in the human feto-placental unit. Acta Endocrinol. *56*:203–220.

Bender, LA (1957) Specific reading disability as a maturational lag. Bull. Orton Soc. *7*:9–18.

Benton, AL (1975) Developmental dyslexia: Neurological aspects. Adv. Neurol. *7*:1–27.

Bonnevie, K (1929) Zur Mechanic der Papillarmusterbildung. I. Die Epidermis als formativer Faktor in der Entwicklung der Fingerbeeren und der Papillarmuster. Arch. Entwicklungsmech. Organismen *117*:384–420.

Bonnevie, K (1932) Zur Mechanik der Papillarmusterbildung. II. Anomalien der menschlichen Finger- und Zehenbeeren wirksamen Epidermispolster. Arch. Entwicklungsmech. Organismen *126*:348–373.

Bynny, RL, Orth, DN, and Cohen, S (1972) Radioimmunoassay of epidermal growth factor. Endocrinology *90*:1261–1266.

Chamley, JH, Goller, I, and Burnstock, G (1973) Selective growth of sympathetic nerve fibers to explants of normally densely innervated autonomic organs in tissue culture. Dev. Biol. *31*:362–379.

Chi, JG, Dooling, EC, and Gilles, FH (1977) Gyral development of the human brain. Ann. Neurol. *1*:86–93.

Cromwell, H, and Rife, DC (1942) Dermatoglyphics in relation to functional handedness. Hum. Biol. *14*:516–526.

Cruickshank, WM (1983) Learning disabilities: A neurological dysfunction. J. Learn. Disabilities *16*:27–29.

Cummins, H (1929) The topographic history of the volar pads (Walking pads; tastballen) in the human embryo. Contributions to Embryology. No. 113. Carnegie Institute of Washington *20*:102–126.

Dell, DA, and Munger, BL (1986) The early embryogenesis of papillary (sweat duct) ridges in primate glabrous skin: The dermatotopic map of cutaneous mechanoreceptors and dermatoglyphics. J. Comp. Neurol. *244*:511–532.

Ford Walker, N (1957) The use of dermal configurations in the diagnosis of mongolism. J. Pediatr. *50*:19–26.

Gaddes, WH (1980) Learning Disabilities and Brain Function. New York: Springer-Verlag.

Garn, SM, Burdi, AR, and Babler, WJ (1974) Male advancement in prenatal hand development. Am. J. Phys. Anthropol. *41*:353–360.

Geschwind, N, and Behan, P (1982) Left-handedness: Association with immune disease, migraine, and developmental learning disorder. Proc. Nat. Acad. Sci. USA *79*:5097–5100.

Geschwind, N, and Galaburda, AM (1985) Cerebral lateralization: Biological mechanisms, associations, and pathology. A hypothesis and a program for research. Parts I, II, and III. Arch. Neurol. *42*:428–459; 521–552; 634–654.

Greene, LA (1977) Quantitative in vitro studies on the nerve growth factor (NGF) requirements of neurons. II. Sensory neurons. Dev. Biol. *58*:106–113.

Hagerman, RJ (1984) Pediatric assessment of the learning-disabled child. Dev. Behav. Pediatr. *5*:274–284.

Hale, AR (1949) Breadth of epidermal ridges in the human fetus and its relation to the growth of the hand and foot. Anat. Rec. *105*:763–776.

Hale, AR (1952) Morphogenesis of volar skin in the human fetus. Am. J. Anat. *91*:147–173.

Hirsch, W, and Schweichel, JU (1973) Morphological evidence concerning the problem of skin ridge formation. J. Ment. Defic. Res. *17*:58–72.

Ingram, TTS, Mason, AW, and Blackburn, I (1970) A retrospective study of 82 children with reading disability. Dev. Med. Child Neurol. *12*:271–281.

Jantz, RL, Fohl, FK, and Zahler, JW (1979) Finger ridge-counts and handedness. Hum. Biol. *51*:91–99.

Jantz, RL, and Hunt, DR (1986) The influence of sex chromosomes on finger dermatoglyphic patterns. Ann. Hum. Biol. *13*:287–295.

Korsching, S, and Thoenen, H (1983) Nerve growth factor in sympathetic ganglia and corresponding target organs of the rat: Correlation with density of sympathetic innervation. Proc. Nat. Acad. Sci. USA *80*:3513–3516.

Levi-Montalcini, R, and Angeletti, PU (1963) Essential role of the nerve growth factor in the survival and maintenance of dissociated sensory and sympathetic embryonic nerve cells in vitro. Dev. Biol. *7*:653–659.

Levitz, M, Condon, GP, Dancis, J, Goebelsmann, U, Eriksson, G, and Diczfalusy, E (1967) Transfer of estriol and estriol conjugates across the human placenta perfused in situ at midpregnancy. J. Clin. Endocrinol. *27*:1723–1729.

Loesch, D (1983) Quantitative Dermatoglyphics: Classification, Genetics, and Pathology. Oxford: Oxford University Press.

Lowrey, GH (1986) Growth and Development of Children. 8th Edition. Chicago: Yearbook Medical Publishers.

Meier, RJ, Sorenson Goodson, C, and Roche, EM (1987) Dermatoglyphic development and timing of maturation. Hum. Biol. *59*:357–373.

Mulvihill, JJ, and Smith, DW (1969) The genesis of dermatoglyphics. J. Pediatr. *75*:579–589.

Myklebust, HR (1968) Learning disabilities: Definition and overview. In H Myklebust (ed): Progress in Learning Disabilities. Vol. I. New York: Grune and Stratton.

Oldfield, RC (1971) The assessment and analysis of handedness: The Edinburgh Inventory. Neuropsychologia *9*:97–113.

Penrose, LS (1965) Dermatoglyphic typology. Nature *205*:544–546.

Penrose, LS, and Loesch, D (1967) A study of dermal ridge width in the second (palmar) interdigital area with special reference to aneuploid states. J. Ment. Defic. Res. *11*:36–42.

Penrose, LS, and Loesch, D (1970) Topological classification of palmar dermatoglyphics. J. Ment. Defic. Res. *14*:111–128.

Penrose, LS, and Ohara, PT (1973) The development of epidermal ridges. J. Med. Genet. *10*:201–208.

Rife, DC (1943) Genetic interrelationships of dermatoglyphics and functional handedness. Genetics *28*:42–48.

Rife, DC (1955) Hand prints and handedness. Am. J. Hum. Genet. *7*:170–179.

Robertson-Neufeld, L, and Murray, J (1978) An inkless method of recording dermal ridges. In J Mavalwala (ed): Dermatoglyphics: An International Perspective. The Hague: Mouton, pp. 3–9.

Rudel, RG (1985) The definition of dyslexia: Language and motor deficits. In FH Duffy and N Geschwind (eds): Dyslexia: A Neuroscientific Approach to Clinical Evaluation. Boston: Little, Brown, and Company, pp. 33–53.

Schaumann, B, and Alter, M (1976) Dermatoglyphics in Medical Disorders. New York: Springer-Verlag.

Sorenson Goodson, C (1986) A revised methodology for locating palmar axial triradii. Newslett. Am. Dermatoglyphics Assoc. *5*(3):12–16.

Sorenson Goodson, C, and Meier, RJ (1986) Topological description of Easter Islander palmar dermatoglyphics. Am. J. Phys. Anthropol. *71*:225–232.

Sorenson Jamison, C (1987) Palmar Dermatoglyphics of Dyslexia: A Test of the Geschwind Hypothesis. Ph.D. dissertation, Indiana University, Bloomington.

Thatcher, RW, Walker, RA, and Giudice, D (1987) Human cerebral hemispheres develop at different rates at different ages. Science *236*:1110–1113.

Watson, BU, and Goldgar, DE (1988) Evaluation of a typology of reading disability. J. Clin. Exp. Neuropsychol. (in press).

Wilson, JD, George, FW, and Griffin, JE (1981) The hormonal control of sexual development. Science *211*:1278–1284.

Wright, HT, Parker, CE, and Mavalwala, J (1972) Unusual dermatoglyphic findings associated with cytomegliac inclusion disease of infancy. Calif. Med. *116*:14–20.

Zaaijer, JJP, and Price, D (1971) Early secretion of androgenic hormones by human fetal gonads and adrenal glands in organ culture and possible implications for sex differentiation. In M Hamburgh and EJW Barrington (eds): Hormones in Development. New York: Appleton-Century-Crofts, pp. 537–546.